

International Symposium on Safety of Vulnerable Road Users

25-26 March 2019
Changsha, China

Proceedings

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Trend In Transport Injury Incidence and Mortality for Old Adults Aged 65+ In Brics, 2008-2017

Jing Wu^{1a}

Abstract

Key words: transport injury; mortality; incidence; trend

OBJECTIVE

To examine changes of transport injury incidence and mortality rates for old adults aged 65 and above in BRICS (Brazil, Russia, India, China, and South Africa) from 2008 to 2017.

METHOD

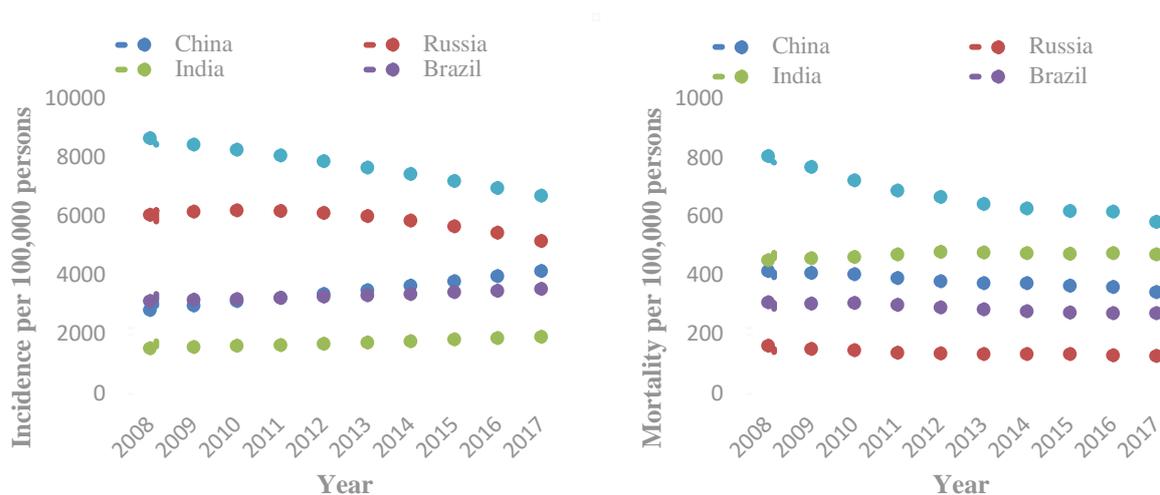
Using data from the Global Burden of Disease 2017, Poisson regression was used to examine trends in incidence and mortality rates among old adults aged 65 and above in five BRICS countries.

RESULTS

During 2008-2017, incidence of transport injury among elderly adults aged 65 and above increased significantly in China, India and Brazil, with the highest increase occurred in China (52%). The incidence rate of transport injury in Russia first increased from 2008 to 2010 and then decreased since 2011. In contrast, South Africa experienced a decrease of the transport injury incidence during the study time period. However, the mortality rate of transport injuries decreased in all five BRICS countries except for India, with South Africa witnessed the highest decline of -30%.

CONCLUSION

During 2008-2017, although the transport injuries incidence rate among the elderly aged 65 and over in China, India and Brazil showed an upward trend, the transport injuries mortality rate in almost all BRICS countries decreased year by year. It is valuable to do further study to interpret the observed changes revealed by the GBD estimates and take actions to reduce fatal and nonfatal road traffic injury in the future.



Trend in transport injury incidence and mortality for old adults aged 65+ in BRICS, 2008-2017

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Analysis on the Long-Term Trend of Road Traffic Injury and Its Leading Factors in China (1970-2017)

Shengyong Wang¹

Abstract

During the 48 years of 1970-2017, the secular trend of mortality of road traffic injuries (RTI) in China can be divided into three stages:

1. Mortality of RTI rising rapidly in 1970-2002. It doubles every 10 years (1970 1.16/100000, 1980 2.21/100000, 1990 4.31/100000, 2002 8.52/100000). The mortality of RTI in 2002 was 7.35 times as many as 1970, an average annual growth of 19.23%.
2. Mortality of RTI was relatively stable period from 2001 to 2004. The mortality fluctuated around 830/100,000 over a four-year period. It was showing signs of stability and decline.
3. Mortality of RTI was a significant decline From 2004 to 2017. It fell by 44.29% during the 48 years (8.24/100,000 -- 4.59/100,000), with an average annual 3.4% degradation.

The ecological relationship between mortality of RTI and economic development in China:

The regression results of the curve were $Y = 5.107 \times \exp(0.128 \times X)$. The mortality of RTI has been on the rise for half a century before 2005, with the rapid development of the national economy. From 1970 to 2001 per capita GDP increased 8.3 times (US \$ 113~US \$ 1,053), the mortality of RTI increased 6.2 times (116/100,000 ~ 830/100,000) over the same period. There has been continued rapid growth in per capita GDP from 2001 to 2017 (US \$ 8826). The annual growth rate was 46.14%, but the mortality of RTI did not rise at the same time. The mortality of RTI was the highest in history (more than 8.00/100,000) with the per capita GDP was US \$ 1,136 to US \$ 1,500 in 2001~2004. When the per capita GDP reached US \$1,753, the mortality of RTI dropped precipitously in 2005. After the per capita GDP reached US \$1753 in 2005, the mortality of RTI showed an obvious downward trend year by year. Since then, the per capita GDP is still growing at an annual rate of 41.96%, but the mortality of RTI continued to decline. The mortality of RTI decreased by 44.30% in 2004~2017 (the average annual decline was 3.41%).

With the continuous improvement of motorization degree, the quantity and quality of roads obviously cannot meet the demand. Rapid economic development makes the mortality of RTI increase with the growth of per capita GDP. When the economy develops to a certain extent (per capita GDP reached US \$1,500), the government is able to increase investment in road transportation and take a series of comprehensive security measures: such as improves the quantity and quality of roads, enhance the safety performance of vehicles and other means of transportation, strengthening the legal management of road traffic safety, constantly improves the level of traffic safety management and services etc. A leading measure by government action to reduce the mortality of RTI, such as improve the road traffic environment, strengthening the automobile products quality supervision and improve the level of emergency treatment, etc.

The economic development level with per capita GDP as the index is the indicator of the change for the mortality of RTI.

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Managing Change in Driving Behaviour for Creating Safe Community by Students

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Abstract

Safe driving behaviours cannot be achieved by law enforcement alone, and without cooperation from the public. To be successful, changing driver behaviour must be a structured process that is carefully planned and managed seamlessly with public participation. In many developing countries, most young people use two-wheelers which are therefore exposed to the risk of crashes involving larger and faster moving vehicles. Moreover, young people are more prone to take risks on the road, particularly as motorcycle drivers. Thus, this study focuses on students in universities. The objectives of the project are: (1) to study students' attitudes and perceptions on road accident, and (2) to manage change in unsafe driving behaviours. It focused on students' wearing helmet behaviour. A few workshops were organised in universities. Then evaluation of behaviour change was done in order to understand what activities and factors could influence wearing helmet behaviour.

Keywords: Safe driving behaviours, wearing helmet behaviour, behaviour change

1 INTRODUCTION

In 2015, Thailand was ranked the second highest in road traffic fatality rate in the world according to the World Health Organization (1), with 36 deaths per 100,000 population. Thai government has been putting a lot of efforts and budget to save more lives from road accident. Many activities have been deployed to reduce number of accidents, such as raising public awareness on driving safely through public events and media, improving road geometries, and law enforcement. However, the latest statistics indicates that our efforts have not yet reach the goal of saving lives.

Most of accidents cause by drivers. It was found that three distinct patterns of behaviour have a powerful influence on driver safety: lapses or absentminded behaviour, errors caused by misjudgement of danger or failures of observation, and violations or deliberate neglect of safe driving (2-3). However, research on driver behaviour has focused almost entirely on individual differences as contributors to unsafe driving behaviour (4). They suggest that safety culture is an important influence on driving behaviour, and plays a critical role in driving safety (5).

It is very likely that improving driving behaviour can decrease accident rate significantly. Safe driving behaviours cannot be achieved by law enforcement alone, and without cooperation from the public. To be successful, changing driver behaviour must be a structured process that is carefully planned and managed seamlessly with public participation.

The objectives of the project are: (1) to study students' attitudes and perceptions on road accident, and (2) to manage change in unsafe driving behaviours. The project mainly focuses on students in universities. This is because most young people use two-wheelers which are therefore exposed to the risk of crashes involving larger and faster moving vehicles. Moreover, young people are more prone to take risks on the road, particularly as motorcycle drivers.

ATRANS Road Safety Clubs were established in three universities in Thailand including Ubon Ratchathani University (UBU), Khon Kaen University (KKU), and Prince of Songkla University (PSU). The clubs called "Safe You Safe Me: Road Safety Club" (SYSM). The key project activities including: safety workshops and campaigns for managing change in driving behaviour, as well as data collection on students' attitudes and behaviours.

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2 METHODOLOGY

Methodology of this research is based on Participatory Action Research (PAR). This is defined as “systematic inquiry, with the collaboration of those affected by the issue being studied, for purposes of education and taking action or effecting change” (6). PAR typically involves community action to address issues raised through the research process (7). This reframes social research as a powerful form of public engagement (8).

SYSM Clubs established in the universities aims to educate, enlighten and empower students to create their own safe community. Objectives of the clubs are for studying unsafe driving behaviours, designing and implementing countermeasures to manage the behaviours, and propagating them to road users to make culture of safe driving. The clubs also develop young ambassadors as trainers to take up this to each individual to bring the change in driving behaviours.

The clubs were organised and managed by students, and supervised by ATRANS professional members. The clubs’ members were trained about road safety. Then, they planned and studied unsafe driving behaviours. Data collection was based on secondary data, ATRANS road safety map, focus group and questionnaire survey. The data were analysed to understand causes of unsafe driving behaviours. The clubs designed and implemented countermeasures (which are suitable for local conditions) to manage the behaviours. The comparative case studies provided an assessment of the project as a whole. Evaluation process was done to identify best practices. Finally, the experiences were summarised and disseminated to road users to make culture of safe driving.

The project was divided two tasks: (1) encouragement of behaviour change, and (2) evaluation of behaviour change.

2.1 Encouragement of behaviour change

This task involved campaigns for encouraging change of unsafe driving behaviour. The activities include:

1. Education for students. This related to activities that encourage students in the universities to drive safely on roads. The main target was motorcycle which was the main travel mode for students. Campaigns focused on three main behaviours including helmet wearing.
2. Soft enforcement on students’ behaviour. This related to campaigns that enforced students to behave safely while riding motorcycle, particularly on helmet wearing.

2.2 Evaluation of behaviour change

After the campaigns for encouraging change of unsafe driving behaviour, the project evaluated the behaviour change based a questionnaire survey. The evaluation was based on the Transtheoretical Model (TTM) which aimed to explain a change in risky behaviour.

Two main dimensions of TTM (9-12) include:

1. Stages of Change: people make attitudinal, intentional, motivational, and behavioural changes as they move through the precontemplative, contemplative, preparation, action, and maintenance stages of readiness for change.
 - Precontemplation stage – being unaware of the problem behaviour
 - Contemplation stage – starting to think about the problem and ambivalence
 - Preparation stage – being motivated to take action in the immediate future
 - Action stage – investing time and energy in taking the necessary steps toward an actual behavioural change
 - Maintenance stage – working steadily to sustain the achieved change
2. Processes of Change: These are the overt and covert activities that various therapy systems use to initiate change.

Experiential processes include:

- “consciousness raising” (greater awareness) is characterized by active gathering of information about oneself and the problem behaviour;
- “dramatic relief” (emotional arousal) is the process of experiencing and expressing feelings about the problem behaviour and possible solutions;
- “environmental reevaluation” (social reappraisal) means the consideration and assessment of how the problem behaviour affects the physical and social environment;

- “self-reevaluation” (self-reappraisal) is the emotional and rational analysis of how the problem behavior or the behaviour change affects the self and self-perception;
- “social liberation” (environmental opportunities) is characterized by awareness, availability, and acceptance of alternative life styles and cues that support the change;

Behavioral processes include:

- “self-liberation” (committing) means deciding to commit to changing the problem behaviour, including the belief in the ability to change successfully;
- “stimulus control” (re-engineering) involves the control or avoidance of situations, persons, or other cues that trigger the problem behaviour, in order to support the occurrence of new behaviour;
- “counter-conditioning” (substituting) is the act of substituting an alternative and healthier behaviour for the problem behaviour;
- “helping relationships” (supporting) implies the active use of social support to make the attempts to change easier;
- “reinforcement management” (rewarding) is the systematic use of reinforcement and (self-)rewarding strategies to attain and stabilize the target behaviour.

3 RESULTS

The project was divided two tasks: (1) encouragement of behaviour change was done during May – August 2017, and (2) evaluation of behaviour change was during October - November 2017. The campaigns for encouraging change of unsafe driving behaviour were evaluated basing on the Transtheoretical Model (TTM) which aimed to explain a change in risk behaviour (as presented in Section 2). A questionnaire survey was designed to collect data on attitudes and behaviour change.

3.1 Data collection and descriptive statistic

Data collection in three Universities: Khon Kaen University (KKU), Prince of Songkla University (PSU), and Ubon Ratchathani University (UBU) was done during October- November 2017, in total 1,250 samples. This was divided equally among universities and groups of faculties, as presented in Table 1.

Most of students use motorcycle as a main transport mode. Most students have experiences on road accident at least once, particularly PSU students (as presented in Table 2). Most of those who ever have experiences on road accident were slightly injury, only few ever got serious injury (as presented in Table 3). Only a third always wear helmet (as presented in Table 4).

Table 1. Number of samples from each university

	All	KKU	UBU	PSU
Number of sample	1,250	450	401	399
Science faculties	33%	33%	30%	36%
Health care faculties	31%	33%	28%	33%
Social faculties	35%	33%	42%	31%

Table 2. Experiences of road accident

Number of accident	All	KKU	UBU	PSU
0	37%	45%	49%	0%
1	33%	28%	27%	53%
2	18%	16%	14%	27%
+3	12%	10%	10%	20%

Table 3. Injury levels

Injury	All	KKU	UBU	PSU
Slightly Injury	62%	67%	60%	59%
Some Injury	32%	27%	34%	37%
Serious Injury	6%	6%	6%	5%

Table 4. Wearing helmet

	All	KKU	UBU	PSU
Always	30%	23%	36%	33%
Often	43%	38%	44%	48%
Sometime	19%	28%	15%	14%
When having enforcement	4%	5%	3%	5%
Never	3%	6%	1%	1%

Most students wear helmet because they think helmet can reduce accident injury, and when there is police enforcement (as presented in Table 5). They tend to not wear helmet when travelling for a short distance or on small roads (as presented in Table 6).

Table 5. Reasons to wear helmet

Reducing accident injury	86%
Police enforcement	75%
Families or close friends force to wear	24%
Families or close friends suggest to wear	21%
Others wear	14%

Table 6. Reasons not to wear helmet

Short distance travelling	76%
Travelling on small roads	55%
No police	31%
In a hurry	30%
Loss of hair style	23%
Difficulty in carrying	20%
Uncomfortable	19%
No helmet	19%
Confidence in riding without accident	6%
Others not wearing	5%

3.1.1 Analysis of the Transtheoretical Model (TTM)

This study applies TTM to evaluate behaviour change of helmet wearing. The core constructs of the TTM contain three main dimensions: stages of change (5 stages), processes of change (10 processes) and decisional balance (Pros & Cons). The behaviour change is evaluated through the stage of change. Activities or campaigns

could directly influence wearing helmet behaviour or through the processes of change. Wearing helmet behaviour could be also affected by personal characteristics, experiences and perceptions. The framework for evaluation of the helmet behaviour change is shown in Figure 1.

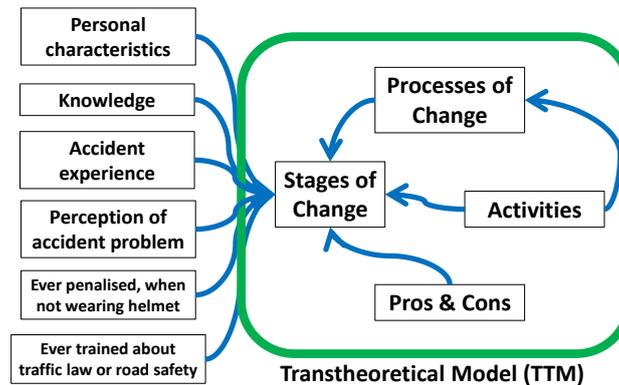


Figure 1. Framework for evaluation of the helmet behaviour change

According to TTM, stages of change for wearing helmet behaviour are divided into five stages, and can be seen as three broad groups as: unaware, having intention, and being behaviour, as shown in Table 7.

Table 7. Stages of change for wearing helmet behaviour

Stages of change		Wearing helmet	
Precontemplation stage	being unaware of the problem behaviour	Wearing helmet is not an important behaviour	Unaware
Contemplation stage	starting to think about the problem and ambivalence	Wearing helmet is an important behaviour	Having intention
Preparation stage	being motivated to take action in the immediate future	Wearing helmet is a behaviour that I should do	
Action stage	investing time and energy in taking the necessary steps toward an actual behavioural change	I usually wear helmet	Being behaviour
Maintenance stage	working steadily to sustain the achieved change	I have been wearing helmet more than a year	

The questionnaire asked students to indicate which stages they were currently (during last year) and previously (longer than a year). The results found that proportion of those who usually and always wear helmet (helmet wearing as behaviour) increases from 20% to 35% (as presented in Table 8). About 40% of students have increased their stages of helmet wearing behaviour (at least one stage), while another 40% have not changed, and less than 20% have decreased their stages of behaviour (as presented in Table 9).

The processes of change for wearing helmet behaviour are divided into 10 stages. The students were asked how much (with 1-4 scales) road safety activities or campaigns influence their processes of change. The students were also asked what road safety activities they involved during last year, including:

- Seeing campaigns in media (TV, Radio)
- Seeing campaigns organized by related agencies (public, private, university)
- Attending campaigns organized by related agencies (public, private, university)
- Enlightened by families or close friends to wear helmet

All data collected by the questionnaire was analysed basing on the framework in Figure 1. The five stage of change (in Table 7) were grouped into three categories of behaviours (unaware, having intention and being behaviour). However, the sample of the unaware group was only 20% and not significantly different from having intention group, so these were merged to be one group. Thus, in the statistical analysis, there were two

stages of behaviour: helmet wearing as behaviour (helmet behaviour) and not wearing helmet as behaviour (others).

Table 8. Proportion of students for each stages of wearing helmet behaviour

Stages of change	Pervious	Current
Wearing helmet is not an important behaviour	16%	4%
Wearing helmet is an important behaviour	27%	27%
Wearing helmet is an behaviour that I should do	37%	35%
I usually ware helmet	10%	20%
I always ware helmet more than a year	10%	15%

Table 9. Proportion of students for changing stages of wearing helmet behaviour

Changing	All	KKU	UBU	PSU
Decrease	17%	14%	20%	18%
Stable	41%	44%	38%	42%
Increase	42%	42%	42%	40%

There were two types of measurement scales for the collected data: nominal and ordinal. These data were analysed by nonparametric methods, including: Chi Square test and Phi (to test whether 2 nominal variables are associated) and Cramer's V (Value between 0 and 1 that indicates how strongly two nominal variables are associated), in order to test which factors significantly associate with helmet wearing behaviour (dependent variable). Only variables that associated with the behaviour change were included in the logistic regression model, as Eq. 1. The result of parameter in the model is presented in Table 10.

$$\ln \left[\frac{\Pr(\text{Helmet behaviour})}{\Pr(\text{Others})} \right] = \text{Constant} + \beta_1(\text{HR}) + \beta_2(\text{RM}) + \beta_3(\text{SD}) + \beta_4(\text{NPE}) \quad (1)$$

Where

- HR = Process of helping relationship
- RM = Process of reinforcement management
- SD = Short distance travelling
- NPE = No police enforcement

Table 10. Multinomial logistic regression model for wearing helmet behaviour

Variables	Coefficients	P-value
Constant	-0.3962	0.01
β_1	0.3738	0.03
β_2	0.3197	0.04
β_3	-0.4002	0.01
β_4	-0.3882	0.01
No. of sample	1,066	
Nagelkerke R^2_N	0.069	

The variables that significantly influence wearing helmet behaviour include (1) process of helping relationship (The activities support me to wear helmet), (2) process of reinforcement management (The activities make me feel that wearing helmet is useful), (3) short distance travelling, and no police enforcement.

Coefficients of the two processes have positive sign, indicating that the processes would influence wearing helmet behaviour. On the other hand, coefficients of the other variables have negative sign indicating that for a short distance travelling and when having no police enforcement; students tend to not wearing helmet as behaviour. The constant also has negative sign, indicating that without any encouragement; students basically

are not likely to wear helmet as behaviour. The goodness of fit is rather low. This indicates that although the four variables are significant, still there are unknown various factors that affect the behaviour.

The analysis also assessed how road safety activities affect the behaviour. It found that the activities did not directly affect the behaviour, but they influence through the process of change. The campaigns organised by government and private sectors could support those who attend the events to wear helmet, while families and close friends of students could make them feel that wearing helmet is useful. Activities that students do not personally involve (including campaigns in media e.g. TV and Radio, and campaigns presented by related agencies) could not significantly influence the helmet wearing behaviour.

4 CONCLUSION

This study aimed to manage change in unsafe driving behaviour. It focused on students' wearing helmet behaviour. A few workshops were organised in universities. Then evaluation of behaviour change was done in order to understand what activities and factors could influence wearing helmet behaviour.

The study found that all students understand that helmet can save life and know that by law motorcycle users (both riders and passengers) must wear helmet. However, only about a third of students always wear helmet as behaviour, and only 30% perceive accident problem as serious. Students are less likely to perceive road accident as "my serious problem". So they value the cost of accident less than the convenience of unsafe driving behaviours e.g. not wearing helmet. Driving behaviour change is the first and most important thing that has to be changed, in order to create safe society. However, typical campaigns and activities (TV, roadside messages, etc.) are unlikely to influence behaviour (only intention).

Some activities directly affect the processes of change. Students attending campaigns organised by government and private sectors perceive that the activities support them to wear helmet. The enlightenment by families and close friends also significantly make students feel that wearing helmet is useful. To manage change in risk driving behaviour, the study suggests that enforcement is the most effective strategy to influence the change, particularly in a short term. Effective enforcement and penalty could reduce value of the convenience of not wearing helmet. However, safe driving behaviours cannot be achieved by law enforcement alone. For a long term, road safety education could increase students' perception on the value of the cost of road accident. The study found that education measures that could affect the behaviour change include campaigns promoting to save lives of families and friends, direct campaigns for each road user group and each behaviour, and campaigns to change perception of "no accident for short distance travelling".

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The Diffusion Mechanism of Road Safety, from Traffic Education / Traffic Enforcement/ Discussion on Traffic Engineering

Tai-Shen Yin^a and Titan Cheng Yin^{1a}

1 INTRODUCTION

Transportation is the foundation of economic development, the core of Sun (孫中山) theory is traffic construction, especially China's big land, the broad-man thick, and now the traffic load is fast and the speed is high, traffic accidents are an important issue, to reduce or avoid, it is necessary to start with the norms of human behavior and education.

2. RESEARCH METHODOLOGY

2.1 Literature discussion and qualitative research

2.2 Actual Case Discussion

Road Safety Committee

3. OVERVIEW OF THE CURRENT SITUATION

Traffic is the interaction between man and carrier, in motion, there will be conflict and harm, car accident casualties.

Traffic Safety Supervision Committee of the Ministry of Communications:

1. To strengthen the coordination, supervision and promotion of national road traffic safety affairs, set up the road of the Ministry of Communications, Traffic Safety Steering Committee.
2. Second, the tasks of this Council are as follows:
 - (1) Planning, coordinating and supervising the implementation of national road traffic safety matters.
 - (2) Review of the road traffic safety work plan and implementation of the municipal, county (city) government, supervision and verification matters.
 - (3) Proposals for the revision of road traffic safety regulations.
 - (4) Collection, comprehensive analysis and special research items of road traffic safety data.

4. EFFECT OF IMPLEMENTATION

From education rooting advocacy
From Traffic engineering
From Traffic enforcement

5. CONCLUSIONS AND RECOMMENDATIONS

Traffic safety is the relationship between the dynamic effect of a row, to have an open pipeline and a collaborative organization. - Road Safety Committee

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Road Safety Committee – MOTC/TW

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Multiple Influences on Children's Street-Crossing Behavior in A VR Environment

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Abstract

Pedestrian accidents are among the most common causes of death and serious injury to children. A range of risk factors, including individual differences such as gender and sensation-seeking, and traffic environment factors such as oncoming vehicle speeds and distances apart, have been investigated as predictors of children's pedestrian behaviors. There is mixed consensus concerning the influence of these effects and little evidence examining how they might interact with each other to influence children's risk. The present study was designed to examine the independent and joint influences of individual differences (gender, sensation-seeking) and traffic environment factors (vehicle speeds and distances) on children's pedestrian safety. 120 children in 4th and 5th grade (ages 10-13 years) were recruited and assigned to four groups with 30 children each: boys high in sensation seeking, boys low in sensation seeking, girls high in sensation seeking, and girls low in sensation seeking. Children's pedestrian crossing behaviors were evaluated in virtual reality traffic environment system using a head mounted display. A 2 (gender: female vs. male) * 2 (sensation seeking: high vs. low) * 2 (vehicle distance apart: 75m vs. 130m) * 2 (vehicle speed: 5m/s vs. 10m/s) mixed factorial design was implemented. Results showed that children low in sensation seeking missed more safe opportunities to cross and had longer start gaps to enter the roadway compared to those high in sensation seeking, and these effects were more substantial when vehicles were spread further apart but traveling slowly. Children experienced more virtual crashes and ran across the lanes more often when vehicles were traveling faster, and children tended to have shorter start gaps, more missed safe opportunities to cross, and fewer crashes when the vehicles were traveling closer together. Interaction effects between vehicle distance and speed were also detected, with children engaging in riskier crossings when the car was moving more quickly and the vehicles were spread further, than when the vehicles were moving quickly but were closer together. No gender differences emerged. We conclude that both sensation seeking and traffic environment factors impact children's behavior in traffic, and that there are interactions between sensation seeking, traffic speeds, and distances between vehicles that impact crossing behavior.

Keywords: Virtual reality environment; pedestrian crossing behavior; risk-taking; individual difference; traffic environment

1. INTRODUCTION

Road traffic crashes are the leading cause of death and injury to children in China (Chinese Center for Disease Control and Prevention and Safe Kids Worldwide, 2017). Among road traffic injury causes, pedestrian injury is the most common cause of mortality for Chinese children, with Global Burden of Disease 2016 estimates suggesting 68.74% of Chinese children ages 5-14 who die in road traffic injuries are pedestrians rather than other road users (Institute for Health Metrics and Evaluation, 2018).

Previous researchers have summarized a range of risk factors that influence children's pedestrian injuries (Schwebel et al., 2012). Among these, the effects of individual differences in temperament and personality are commonly cited; several studies indicate higher levels of sensation seeking, for example, are associated with pedestrian injury risk (e.g. Rosenbloom and Wolf, 2002; Zuckerman and Duby, 1985).

Also mentioned with some frequency as a risk factor for child pedestrian injury is male gender (e.g.,

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Barton and Schwebel, 2007a; Barton et al., 2011; Fu and Zou, 2016; Granié, 2007; Sullman et al, 2012), although there is mixed consensus concerning the effects of gender on children's pedestrian behavior. For example, Fu and Zou (2016) observed boys were more likely to run near traffic than girls and Sullman and colleagues (2012) found boys played on road more often than girls, but other studies reported no gender effect on children's pedestrian safety (Ampofo-Boateng and Thomson, 1991; Barton and Schwebel, 2007b; Morrongiello and Corbett, 2015). Several factors might explain conflicting previous results (e.g., different age ranges studied; different pedestrian tasks; see Wang et al., 2018a), but one likely factor is that most studies consider gender as an independent risk factor without considering the possibility that gender might interact with other risk factors to influence children's pedestrian behavior. Behavioral theory suggests risk behaviors are likely influenced by multi-layered and multi-factored rather than discrete factors (Herrero-Fernández et al., 2016; Schwebel and Barton, 2005; Ulleberg and Rundmo, 2003).

A challenge in parsing apart multi-layered and multi-factored individual difference factors that predict children's safety in pedestrian environments is that pedestrian safety is also greatly influenced by children's cognitive development. For example, perception and judgment of factors such as vehicle speed and distances may impact safe crossing behavior. Children's skill in judging vehicle distances is consistently demonstrated to influence children's selection of crossing gaps (Connelly, et al., 1996, 1998), their fear and danger appraisals of road-crossing scenarios (Rosenbloom et al., 2008), and actual crossing behaviors (Morrongiello et al., 2016; Simpson et al., 2003). Effects of vehicle speed on children's pedestrian behavior is less established. In fact, research specifically comparing the influence of vehicle speeds and vehicle distances tends to suggest vehicle distance is used more often than speed by children in judging traffic safety. For example, Simpson and colleagues (2003) studied pedestrian behavior among children (5-9 years old and 10-14 years old), adolescents (15-19 years old) and adults (above 19 years old) in a virtual traffic environment with either vehicles traveling at either a uniform distance apart or at a uniform speed, and found that pedestrians of all ages based road crossing decisions on inter-vehicle distance more than vehicle speed. Others report similar findings (Connelly et al., 1996, 1998; Morrongiello et al., 2016; Oxley et al., 2005), although Velde and colleagues' results (2005, 2008) suggested that children relied both on vehicle distance and vehicle speed to judge pedestrian safety.

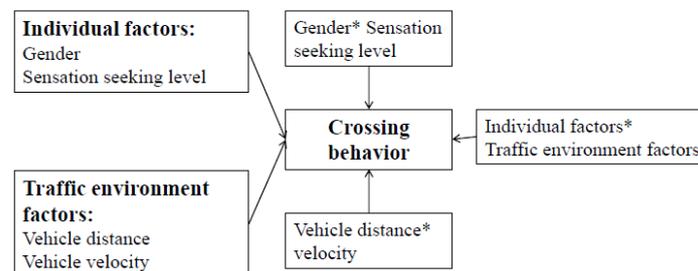


Fig. 1 Hypothesized conceptual model whereby children's gender, sensation seeking level, oncoming vehicle speed, and distance between oncoming vehicles predict children's crossing behavior

Given the apparent independent and joint influences of individual differences and cognitive judgment of vehicle speed and distances on children's pedestrian safety, we designed a study to evaluate the conceptual model pictured in Fig.1. To test our hypotheses, we used a virtual pedestrian environment that allowed us to (a) evaluate behavior safely without actual risk of injury and (b) manipulate traffic speed and distances between vehicles in a controlled manner. We posited three primary hypotheses: 1) Boys and children with high sensation seeking levels will take more risks crossing the virtual road; 2) Children will take fewer risks as the distance between vehicles increases, as well as when approaching traffic is moving more slowly; 3) Given the lack of previous evidence, we posed an exploratory hypothesis that individual difference and vehicle speed/distance factors would interact to influence risk-taking in children's crossing behaviors.

2. METHODS

2.1 Participants

120 children in 4th and 5th grade were recruited from an elementary school in Nantong city, China. In order to select children with varying levels of sensation seeking, we administered the Chinese version of the Primary and Middle School Students' Sensation Seeking Scale (Chen et al., 2006) to all 300 4th

and 5th grade students in the school (167 boys and 133 girls), and then selected 120 students to participate in the remainder of the study based on their scores, with 30 boys and 30 girls scoring high in sensation seeking (top 17.96% and 22.56% for boys and girls, respectively) and 30 boys and 30 girls scoring low in sensation seeking (bottom 17.96% and 22.56% for boys and girls, respectively) included. The average sensation seeking score for the low sensation seeking group was 29.02 ($SD=2.27$, range = 27-36), and the average score in the high sensation seeking group was 61.92 ($SD=8.14$, range = 50-97). As expected, the difference between groups was statistically significant ($t(118)=-30.16$, $p<0.001$) and there was no significant difference between boys and girls in sensation seeking ($p>0.05$).

The research design created 4 groups therefore: boys high in sensation seeking, boys low in sensation seeking, girls high in sensation seeking, and girls low in sensation seeking. Each group had 30 children. The sample had a mean age of 11.7 years ($SD = 0.82$; range = 10-13 years old).

Approval for the research was obtained from the Nantong University Academic Ethics Committee and the Primary Education Office of the participating school. Written parental consent and verbal child assent was secured prior to each child's participation. Participants were compensated with educational gifts.

2.2 Virtual environment

A virtual urban traffic environment was created with buildings, roads and vehicles. The virtual environment was viewed through HTC VIVE, a virtual reality display which contains dual AMOLED screens with diagonal diameters of 3.6 inches. The head-mounted resolution of the 90HZ head-mounted display is 1080×1200 pixels (Combined resolution is 2160×1200 pixels). Its field of view is 110 degrees. Sensors for the helmet displays include Steam VR tracking technology, G-sensor calibration, gyroscopes and proximity distance sensors. The system includes two VIVE locators that use 360-degree positioning coverage and wireless synchronization technology.

The virtual environment consisted of a straight, flat section of roadway, several intersections that could be used for experimentation, and typical local buildings, street lights and vehicles. The road itself was 5.6m wide, presenting bidirectional traffic on two lanes. The lanes were marked with continuous white edge lines, dashed central white stripes and zebra crossings at intersections. Vehicles included typical models of private cars, police cars and taxis, all of which were 1.6m in width and 3m in length. Cars appeared in five different colors (blue, yellow, green, red, orange). Fig.2 illustrates a car crossing the zebra. The sound of traffic in the environment corresponded to vehicle distances and speeds, offering Doppler sound effects to increase realism. When a participant was hit by the vehicle, the screen instantly became gray and the sound of an ambulance siren was heard.



Fig. 2. Schematic representation of virtual reality traffic scene

Four types of traffic flow were presented to participants, varying by inter-vehicle distances and vehicle velocities that represented common traffic behavior on urban Chinese roads:

- vehicles driving at 5m/s and distance between vehicles was 75m;
- vehicles driving at 5m/s and distance between vehicles was 130m;
- vehicles driving at 10m/s and distance between vehicles was 75m;
- vehicles driving at 10m/s and distance between vehicles was 130m.

In all traffic flow conditions, the vehicles drove at constant and equivalent speeds and distances in both directions.

2.3 Experimental Design

We implemented a 2 (gender: female vs. male) * 2 (sensation seeking: high vs. low) * 2 (vehicle distance: 75m vs. 130m) * 2 (vehicle speed: 5m/s vs. 10m/s) mixed factorial design. Sensation seeking and gender served as between-subject predictors, and vehicle speed and vehicle distance as within-subject predictors.

2.4 Procedure

Each participant was tested individually by a group of three trained research assistants. One research assistant worked directly with the child participant on the VR street crossing trials. That assistant's roles included guiding children on how to wear the VR headset, informing them of the task requirements and monitoring the safety of participants during the experimental process. The second research assistant oversaw operation of the computer that controlled the VR equipment, and the third used a HD video camera to film participants' behavior during the experimental sessions.

Following consent procedures, each session began by fitting participants with the VR headset (HMD). Children were told that they should try their best to cross the road safely to the other side. Instructions were given verbally and children offered the opportunity to ask questions of the research assistants. Participants were given two practice trials first, both at intersections similar to those used in the experimental trials, and with vehicles traveling at 8m/s and 100m apart from each other. A research assistant instructed participants to wait on the curb and observe the traffic, then to start crossing the road when they felt it was safe. Once the participant crossed to the other side of the road, the research assistant guided him/her back to the curb and initiated the next practice trial. If a participant was hit by a vehicle, the research assistant assured the participant it was fine since this was a simulation, guided him/her to safety, and then gave the child another practice trial.

Following the practice trials, children completed four sets of three unique trials following a procedure similar to that used in the practice trials. In total therefore, each participant completed 12 experimental trials (3 crossings by 4 traffic flows). The order of traffic flows was randomly assigned. During all experimental trials, data concerning children's decisions were recorded automatically by the virtual reality computer system, offering rich data on pedestrian behavior and decisions. Specific outcome measures are described below.

On average, experimental sessions lasted approximately 30 minutes. The full experimental process was videotaped, enabling subsequent behavioral coding of participants' behavior. Videotape coding was performed by two trained research assistants, who established inter-rater reliability through independent viewing of the full sample ($r=0.98$ for variable "running", and $r=0.94$ for variable "missed opportunity"). Rare disagreements were resolved through discussion between the coders and a third senior researcher.

2.5. Measures

The data recorded by the computer and those coded from videotapes were used to calculate the following pedestrian safety outcome measures for each participant, with results averaged across the three crossings in each traffic flow condition.

(1) Dangerous crossings (count) - number of crossings when the child was either hit by a virtual car or was within 1 second of being struck by an approaching vehicle (adapted from Schwebel et al., 2014; Stavrinos et al., 2011; Stavrinos et al., 2009).

(2) Start gap (seconds) - for the traffic gap that the child chose to enter, the time elapsed between the last vehicle leaving the crosswalk until the child's foot contacted the road from off the curb. This temporal lag before initiation of crossing into a traffic gap is considered an indicator of children's efficiency of cognitive processing in pedestrian situations (also called start delay in the literature; adapted from Pitcairn and Edlmann, 2000; Stavrinos et al., 2009).

(3) Running (count) - number of crossings during which the child ran while crossing the road, defined as both feet being off the ground simultaneously. This kind of behavior is relevant to safety for two primary reasons: (a) running can lead to failure to observe oncoming traffic (Charron et al., 2012; Zeedyk et al., 2002), and (b) running increases risk of falling down while crossing. Running children may also confuse drivers, leading to vehicle-child pedestrian crashes because drivers respond incorrectly.

(4) Missed opportunities (count) - number of times the child chose not to cross within a traffic gap that was 1.5 times or greater than the time required for the child to cross the street safely (adapted from O' Neal et al., 2016; Corbett, 2017). Because of the experimental design we used – gaps between traffic ranged from 7 to 26 seconds – children could have safely crossed within any gap presented to them (the road width was 5.6 m across both lanes, children walked about 1.45 m/s, so crossing took children on average 3.86 s). Therefore, we computed missed opportunities by tallying the number of vehicles that passed a child before he/she crossed, excluding the first vehicle to pass.

3. DATA ANALYSIS

Before evaluating the influence of multiple factors on children's crossing behavior, data were pre-screened on a trial by trial basis to remove extreme univariate outliers (values > 5 standard deviations above or below the mean). Univariate outlier removal occurred for 0.003% of trials (4 data points from 1224 trials). Data cleaning also excluded 18 participants due to technical or experimental error with the VR system. Analyses comparing the 101 valid participants for analysis to the 18 excluded participants found they were not statistically different in terms of age, gender or sensation seeking scores.

Primary analyses were conducted through a series of repeated measures ANOVA models with gender, sensation seeking level, vehicle distance and vehicle speed serving as the independent variables and the four pedestrian behavior outcomes as the dependent variables. Both main effects and interactions between multiple factors were tested.

4. RESULTS

One hundred and one children, including 27 boys high in sensation seeking, 27 boys low in sensation seeking, 25 girls high in sensation seeking, and 22 girls low in sensation seeking, were included in the primary analyses. Each participant completed 12 trials, 3 at each of the 4 traffic flows.

4.1 Dangerous crossing

We considered dangerous crossing first. Eighty-two of the 1212 valid trials (6.8%) resulted in collisions and 136 trials (11.2%) involved close calls. We combined the numbers of collisions and close calls and then averaged across trials for each of the 4 types of traffic flow to yield a measure of the percentage of dangerous crossing for each child in each traffic flow. A 2 (gender: female vs. male) * 2 (sensation seeking: high vs. low) * 2 (vehicle distance: 75m vs. 130m) * 2 (vehicle speed: 5m/s vs. 10m/s) ANOVA with repeated measures on the vehicle distance and speed factors was computed. The percentage of dangerous crossings served as the dependent variable. Fig. 3 illustrates the distribution of dangerous crossings as a function of child gender and sensation seeking, and vehicle distance and speed. As shown, the results indicate significant effects of vehicle distance ($F_{\text{distance}}(1,97) = 10.99$, $p = 0.001$, $\eta^2_p = 0.10$) and vehicle speed ($F_{\text{speed}}(1,97) = 110.97$, $p = 0.000$, $\eta^2_p = 0.53$) on children's dangerous crossings. We also detected a significant interaction effect between the two vehicle variables, $F(1,97) = 11.13$, $p = 0.001$, $\eta^2_p = 0.10$. Simple effect tests showed that when the car was moving more quickly and the vehicles were spread further, children engaged in riskier crossings than when the vehicles were moving quickly but were closer together ($M = 20\%$ vs. 11% for 10 m/s ; $p < 0.05$). When the car was moving more slowly, children engaged in dangerous crossings at similar rates ($M = 2\%$ vs. 2% for further vs. closer distances at 5 m/s ; $p > 0.05$) (Fig. 4). There also were no significant effects of gender or sensation seeking level, $F_s(1,97) < 1$.

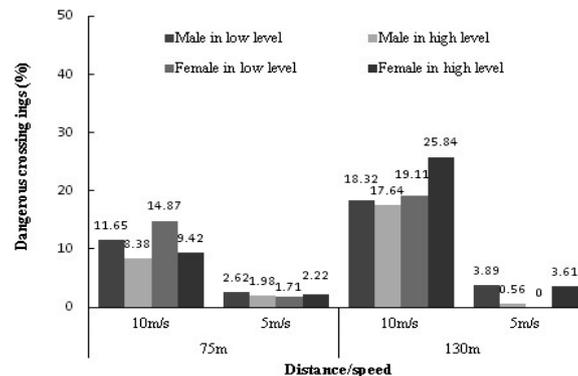


Fig. 3. Percentage of dangerous crossings as a function of gender and sensation seeking level.

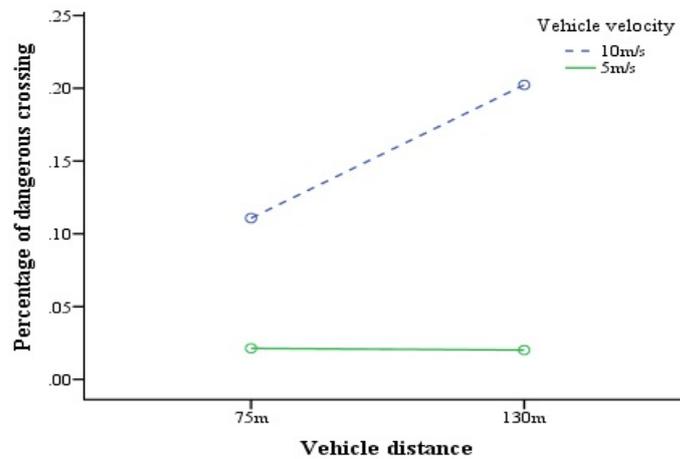


Fig. 4. Percentage of dangerous crossings as a function of vehicle distance and vehicle speed.

4.2 Start gap

A 2 (gender: female vs. male) * 2 (sensation seeking: high vs. low) * 2 (vehicle distance: 75m vs. 130m) * 2 (vehicle speed: 5m/s vs. 10m/s) repeated measures ANOVA analyzed the effects of the factors of interest on start gap, or children’s temporal delay to enter the selected traffic gap after it appeared. The results showed that sensation seeking level had a pronounced effect on the ‘start gap’ measure: Children scoring low in sensation seeking waited much longer to enter gaps than those scoring high in sensation seeking ($M=9.27$ s vs. 8.39 s), $F(1,97)=5.35$, $p=0.023$, $\eta^2_p=0.06$. Moreover, significant differences in start gap also emerged based on vehicle distance and speed, $F_{\text{distance}}(1,97)=27.33$, $p=0.001$, $\eta^2_p=0.22$; $F_{\text{speed}}(1,97)=6.83$, $p=0.01$, $\eta^2_p=0.07$, and there was a significant interaction effect between vehicle distance and vehicle speed, $F_{\text{distance} \times \text{speed}}(1,97)=59.93$, $p=0.000$, $\eta^2_p=0.41$. Simple effect analysis showed that children tended to have shorter delays starting into a traffic gap when vehicles were spaced closer together ($M=6.36$ s vs. 13.21 s) and when vehicles were moving more quickly ($M=6.79$ s vs. 12.77 s). Descriptive data appear in Table 1. Post-hoc Bonferroni tests found children had the longest start gap when vehicles approached slowly at greater distances apart, followed by vehicles approaching quickly at greater distances apart, then approaching slowly at closer distances and finally when vehicles approached quickly at closer distances apart ($p<0.05$).

Finally, a significant three-way interaction between vehicle distance, vehicle speed and sensation seeking emerged, $F_{\text{distance} \times \text{speed} \times \text{sensation seeking level}}(1,97)=8.84$, $p=0.004$, $\eta^2_p=0.09$. As shown in Fig.5, sensation seeking was most relevant when vehicles were not close together but were traveling slowly; in the 130 meter distance and 5 m/s condition, there was a significant difference between high ($M=13.02$ s) and low ($M=16.53$ s) sensation-seeking levels, $F(1,97)=8.10$, $p=0.005$, that was not statistically significant in the other traffic conditions ($p>0.05$). There also were no significant gender differences, $F_s(1,97)<1$.

Table 1: Descriptive Statistics Giving the Mean (SD) for start gap (seconds) as a Function of Traffic flow types, Gender, and sensation seeking level group

Gender	Distance	Sensation seeking level	75 m		130 m	
			10 m/s	5 m/s	10 m/s	5 m/s
Male		low level	4.58(1.11)	7.36(0.91)	8.47(2.37)	16.94(8.55)
		high level	4.92(0.66)	7.59(1.25)	7.95(1.22)	12.94(1.28)
Female		low level	4.67(0.89)	7.53(1.45)	8.52(1.63)	16.07(7.89)
		high level	4.90(0.52)	7.35(0.59)	8.37(0.74)	13.12(1.5)

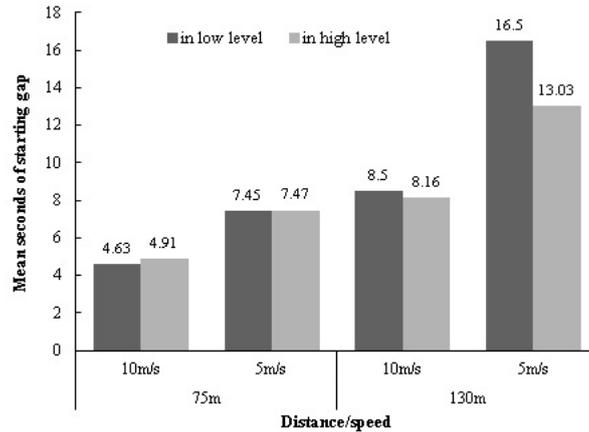


Fig. 5. Mean seconds of start gap as a function of sensation seeking level, vehicle distance, and vehicle speed

4.3 Running

Participants ran across the road on 154 of the 1212 valid trials (12.7%). Fig. 6 illustrates the distribution of running as a function of gender and sensation seeking level across vehicle distances and speeds. A 2 (gender: female vs. male) * 2 (sensation seeking: high vs. low) * 2 (vehicle distance: 75m vs. 130m) * 2 (vehicle speed: 5m/s vs. 10m/s) repeated measures ANOVA yielded just one significant effect, for vehicle speed, $F(1,97) = 6.22, p = 0.014, \eta^2_p = 0.06$. Post hoc Bonferroni tests indicated children ran more often when they faced vehicles traveling more quickly (10 m/s) than when they faced vehicles traveling more slowly (5 m/s; $M = 14.7\%$ vs. 11.3%). No other main effect was statistically significant, $F_s(1,97) < 1$.

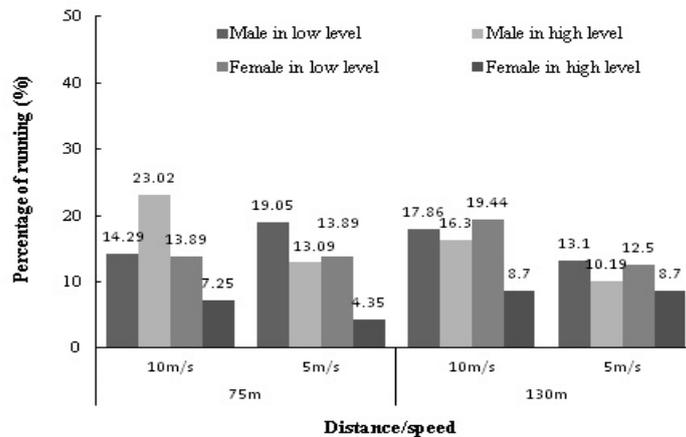


Fig. 6. Percentage of running as a function of gender, sensation seeking level, and four types of traffic flows.

4.4 Missed opportunities

Participants missed at least one safe opportunity to cross the street on 325 of 1212 trials (26.82%), including 24 trials in which children missed 10 or more safe opportunities to cross. We computed the average number of missed opportunities to cross within each traffic flow condition for analysis.

As shown in table 2, children with low sensation seeking ($M = 1.16$ missed opportunities per crossing trial, $SE = 0.15$) missed more opportunities than those with high sensation seeking level ($M = 0.58$ missed opportunities per crossing trial, $SE = 0.16$), $F(1,97) = 7.29, p = 0.008, \eta^2_p = 0.08$. Moreover, there were significant main effects of vehicle distance and vehicle speed, $F_{\text{distance}}(1,97) = 27.33, p = 0.001, \eta^2_p = 0.22$; $F_{\text{speed}}(1,97) = 6.83, p = 0.01, \eta^2_p = 0.07$. Post hoc comparisons showed that children missed more opportunities when vehicles were spaced close together than when they were greater distances apart ($M = 1.31$ vs. 0.43), and that they missed more opportunities to cross when vehicles were traveling quickly than when the vehicles traveled more slowly ($M = 1.12$ vs. 0.62). Further Bonferroni post-hoc comparisons suggested children missed safe opportunities to cross most often with cars traveling quickly and at close distances apart compared to the other traffic flow conditions, especially when the cars traveling from a distance ($p < 0.05$).

No significant gender differences were presented in missing safe opportunities to cross ($F(1,97) < 1$), nor did any interaction effects emerged among the factors ($p > 0.05$).

5. DISCUSSION

We investigated the direct and interacting roles of fourth- and fifth-grade Chinese children's individual differences (gender and sensation seeking) and the traffic environment (traffic speeds and distance between vehicles) on children's behavior while crossing a virtual street. The findings reinforce the notion that pediatric pedestrian behavior is not a single activity based on single risk factors, but rather represents complex interplay of individual differences and the traffic environment that together impact children's safety.

Table 2: Descriptive Statistics Giving the Mean (SD) for miss opportunities as a Function of Traffic flow type, Gender, and sensation seeking level group

Gender	Distance Sensation seeking level	75m		130m	
		10m/s	5m/s	10m/s	5m/s
Male	low level	1.89(3.29)	1.48(2.42)	0.87(1.69)	0.38(0.62)
	high level	0.99(1.93)	0.20(0.48)	0.19(0.38)	0.09(0.21)
Female	low level	2.72(3.69)	0.92(1.46)	0.67(1.05)	0.33(0.66)
	high level	1.15(1.99)	1.14(2.88)	0.49(0.78)	0.39(0.91)

5.1 The effect of individual factors on pedestrian behaviors

Similar to previous findings (e.g. Rosenbloom and Wolf, 2002; Greene et al., 2002; Schwebel et al., 2009), our findings confirm that sensation seeking plays a role in children's pedestrian behaviors. Children low in sensation seeking missed more safe opportunities to cross, and they tended to hesitate much longer prior to starting to cross compared to those high in sensation seeking. Interestingly, sensation seeking did not influence running behavior on the road nor did it influence the ultimate safety of children's crossings. In other words, our results suggest children high in sensation seeking may have been more efficient in their crossing – they entered gaps more quickly and missed fewer safe opportunities to cross – but they did not actually experience higher risk of injury or crash compared to children lower in sensation seeking. Children lower in sensation seeking were more cautious, leading to diminished efficiency, but were equally safe in their pedestrian decisions.

The impact of sensation seeking on children's behavior also varied somewhat across traffic flow environments. Specifically, the results suggested that sensation seeking did not impact behavior except when vehicles traveled slowly and at greater distances apart. In that traffic flow condition, children with low sensation seeking levels had much longer delays before starting their crossing and they left shorter crossing gap when crossing compared to children with high sensation seeking levels. This traffic condition, of course, represented what one might describe as the "easiest" environment to cross within – the traffic was moving more slowly and there were larger gaps between vehicles. Thus, sensation seeking influenced behavior when cautious behavior still allowed safety. When the traffic environment presented was more challenging to cross within, even those with low sensation seeking were obligated to take some risk in order to maintain their safety, so they behaved more like their peers with higher sensation seeking levels. This hypothesis should be couched in the fact that the children in this study were ages 10-13, and therefore should have developed the cognitive capacity to cross streets safely (Ampofo-Boateng and Thomson, 1991; Meir et al., 2015; Velde, et al., 2008). In other words, they had the cognitive capacity to cross and their sensation seeking influenced behavior when the children faced an environment that permitted greater caution within the context of safety. With a riskier environment, even children with low sensation-seeking levels had the cognitive capacity to recognize they should take risks to maintain safety. Results might be different with younger children whose cognitive skills to cross safely are less sophisticated. The results also confirm the conceptual model presented in Fig. 1, suggesting traffic environment factors like vehicle speeds and distances apart may impact the relation between sensation seeking and children's pedestrian behavior (Schwebel and Barton, 2005).

Our results did not yield any gender-based differences in children's pedestrian behavior. The existing literature is mixed on this point, with some studies reporting boys take more risks in pedestrian environments than girls (Barton and Schwebel, 2007a; Barton et al., 2011; Fu and Zou, 2016; O'Neal et al., 2016; Sullman et al., 2012), but others reporting no gender differences (Barton and Schwebel,

2007b; Briem and Bengtsson, 2000; Morrongiello and Corbett, 2015).

5.2 The effect of traffic environment on children's crossing behavior

As predicted and consistent with previous studies (Connelly 1996; Oxley et al., 2005; Velde et al., 2008), we found significant effects of both vehicle distance and speed on children's pedestrian behaviors. Specifically, children exhibited riskier crossings when vehicles were traveling faster. Moreover, when vehicles were traveling more densely (closer together), children tended to have shorter delays entering traffic, missed more safe opportunities to cross, and suffered fewer dangerous crossings. We also detected interaction effects. For example, the distance between cars did not seem to influence children's dangerous crossing when vehicles travelled more slowly at 5m/s, but children experienced more dangerous crossings when vehicles were spread further apart than when they were close together and travelled faster, at 10m/s.

Our results vary somewhat from those of Connelly and colleagues (1996; 1998), and Oxley et al (2005), who both concluded that pedestrian crossing gap judgments were primarily based on vehicle distances apart, not speeds. The differing conclusions may be due to differences in experimental methodologies. In our study, participants actually crossed immersive virtual roads, allowing them to experience actual traffic information from an immersive perspective, whereas most previous studies asked participants to estimate safe crossing gaps rather than actually crossing virtual or real roads.

We extended previous work by considering also the interaction between vehicle speed and distances in our analyses, and our results suggest the interaction between the two may be relevant to children's decisions. As an example, our analysis of missed opportunities suggested children missed the most opportunities with vehicles traveling quickly and at close distances apart. Demonstrating the role of both speed and distance in children's judgments, however, children missed similar numbers of safe opportunities to cross when vehicles were traveling close together; it was only when vehicles were spread apart that vehicle speed seemed to influence decisions.

Similarly, we found that children experienced many more hits and close calls in fast traffic than in slow traffic flows, especially when vehicles were traveling fast but at larger distances apart. These findings parallel results from Morrongiello and colleagues' 2016 study and suggest children may use distance to judge safe traffic gaps more prominently than speed (see also Simpson et al., 2003), but both factors are relevant and behavior results from the interaction of the two factors. The findings also reinforce the notion that children's spatial concepts develop earlier than temporal concepts (Levin, 1992; Manser and Hancock, 1996).

5.3 Limitations and future research directions

Although the present research had several strengths, including a large sample size, use of immersive virtual reality to assess behavior that would be dangerous to assess in the real world, and recruitment of sub-samples who scored high and low on sensation seeking, we acknowledge some limitations also. First, the participants were all in middle childhood (10-13 years old), and results may vary with younger or older children, especially given age and developmental effects on children's pedestrian behaviors (Granié et al., 2013; Thomson et al., 1996; Wang et al., 2018b). Second, we focused on children's crossing behavior while walking alone. Social influences from peers and adults while crossing streets are both indicated in previous researches (Preffer and Hunter, 2013; Tolmie et al., 2005). Finally, the traffic situation in our VR environment was relatively simple, consisting only of traffic traveling on two lanes and at constant speeds and distances apart. Real-world traffic on Chinese urban roads are far more complex and future research might incorporate greater ecological validity, either in virtual or actual worlds.

6. CONCLUSIONS

In summary, our study suggests both sensation seeking and traffic environment factors impact children's behavior in traffic, and that there are interactions between sensation seeking, traffic speeds, and distances between vehicles that impact crossing behavior. Children with low sensation seeking delayed entry into traffic gaps longer when the traffic environment was safer (vehicle velocities were slower and traffic was less dense). All children estimated traffic gaps through perception of both vehicle speeds and inter-vehicle distances, although they tended to be more sensitive to the in-vehicle distance. Gender did not play a significant role in our results.

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Driver Education – How Effective?

Brian O’Neill ¹

Abstract

In the early 20th century the numbers of motor vehicles in use grew rapidly in the U.S, Canada, and many European countries. By the 1930s automobile crashes and the resulting deaths and injuries had become a significant problem, and various safety organizations tried to address it with education and publicity programs aimed at changing driver behavior.

It is not clear when the high crash risks of young drivers were first identified, but in the early 1930s driver education courses began to be offered in U.S. high schools (feasible because U.S. licensing ages were 16 or younger) and soon such courses were being touted (with no evidence) as “the most obvious way” to reduce traffic crashes.

Over the years many claims were made for the effectiveness of high school driver education, however, it was not until the late 1960s that competent research studies (including randomized control trials) were undertaken. The consistent findings from these studies has been that high school driver education does not reduce crashes. Furthermore, the trained students get their licenses sooner, and because teenagers have very high crash risks, the net result of high school driver education is increased numbers of crashes

Keywords: Education, young drivers, driver licensing, countermeasures not evaluated.

1. INTRODUCTION

In 1929 there were more than 23 million passenger cars registered in the U.S. and deaths and injuries from their crashes was a growing problem. The early efforts to deal with this problem were focused on an approach called “The Three E’s”, standing for engineering, enforcement, and education.

The entire focus of this approach was on preventing crashes, reducing their consequences with crashworthiness designs or eliminating roadside hazards was not part of it. Thus, the engineering focus for vehicles was on brakes, steering, etc., with no consideration of features such as safety belts. Enforcement efforts were limited to catching offenders, not preventing crashes through deterrence. But above all, the principal focus was on the “education” of drivers, with educational, training, and publicity programs aimed at preventing crashes by changing road user behaviour (1).

In the 1930s, driver education courses for beginning teenage drivers in U.S. high schools was claimed (with no evidence) to be an effective way to prevent crashes. The safety establishment enthusiastically endorsed this program, proclaiming it was the only way to produce “safe” beginning drivers. Driver education courses became somewhat standardized in the 1940s and 50s, and included classroom instruction and supervised on-road driving.

As more and more young people in the U.S. had relatively easy access to cars there was a growing recognition that this age group had particularly high crash risks, and school-based driver education became the countermeasure for this problem. The key question that was not addressed with any competent studies until the late 1960s was: does high school driver education, or any other formal driver training, actually reduce the crashes of teenage drivers? In this paper I will summarize the very extensive research on this question that has been conducted since the 1970s.

The data and studies cited in this paper are almost entirely from high income countries (HICs) that have had formal driver education for beginning drivers for many years, and in some jurisdictions have required such training as a prerequisite for young drivers to get their first license. However, many of the basic conclusions can

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be expected to apply elsewhere, although the sizes of the effects may be different because driving exposure by age will differ.

2. DRIVER LICENSING AND DRIVER EDUCATION

For a long time formal education for beginning drivers was closely linked to driver licensing, with the completion of some formal training being a prerequisite for obtaining a first license in several jurisdictions. Thus, for example, in the 1960s, despite no evidence of effectiveness, the completion of a high school driver education course was a requirement for teenagers to obtain their first driver's license in a majority of U.S. states.

2.1. Driver Licensing History

In 1904 the United Kingdom was one of the first countries to require licenses to drive motor vehicles and the minimum age to obtain one was 17. Around the same time in the U.S. a few states began issuing limited numbers of chauffeur's licenses and soon most were issuing general licenses. Restrictions such as the minimum ages varied, as did requirements for testing prior to licensure. By 1921 the U.S. Uniform Vehicle Code recommended 16 as the minimum age, however, the actual minimum ages varied among the states ranging from 14 to 17. Canada and New Zealand had similar low minimum licensing ages. The original rationale for choosing one age over another is not fully clear, however, jurisdictions with lower minimum ages typically had rural economies and young people often were needed to drive farm vehicles, which probably influenced these choices.

It is unlikely that the early choices for the minimum licensing ages were influenced by driver age related crash risks, as aggregated data on crashes did not exist at that time. It is not clear when the high crash risks of young drivers were first recognized, but as they came to be recognized it reinforced the safety community's focus on high school driver education.

2.2. Driver crash risks by age

The high crash risks for teenage drivers have been documented for some time now. Figure 1 shows the U.S. passenger vehicle fatal and police-reported crashes per mile travelled by driver age in 2008 (2). The figure clearly shows the overinvolvement of 16-19-year-old drivers in both fatal and police-reported crashes. For both crash types the risks are highest for 16-year olds, and for each subsequent year of age the risks decrease until about age 25. Beginning at about age 70 they increase again (2).²

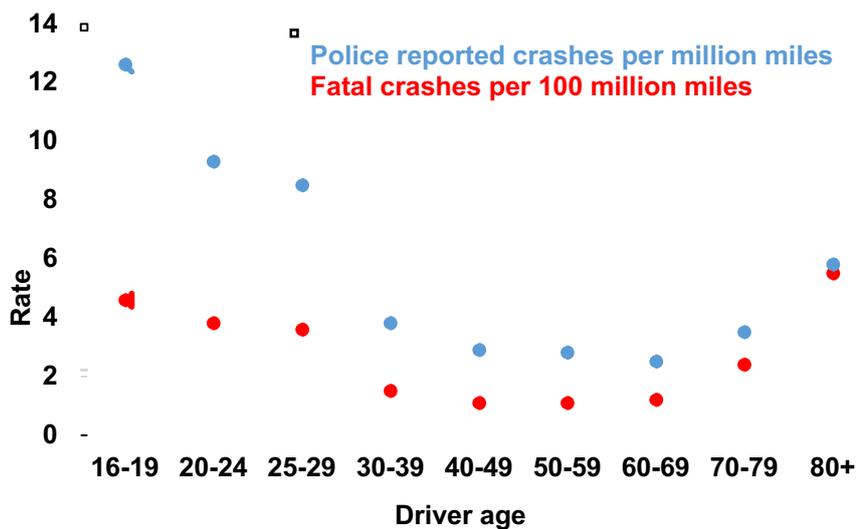


Figure 1: Passenger vehicle driver crash rates per mile traveled by driver age - U.S. 2008

² The reasons for the increases for older drivers in police-reported crashes relate to their decreasing abilities to handle traffic, and for fatal crashes their greater fragility means they are more likely to sustain injuries, such as complicated fractures, that would not be serious for younger drivers but can be fatal for the elderly.

Similar results showing the high crash risks for young drivers have been documented in European countries using data from national travel surveys which measure the on-the-road exposure by different age groups, either in terms of miles travelled or hours spent on vehicle travel (3-6).

2.3. Crash risks and minimum licensing ages

It has been claimed that the high crash rates for 16-year-old drivers is primarily due to driving inexperience, so that if the minimum age for licensure is set at 17 instead of 16, for example, beginning 17-year-old drivers would have crash risks comparable to beginning 16-year-old drivers. The variations in minimum licensing ages in the U.S. provide natural experiments to explore this claim.

A 1983 study compared the fatal crash involvement of teen drivers in three states with different minimum ages for licensure: New Jersey (age 17), Massachusetts (age 16½), and Connecticut (age 16). It reported that New Jersey's 17-year-old minimum licensing age was associated with "greatly reduced fatal crash involvement" (7).

The evidence is strong that immaturity is an important factor in the high crash risks of 16-year-olds, and that for each subsequent year in age as teens become somewhat more mature their crash risks decrease. However, as Figure 1 illustrates, the crash risks continue to decline for drivers into their 30s.

Clearly, young beginning drivers are a safety problem to themselves and other road users and effective countermeasures to this problem are needed.

3. FORMAL DRIVER EDUCATION

3.1. History

From the very early days of motoring the formal training of beginning drivers was widely supported. The British School of Motoring was founded in 1910 and offered training and courses in driving skills, as well as vehicles for drivers who wished to practice. However, in those days when vehicles were relatively expensive, it is likely that most beginners were adults, it was somewhat later when the focus of driver education shifted to beginning teenage drivers.

Driver education in high schools was largely a North American phenomenon, in large part because teenagers could get driver's licenses at 16 or younger, when they were still in school. In the European countries that were following the U.S. with relatively rapid motorization, teenagers could not get a driver's license until 17 or 18, which was after most of them had left secondary school, so making driver education a school class was not feasible for most students.

In North America high school students were an easy group to target for driver education because their training was in schools and it was "free". Also, the U.S. car industry recognized that teaching high school students to drive was good marketing, and consequently made cars available for these courses.

3.2. Early assessments of driver education

There were no scientific evaluations of the effectiveness of driver education until the late 1960s, however, prior to that time there were many claims made by its advocates and some insurance companies that these courses produced large reductions in the crash rates of young drivers.

These early assessments of driver education, however, had absolutely no validity. In all of them enrolment in the courses was voluntary, and in some cases, there was additional selectivity based on academic performance. As Peck noted in his 2011 review of driver education studies:

"Subsequent research confirmed that self-selected volunteers had much more favourable characteristics than did comparison groups of non-trained students. Thus, any differences on subsequent record were confounded by variables such as socio-economic status, gender, social adjustment, grade point and intelligence...No attempt was made in these early assessments to adjust subsequent differences in crash rates for the aforementioned biases" (8).

These differences (or biases) relate to young drivers, however, in all kinds of driver training programs, including programs aimed at older drivers, there are inevitable differences between the groups who "volunteer" for training and those who do not. Some of these differences are related to driving behaviours and crash rates.

3.3. Scientific evaluations

In the late 1960s the failures of the early assessments were recognized, and since that time more competent research designs have been used to estimate whether or not driver education programs reduce the subsequent crash rates of the students.

Such studies have included retrospective or quasi-experimental designs that compare trained and untrained drivers using analyses that attempt to adjust for the pre-existing conditions. These kinds of studies require detailed information on the students in each group and are still subject to errors if the data used for the adjustments are insufficient.

The ideal designs are randomized control trials (RCTs) in which assignment to trained and untrained groups is random. However, RCTs of driver education are difficult to implement, for example, creating untrained control groups that don't have biases can be complicated. Plus, such studies are expensive because large sample sizes are needed in order to be able to detect relatively small differences.

3.3.1. Randomized control studies

Two comprehensive RCT studies of high school driver education were completed in the mid-1970s (in England) and in the late-1970s and early-80s (in the U.S.). The English study was conducted in the north of England and it involved 1,800 16-17-year-old sixth-form students, approximately half took a school driver education class and half received no training (9, 10).

This was the first time that formal driver education was offered in schools in England, and the curriculum was based on U.S. programs. It included class instruction, simulator training, and in-car instruction for students who were 17. Unlike in U.S. schools, the in-car instruction was provided by a commercial driving school. The conclusion from this study was that there "was no evidence at all that driver education has been successful in reducing the accident rate per mile." However, the total crash involvement per person of the group that had the driver education was higher than the untrained group because the driver education group more often obtained driver's licenses.

The U.S study was conducted by the National Highway Traffic Safety Administration (NHTSA). The study was prompted by the large number of believers in driver education and a smaller group of skeptics. The first step was the development of a "state-of-the-art" driver education program, which as referred to as the Safe Performance Curriculum (SPC), which included 70 hours of instruction including classroom, simulator instruction, closed course (with evasive manoeuvres), and on-road training (including at night).

This study was conducted in DeKalb County, Georgia, and involved 16,000 students who were randomly assigned to one of three groups: the SPC; a shorter Pre-Driver Licensing Curriculum (PDL) with minimal training (20 hours of classroom and one hour of on-road training); and no formal driver education (reference). The driver education community expected this study to conclusively show that a model driver education program such as the SPC would reduce the crashes of beginning drivers.

The study addressed the volunteer effect by identifying students who intended to become licensed and agreed to participate in the study. The students were matched on academics, gender, socioeconomic status and then randomly assigned to one of the three groups.

The data on the subsequent crash rates for the three groups in the study have been subjected to a number of analyses. Comparisons of the crash rates for the three groups for the 24 months following their assignments showed no statistical differences between the groups (11). There were a number of additional analyses of the DeKalb data one of which compared the three groups from the date of their 16th birthday rather than the date of the assignment (12). This analysis reported a significant increase in crash rates for the SPC group compared to the control group, the crash risk differences between the PDL and the control group were not significant. A later analysis with two additional years of data reported that the controls had significantly fewer crashes than either of the training groups in year one, and that none of the differences between the controls and the trained groups were significant in years two through four (13).

As with the English study, the DeKalb study also found that the trained groups obtained their licenses sooner than the control group.

3.3.2. Cochrane review of school-based driver education

In 2001 a Cochrane review considered three RCTs “comparing school-based driver education to no driver education and assessing the effect on licensing and road traffic crash involvement” (14). In addition to the DeKalb county study, there was an Australian and a New Zealand study included in this review (15, 16).

The Strang et. al. study involved only 742 drivers who had been randomly assigned to one of three treatments, but the small sample size meant that even large effects on crash rates were unlikely to be detected. Similarly, the Wynne-Jones study also had a small sample size (561 trained and 227 controls) such that it would have been unlikely to detect a training effect. However, both males and females in the trained group in this study obtained their licenses earlier than the untrained students.

The Cochrane authors conclusions were:

“The results show that driver education in schools leads to early licensing. They provide no evidence that driver education reduces road crash involvement, and suggest that it may lead to a modest but potentially important increase in the proportion of teenagers involved in traffic crashes.”¹

3.3.3. The challenges for RCTs of driver education

It may seem surprising that there have been so few RCTs of driver education, however, these are difficult and expensive studies to conduct. As both the DeKalb county and the English study recognized, simple random selection was not feasible because of the volunteer effect. Another big challenge is the need for large sample sizes, only the DeKalb county study had sample sizes adequate to detect relatively small training effects. Peck in his review of driver education studies concluded that, based on California accident rates for 16-17-year old students, it would require 17,500 students in each group to detect a 10 percent effect with a 12-month follow-up (8). The DeKalb study, which is by far the biggest RCT involved a total of 16,000 students who were followed for 4 years. The cost of this study was over \$4 million in the late 1970s.

3.4. Skid pad training for teenagers

Test track training aimed at preventing skids is a feature of many advanced driving courses. Evaluations of such courses in the U.S., Norway, and Finland, however, “suggest that this type of advanced skill training actually has a detrimental effect, especially for young males – i.e. it is associated with an increase, rather than a decrease, in crash involvement” (17). It appears that the reasons for the increased crash rates is that the trained drivers become overconfident of their abilities as a result of the course.

4. CONCLUSIONS FROM DRIVER EDUCATION EVALUATIONS

4.1. The effects on crashes

There have been numerous evaluations (of varying quality) around the world of the effects of formal teenage driver education on subsequent crash risks, and the overwhelming conclusion that can be drawn from them is that there is no convincing evidence that these courses reduce the crash involvements of the trained drivers, see for example, RACV (18) and Peck (8).

Despite the strong evidence of the ineffectiveness of formal driver education, there are continuing efforts to reinvent/modify such programs because the “believers” are unwilling to accept the conclusions that a few classroom hours and limited on-road training do not reduce the crash involvements of beginning young drivers. Thus, for example, a recent evaluation of beginning driver education in Oregon was “cautiously optimistic” that there could be a small beneficial effect from the training (19). However, the authors acknowledge that “only a few factors” that may differ between the trained and untrained drivers “could be controlled in the analysis.”

4.2. Licensure acceleration

The finding from the 1975 English RCT that driver education accelerates licensure, was the first indication that such courses had negative effects on safety. The Cochrane review also highlighted the problem of teenage licensure acceleration resulting from formal driver education courses. Many other studies have documented this effect.

In the U.S. a 1978 study reported that “About 80 percent of the 16-17-year-olds who took high school driver education obtained licenses that they would not otherwise have obtained until 18 or thereafter” (20). At the time NHTSA and the driver education establishment reacted furiously to this conclusion claiming it was based on

¹ This 2001 review was edited in 2008 with no change to the conclusions and republished in Issue 4.

faulty statistics (while apparently ignoring the same finding from the English RCT which had been reported in the Robertson and Zador paper). A subsequent NHTSA analysis reached the same conclusion, but with a smaller effect than reported by Robertson et. al.

The findings that high school driver education was not reducing crashes together with high school budget squeezes led a number of US states to eliminate driver education classes. A 1980 study assessed the effect of eliminating these classes on driver licensure in several communities in Connecticut, it reported substantial reductions in the numbers of 16-17-year-olds who became licensed, and as a result, substantial reductions in the numbers of crashes involving 16-17-year-old drivers (21).

4.3. Overall effects

The post-1970s driver education evaluations provide no convincing evidence of crash risk reductions associated with the training, but strong evidence that the training accelerates the licensure of teen drivers, and as a result driver education has had a negative overall effect on safety.

5. CRASH RISKS FOR TEENAGE DRIVERS

If driver education does not work, what can be done to reduce the crash risks for young drivers? It is clear that delaying teen driver licensure will reduce crashes, and a safety case can be made that minimum license ages should be increased, especially in jurisdictions with 16-year-old or lower ages, but such changes have proven to be difficult to accomplish politically. So what other countermeasures could be considered for the young driver problem? To answer this question, it is helpful to understand some of the driving scenarios that pose high risks for young drivers.

5.1. Night-time crash risks for teenagers

Figure 2 shows fatal passenger vehicle crash rates per 100 million miles travelled by driver age separated into night-time and daytime events (2). It shows elevated fatal crash risks for night-time travel for all age groups, but the risks for drivers under 30 are very high. These night-time risks, in part, reflect the problems of alcohol-impaired driving. Teens are less likely than adults to drive after drinking alcohol, but their crash risk is substantially higher when they do and is thought to result from their relative inexperience with both drinking and driving, and combining the two.

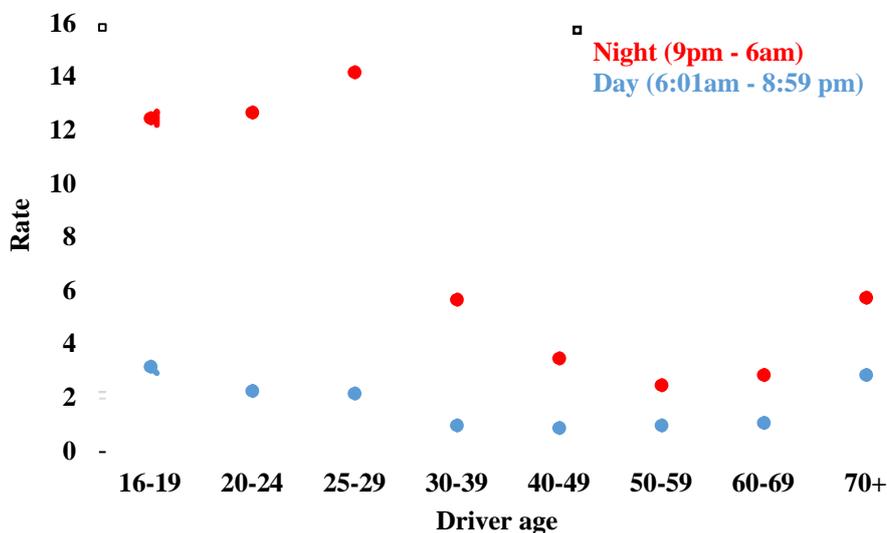


Figure 2. Passenger vehicle driver fatal crash rates per 100 million miles travelled by driver age and day vs night - U.S. 2008

5.2. Crash risks for teenagers transporting passengers

Another particularly high-risk scenario for beginning teenage drivers is when they transport other passengers, especially other teenagers. Figure 3 shows the risks of fatal crash involvement in the U.S. from 1990 to 1995 for drivers by themselves compared to when they have passengers. The risks shown are relative to the risks for 30 to 59-year-old drivers (22). For age groups under 30 the presence of passengers increases the fatal crash risks, and these increases are especially high for 16-year-olds, but also substantial for 17,18, and 19-year old drivers. In contrast for drivers over 30 passenger presence has essentially no effect on their fatal crash risks.

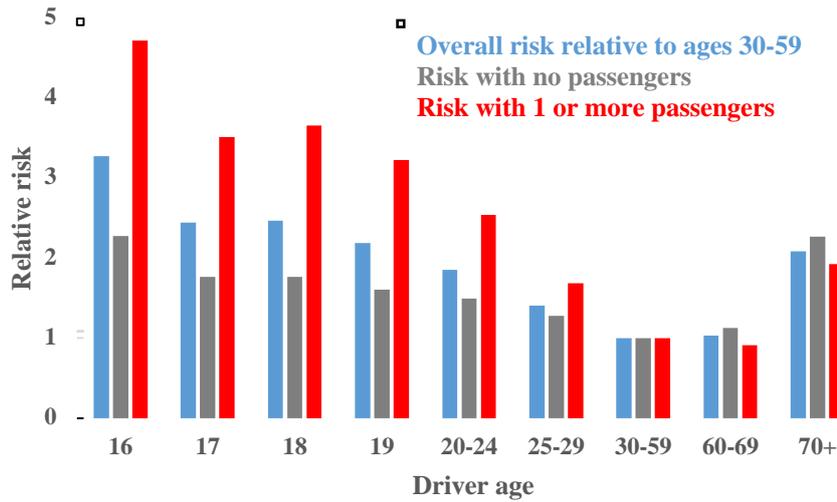


Figure 3. Relative risk of fatal crash involvement by driver age and passenger presence - U.S. 1990 to 1995

Figure 4 shows how the fatal crash risks for teen drivers increases dramatically with more passengers. It shows driver deaths per 10 million trips for 16-, 17-year-old, and 30-59-year-old drivers by the number of passengers. The teen drivers have dramatically increasing fatality risks as the numbers of passengers in their vehicles increases. In contrast, the 30-59-year-old driver fatal crash risks show no change as the number of passengers increases (23).

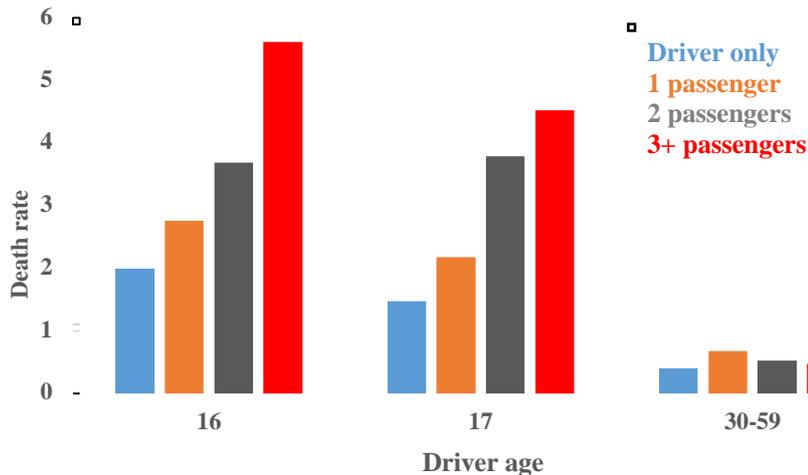


Figure 4. Driver deaths per 10 million trips by number of passengers and driver age - U.S. 1992 to 1997

6. DRIVER LICENSING TODAY

Minimum licensing ages around the world have varied from 14 to 18. There is no question that higher licensing ages would save many lives by reducing teenage driving exposure. As noted earlier, the crash rates of young drivers decline rapidly with each yearly increase of age. Furthermore, research looking at teen driver crash rates by months since licensure has shown that teen driver crash rates declined dramatically during the first six months of driving. These rates also varied by age, 16-year-old-drivers had the highest initial crash rates, and also the most rapid drop in the first six months (24). It is clear that both age and experience are independent factors contributing to the high crash rates of teen drivers.

Despite some public support for higher licensing ages, only a few jurisdictions have actually raised the minimum ages (25). Some jurisdictions have made the licensing process difficult or costly, effectively raising the minimum ages for licensure. In England, for example, with a minimum age of 17 (lower than most other European countries) has difficult written and driving tests (with many failures) and high costs for training and testing. As a result, in 1999-2001 only 41 percent of males 17-20-year-olds had full licenses, and 31 percent of females (26).

6.1. Graduated drivers licensing

An alternative licensing process (and probably fairer, because it doesn't involve any economic discrimination) is an approach referred to as Graduated Drivers Licensing (GDL). GDL delays unrestricted driving by starting the licensing process with a supervised learning period during which new drivers are allowed to drive, but only with a supervising adult for either a given period of time or minimum number of hours. Following this, drivers move to an intermediate license, which allows driving without adult supervision. During this phase there are some driving restrictions, including nighttime restrictions and limits on passengers. Typically, there are also low BAC thresholds for teen drivers during this period. At the end of the process drivers can then get an unrestricted license, and in most cases, this will be at a higher age than in the earlier licensing systems.

New Zealand was the first country to introduce such a system in 1987. Today many jurisdictions, including U.S. states, Canadian provinces, and Australian states have GDL. The lengths of learner and intermediate phases vary among jurisdictions, the most common practice requires the learner's license to be held for a minimum of six months, although there are longer learner periods of 12 months in some jurisdictions. The durations of the intermediate phase can vary from six months to two years.

Despite the evidence that driver education is ineffective, in some jurisdictions the learner permit period can be shortened by taking a driver education course.

6.2. The effectiveness of graduated licensing

GDL does not directly address the risks that are associated with immaturity, but it does address the issue of inexperience by allowing on-the-road driving, while avoiding some particularly high-risk scenarios. How well GDL reduces the high risks for teen drivers depends on the restrictions and the compliance of the teen drivers. Compliance with the GDL restrictions will not be perfect, and just as young drivers with higher risks of crashing typically are less likely to volunteer for driver education courses, some of the same driver characteristics – rebelliousness, over-confidence, less parental involvement, etc. – probably result in less compliance with the GDL restrictions.

The components of GDL programs vary significantly among jurisdictions with differing lengths for each phase, differing requirements for supervised driving, restrictions for night driving, and numbers of passengers, etc. In some cases, the restrictions are very weak, for example, nighttime driving restrictions starting at 1am.

An early evaluation of the New Zealand GDL reported that there were significant reductions in traffic-related injuries among young people since it was introduced (27). A later study focused on the three main driving restrictions, the night-time restrictions, no carrying of young passengers, and a low blood alcohol limit. The results indicated that the night-time restrictions in particular contributed to a reduction in serious crashes involving young drivers (28).

Evaluations of graduated licensing systems in U.S. states and Canadian provinces have shown they reduce crashes. A 2007 review of 21 GDL studies from 14 jurisdictions, and 6 nationwide studies concluded that “GDL programs have reduced the youngest drivers' crash risk by roughly 20 to 40%” (29). A later comprehensive review of GDL in the U.S. confirmed the substantial crash reductions associated with GDL at ages 16 and 17, especially 16. In addition, one possible concern had been that by keeping 16-17-year-olds from some high-risk situations there could be negative effects on crashes at ages 18 and 19 when the restrictions are lifted, this later review found such concerns to be unwarranted (30).

Although GDL has reduced the crash risks of teenage drivers, differences in these programs among jurisdictions influences their effectiveness. The Insurance Institute for Highway Safety has developed a rating system for the various U.S. programs based on their components, the ratings are based on: minimum ages; permit holding periods; required practice hours; nighttime and passenger restrictions; durations of the restrictions; etc. Laws were rated as good, fair, marginal, or poor. The study reported that “Compared with licensing laws rated poor, laws rated good were associated with 30 percent lower fatal crash rates among 15- 17-year-olds (31). So, there is considerable room to improve many of today's GDL systems.

7. CONCLUSIONS

Formal driver education was the countermeasure aimed at reducing the high crash risks of beginning teenage drivers for many decades when its effectiveness was not questioned. It was some 60+ years before competent research showed that not only did it fail to reduce the crashes of young drivers, but that it directly led to increases in crashes (including fatal ones) by increasing the driving exposure of the highest risk age groups.

This happened because in the early days of motoring, highway safety countermeasures were not subjected to any scientific evaluations, and when some effectiveness assessments were attempted, they were not competent. Despite the evidence of adverse effects, there still is a community of “true believers” who assert that driver education still has an important role to play in addressing the crash risks of beginning teenage drivers. Thus, for example, in 2000 the British government launched a road safety plan which included a significant role for driver education, despite the earlier British RCT study showing it to be harmful. Another example involves BMW which in 2003 introduced a free student driving program, which included instruction in skid control and emergency recovery that research has shown increases crashes (32).

In the U.S., NHTSA (a very important vehicle and highway safety agency that is largely science-based) has prepared a Driver Education Toolkit “with the assistance from national driver education community of experts and practitioners. Taken together, this impressive assembly of information and guidelines should give the States their best chance to produce safe young drivers.” This Toolkit also asserts that “Driver education and training should be an integral part of the GDL system.” There is no research support for these claims.

As noted in section 6.1, one unfortunate consequence of the continuing influence of driver education advocates is the fact that in some GDL programs the learner permit period can be shortened by taking a driver education course, a provision that has no scientific justification and can only reduce the effectiveness of GDL.

There are salutary lessons from this experience that go beyond driver education. Driver education was adopted in the U.S. decades before countermeasures were scientifically evaluated. By the time competent evaluations were undertaken there was a very large community of driver education teachers and their trade groups¹ with a vested interest in continuing this program, and it is clear that their influence is still strong.

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The Short-term Intervention Effect on Kindergarten Children using CRS

Liping Li^{1a}

1 INTRODUCTION

Child restraint systems (CRSs) have been effective in reducing deaths and injuries in children in motor vehicle crashes (1, 2). Numerous intervention efforts, including child passenger restraint laws, have been made in China to increase CRS use (3, 4). Although China does not have a national law, 1 province (Shandong) and 3 cities (Shanghai, Hangzhou, and Shenzhen) have enacted child passenger restraint laws since 2015. Currently, the rates of CRS use in areas with the laws range from 16% to 27%, but the rates are lower than 1% in Shantou where such a law is lacking (5). The main reason for low CRS use was lack of parental awareness of CRSs. Recent evidence shows that education combined with free child safety seats led to an increase in CRS use among parents of newborns (6).

We evaluated the effectiveness of parent-based CRS education with and without a hands-on CRS installation training program implemented in kindergarten classes. We hypothesized that CRS education would improve CRS use and that augmenting CRS education with hands-on CRS installation training would further improve the outcomes.

2 METHOD

2.1 Study design

We conducted a randomized trial with cluster sampling from May 2016 to January 2017. Six kindergarten classes were conveniently selected from the 2 medium- to small-sized cities located in eastern China: Shantou and Chaozhou. We then randomly assigned the selected kindergartens (3 from each city) into 1 of 3 study groups, with randomization occurring at the kindergarten level: CRS education only, CRS education plus hands-on CRS installation training, and control. All of the parents from the same kindergarten received the same study condition.

2.2 Participants

Eligible parents were those who (1) had a child aged 2 to 5 years, (2) were living in Shantou or Chaozhou for more than 6 months, (3) owned a car and had no CRS, and (4) had a valid driver's license. Parents who had already bought a CRS or were unable to read or write were excluded. A total of 328 parents in the 6 kindergarten classes were invited to participate in the study. Of these, 177 parents who met the inclusion criteria were enrolled in the study). Of these, 52 were in the CRS education only group, 60 were in the CRS education plus hands-on CRS installation training group, and 65 were in the control group. Three months after the intervention, 27 parents were lost to follow up. Of the 150 remaining parents who completed the follow-up, 45 were in the CRS education group, 51 were in the CRS education plus hands-on CRS installation training group, and 54 were in the control group.

2.3 Interventions

The CRS education only group received the following: (1) a pamphlet on child passenger safety and CRS legislation, (2) two 5-minute videos (1 displayed road traffic crash outcomes with and without the CRS, and another showed how to use a CRS correctly), and (3) a 30-minute lecture on child passenger safety.

The CRS education plus hands-on CRS installation training group received the CRS education described in the previous paragraph. In addition, parents received the following: (1) hands-on training on installation of a CRS conducted in a small group (3–4 parents per group) by 2 child passenger safety technicians trained in the study protocol and (2) a 3-month free trial of a CRS used in the parent's own car.

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The control group received a lecture about child electricity safety but no information on child passenger safety or CRS use.

2.4 Measures

We conducted a baseline survey before the intervention asking about child passenger safety awareness, CRS use, and demographics. We sent a WeChat link to the follow-up survey 3 months after the intervention to measure study outcomes on child passenger safety awareness and CRS use.

2.5 Data analysis

We used the Chi-square test to assess differences in child passenger safety awareness and CRS use before and after the intervention across the 3 groups, with an α level of 0.05. We analyzed the data with SPSS version 21.0 (IBM, Somers, NY).

3 RESULTS

Table 1 Demographics of parents and children in three groups

Items	EI		EB		CG		P
	N	%	N	%	N	%	
Parent gender							0.927
Male	11	24.4	13	25.5	15	27.8	
Female	34	75.6	38	74.5	39	72.2	
Parents age (years old)							0.100
≤35	27	60.0	39	76.5	42	77.8	
>35	18	40.0	12	23.5	12	22.2	
Education level							0.404
High school or lower	22	48.9	20	39.2	28	51.9	
College or higher	23	51.1	31	60.8	26	48.1	
Driving experience							0.303
≤5 years	22	37.0	26	51.0	20	37.0	
>5 years	34	63.0	25	49.0	34	63.0	
Family monthly income							0.075
≤5,000 yuan	10	22.2	16	31.4	7	13.0	
>5,000 yuan	35	77.8	25	68.6	47	87.0	
Number of children in family							0.279
1	22	43.1	22	43.1	18	33.3	
≥2	23	56.9	29	56.9	36	66.7	
Child age							0.390
≤4	28	62.2	38	74.5	35	64.8	
>4	17	37.8	13	25.5	19	35.2	
Children height							0.991
≤100cm	12	26.7	13	25.5	14	25.9	
>100cm	33	73.3	38	74.5	40	74.1	
Children weight							0.035
<20kg	39	86.7	47	92.2	40	74.1	
≥20kg	6	13.3	4	7.8	14	25.9	

Note: EI, education group; EB, education-behavior intervention group; CG, comparison group.

Table 2 Comparison of the usage of CRS between the different groups

Groups	using CRS (n/%)	not using CRS (n/%)	χ^2	P
Comparison group	10(18.5)	44(81.5)	-	-
Education group	12(26.7)	33(73.3)	0.943	0.332
Education-behavior group	21(41.2)	30(58.8)	6.471	0.011

Note: 1. Comparison group was a reference group; 2. $\alpha=0.05/2$, $\alpha=0.025$, P-value less or equal than 0.025 was considered statistically significant.

Table 3 Differences in children passenger safety knowledge and attitudes before and after the intervention

	EI		P	EB		P	CG		P
	Before	after		Before	after		Before	after	
Methods for children passenger safe traveling.	14	37	0.001	15	45	0.001	20	44	0.001
Holding children in arms is unsafe.	27	36	0.038	32	42	0.026	32	33	0.844
CRS can't be placed by safety belt.	32	36	0.326	36	45	0.027	36	36	1.000
Rear-facing CRS should be used when children younger than 1 year old.	13	19	0.186	16	28	0.016	18	19	0.839
CRS should change as children grow up.	7	20	0.002	12	24	0.012	15	17	0.673
Children are obliged to use CRS.	28	28	1.000	34	44	0.019	37	40	0.523
Necessary to enact CRS legislation.	31	35	0.340	37	40	0.489	39	38	0.831

Table 4 Changes in parents' knowledge and attitudes on child passenger safety after intervention across three groups

Items	Group	P	Wald χ^2	OR	95% CI
Methods for children passenger safe traveling.	EI	0.167	1.909	0.362	0.085-1.531
	EB	0.238	1.392	0.387	0.080-1.873
Holding children in arms is unsafe.	EI	0.021	5.310	6.310	1.317-9.234
	EB	0.292	1.109	2.166	0.514-9.132
CRS can't be placed by safety belt.	EI	0.685	0.165	1.316	0.350-4.951
	EB	0.022	5.279	8.853	1.378-9.884
Rear-facing CRS should be used for children younger than 1 year old.	EI	0.087	2.936	2.742	0.865-8.695
	EB	0.002	9.168	5.625	1.839-8.204
CRS should change as children grow up.	EI	0.304	1.055	1.726	0.609-4.886
	EB	0.785	0.075	1.146	0.431-3.046
Children are obliged to use CRS.	EI	0.011	6.387	0.246	0.083-0.730
	EB	0.896	0.017	1.078	0.347-3.352
Necessary to enact CRS legislation.	EI	0.743	0.108	1.203	0.399-3.622
	EB	0.824	0.049	0.889	0.316-2.504

The comparison group is the reference group; adjusted for children's age and parent driving experience as confounding factors.

4 DISCUSSION

This research documented that the CRS education plus hands-on CRS installation training increased the use of child restraints 3 months after the intervention; the CRS education only condition improved knowledge and attitudes but did not increase CRS use. CRS use is low in China and only 1% in Shantou; even in cities with legislation, such as Shanghai and Shenzhen, CRS use is 16% to 27%(5). By contrast, in Australia and the United States, the CRS use was 90% and 86%, respectively(7). When children are secured in a correctly installed, age-appropriate CRS, they are far less likely to be seriously injured in crashes(8). Given that China currently has more than 285 million vehicles and no national CRS use requirement, it is vital to implement effective interventions to increase CRS awareness and use to improve child passenger safety.

Our results demonstrated that education alone did not help increase CRS use are consistent with our previous findings that parents of newborns who received the education combined with free child safety seats were significantly more likely to use CRSs after an intervention compared with parents who received education only(6). These results suggest that education plus hands-on interventions might be essential in improving CRS use and should be implemented widely in China to prevent child passenger injuries.

Existing studies suggested that demographics are associated with CRS use. Specifically, child safety car seats are used less frequently in families with low income (9, 10) and low parental educational attainment(5, 11). In this intervention study, distribution of demographic characteristics were balanced in the 3 groups, so confounding factors were well adjusted, and the research results were more reliable.

This study had some limitations. The self-report method used to assess the intervention effect may have led to reporting bias. Child passenger safety awareness and CRS use were measured only in the short term (i.e., 3 months). Thus, future studies must assess the long-term effect of the intervention. Despite the limitations, this study showed that CRS education plus hands-on CRS installation training increased CRS use but that education alone did not. A combination of both methods helped improve CRS use and child passenger safety.

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Improvement of Traffic Safety at School Zones: Engineering and Operational Countermeasures

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1 INTRODUCTION

Traffic safety has been considered as a serious public health problem. This issue is more severe in school zones than others. Sometimes drivers fail to comply with the posted speed limit in school zone areas which create a serious safety problem for children as well as traffic. For these reasons, multiple safety treatments have been applied to school zones. One of the most significant treatments at school zones is the speed limit reduction during school-hours. The speed limit reduction has been implemented by using different traffic control devices e.g., signs, flashing beacons, speed monitoring display (SMD), etc. to protect school-aged children from traffic crashes. Nevertheless, sometimes a sudden speed reduction (e.g., 45 mph to 15 mph) might create a large variation of speed between vehicles and result in rear-end crashes.

In addition, previous studies showed that most of the drivers exceed the speed limits posted in the school zones (1, 2). Ellison et al. (3) found that over 20 percent of the distance driven in school zone areas is at speed higher than the posted speed limit (40 km/h) and 8 percent is driven at 10 km/h or more speed than the posted speed limit. Also, the study implied that the over-speeding rate in the school zones is higher than urban arterials and residential streets. In addition, Roper et al. (4) found that approximately half of all vehicles exceeded the speed limit in school zones and Kattan et al. (5) showed that around 10% of the vehicles exceeded the speed limit by 10 km/h or higher. A similar result was found by McCoy et al. (6) that the drivers' compliance with the posted speed limit in school zones is less than 20 percent. Moreover, Saibel et al. (7) found that around 45 percent of drivers exceeded the speed limit by at least 5 miles/hr, and Tay (8) showed that 54 percent of vehicles exceeded speed limit in school zones. According to Ellison et al. (3), a posted speed limit in school zones depends on the roadway characteristics on which the school is located, and the preceding segments of the roadway before the school zones start. This study showed that if the speed of the previous segment is higher than 70 km/h then it is difficult to reduce the speed with the posted speed limit (40 km/h).

In the last few decades, researchers have tried many approaches to reduce vehicles' speed in the school zones by installing different traffic control devices. i.e., SMD, dynamic speed display signs (DSDSs), flashing beacons, etc. Lee et al. (9) found that SMDs can reduce speed by 17.5% (8.2 km/h) and 12.4% (5.8 km/h) at the SMD location for short-term and long-term (twelve months) studies, respectively in school zones. Also, another study of utilizing SMDs conducted in Utah found that safety and efficiency vary by locations and SMDs can reduce speed and increase drivers speed compliance without any negative impact on the safety of a location (10). Furthermore, a study was conducted to measure the effectiveness of DSDSs in the school zones and showed that speeds were reduced by 9 mph at the school zone where DSDSs are present (11). Some previous studies examined the impact of flashing beacon to improve drivers compliance rate with the posted speed limit as well as safety in school zones (12, 13).

According to Hawkins et al. (14) rear-facing school speed limit beacons can substantially reduce speed in school zone areas. Similarly, Rose et al. (15) found that the rear-facing flashing beacon installed at the end of the school zone was a potentially effective mean of improving speed limit compliance. Moreover, Saibel et al. (7) found that school zone signs with flashing beacons were more effective in slowing traffic than those without flashing beacons. Hence, some of those studies (16, 17) have shown a positive effect of the traffic control devices on reducing speed while others (13, 18) showed that they have no effect on reducing speed compared to the posted speed limit in school zones. The NHTSA conducted a study and determined how automated speed enforcement (ASE) impacted speed reduction efforts in school zones in Portland, Oregon (19). The result of this study showed that the average speed dropped when ASE's was present, and this drop was more with the combination of ASE and flashing beacon. Zhao et al. (20) conducted a study in China to examine the effectiveness of traffic control devices on driver behavior by using driving simulation and found that flashing beacons with school crossing warning ahead, reduced speed and school crossing pavement markings were

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suggested for the school zone which is located adjacent to a major multilane roadway characterized by high traffic volume with median strip. In addition, Tay (8) found that mean speed and non-compliance rates were lower in school zones with chain-link fencing than without fencing.

Although these existing studies and established guidelines provide useful information regarding different traffic control devices in the school zones, very few studies investigated the effect of different roadway countermeasures in the school zones. So, the objective of this study is to find out the effectiveness of different roadway characteristics i.e., two-step speed reduction, decreasing the number of driveways, etc. in the school zone area and measure the traffic safety by using microsimulation software. Furthermore, in most of the previous studies (13, 18), traffic control devices were installed in the school zones and the authors measured the effectiveness of them. Sometimes, there was no significant improvement of safety in the school zone by implementing this changes. Hence, to address this problem, we analyzed the impact of different roadway characteristics in microsimulation environment which can give a quick and efficient indication of the safety effectiveness to transportation planners or engineers prior to implementing them.

2 METHOD

2.1 Selection of the study area

In order to select the study area, we used school location data, AADT, total crash for the year of 2012 to 2016 from the Signal Four Analytics, managed by the University of Florida GeoPlan Center. Only public schools in Orange and Seminole Counties in Florida were selected in this study.

Table 1: Top ten school based on crash per thousand DVMT

Name	Type	Total Crash	DVMT	Crash rate	Overlap
Westridge Middle	Middle				
Sadler Elementary	Elementary	248	9204.78	26.9	Yes
Innovations Middle School	Middle/Jr. High	411	19145.62	21.5	No
Aloma Elementary	Elementary	333	19451.76	17.1	No
Pine Hills Elementary	Elementary	50	2930.91	17.06	No
Oak Hill Elementary	Elementary	416	26405.63	15.8	Yes
Sunshine High Charter	Senior High				
Union Park Elementary	Elementary	415	27417.99	15.1	Yes
Union Park Middle	Middle				
Howard Middle	Middle	199	13314.79	14.9	No

Table 2: Crash description in the chosen school buffer

Crash Type	Crash Count	Percentage
Rear End	120	48.39
Left Leaving	55	22.18
Same direction Sideswipe	16	6.45
Pedestrian	10	4.03
Off Road	9	3.62
Parked Vehicle	8	3.23
Right Angle	5	2.02
Bicycle	5	2.02
Backed Into	5	2.02
Single vehicle	4	1.61
Right/Through	3	1.21
Opposing Sideswipe	2	0.81
Other	6	2.42
Total	248	100.00

We created a buffer around each school to define the school zone. Sometimes, two or more school zones overlap with each other, so we merged the overlapped school zones and counted them as one zone. A crash rate was used as a performance measure to determine the most dangerous school for traffic safety, which is defined as total crash per thousand daily vehicle miles traveled (DVMT). Hence, to calculate the crash rate, the number of

crashes were counted and DVMT was calculated based on AADT and segment length inside the buffer area of a school. Finally, we identified the top ten school zones based on crash rate, which is presented in Table 1. From the table it could be observed that Westridge Middle and Sadler Elementary School has higher crash rate than others. Table 2 describes the number of crashes and the percentage in the selected school buffer. Almost half of crashes were rear-end (~48%), and left-turn and same direction sideswipe crashes were about 22% and 6%, respectively. Non-motorized user (i.e., pedestrian and bicyclist) involved crashes were about 6%, and none of school-age children pedestrians or bicyclists were involved. Thus, we only focused on vehicle-to-vehicle crashes in this study.

2.2 Data collection

As mentioned above, the most crash-prone school zone, i.e., Westridge Middle and Sadler Elementary School was chosen as the study area. Thus, for developing microsimulation network around the combined school zone, the number of vehicles by type were counted by the researcher team during school hours (on Thursday from 7:00 to 9:00 am) from several locations on the major roadway (West Oak Ridge Road) near the school zone. In this study, three types of vehicle compositions were used i.e., PC (passenger cars), HGV (heavy goods vehicle), SB (school bus) and their percentages were 95%, 3%, and 2% respectively. Also, Travel time data was collected from HERE, NPMRDS (National Performance Measure Research Data Set) on the major roadway of the school zone area. The location of the volume and travel time data collection points, location of selected schools, and roadways for microsimulation network are shown in Figure 1.

2.3 Simulation modeling and calibration

According to the U.S. DOT microsimulation guideline for arterials (22), the model network should include areas that might be impacted by the proposed improvement strategies and extend at least one intersection beyond those within the boundaries of the improvement. Thus, a network was built in VISSIM, which was about 3.21 miles long on West Oak Ridge Road connected with other roadways named South John Young Parkway (1.7 miles long), Millenia Boulevard (0.3 miles). Moreover, around 19 driveway access points and 7 intersections near the school areas were included. Traffic data including traffic volume and travel time were aggregated into 5 minutes intervals. The simulation time was from 7:00 to 9:00 am, where first and last 30 minutes were selected for warm-up and cool-down periods. One of the major roadway geometry features in the school zone was two-way left turn lane (TWLTL) for accessing multiple driveways. The TWLTL was replicated in VISSIM as similar as the real field.

Geoffrey E. Heavers (GEH) statistic is a modified Chi-square statistic that incorporates both relative and absolute differences which was used to compare between field and simulated traffic volumes (23, 24). The definition of GEH is as follows:

$$GEH = \sqrt{\frac{2 \times (V_{obs} - V_{sim})^2}{(V_{obs} + V_{sim})}} \quad (1)$$

where V_{obs} is the hourly observed volume of field detectors and V_{sim} is the hourly simulated volume obtained from the simulation network. The simulated volume replicates the field volume perfectly if the GEH value is less than 5 for 85% of the cases (25–27). Also, to measure the goodness of fit, Correlation Coefficient (CC) was calculated which indicates the degree of linear association between field and simulated volume. The definition of CC is given below:

$$CC = \frac{1}{n-1} \sum_{i=1}^n \frac{(y_{i,sim} - \hat{y}_{sim})(y_{i,obs} - \hat{y}_{obs})}{S_{sim} S_{obs}} \quad (2)$$

where n is the total number of observations in traffic measurement, \hat{y}_{sim} and \hat{y}_{obs} are means value of the simulation and observed measurements aggregated into 5 min interval, respectively. S_{sim} and S_{obs} are the standard deviations of the simulated and observed measurements, respectively. Correlation Coefficient value of 1 shows a perfect and direct correlation while -1 shows a perfect and inverse relationship (28–30). CC value of 0.85 is considered acceptable for the model calibration (30). Another measure that gives information on the relative error is Theil's inequality coefficient, given by:

$$U = \frac{\sqrt{\frac{1}{n} \sum_{i=1}^n (y_{i,obs} - y_{i,sim})^2}}{\sqrt{\frac{1}{n} \sum_{i=1}^n (y_{i,obs})^2 + \frac{1}{n} \sum_{i=1}^n (y_{i,sim})^2}} \quad (3)$$

where n is the number of observations, $y_{i,obs}$ and $y_{i,sim}$ are the overserved and simulated value at time i , respectively. U is the Theil's inequality coefficient which is bounded between zero and one. $U=0$ indicates perfect fit between observed and simulated measurements (29). To compare with the field condition, traffic volume was aggregated into 5-minute interval and ten simulations were run with different random seeds to capture the randomness effect. Finally, the average of the ten simulations was used for the analysis. The results showed that for more than 89% of the cases the GEH value were less than 5 and around 99% of the cases the GEH value were less than 10. Correlation coefficient value is 0.96 which means almost perfect and direct correlation. Also, Theil's inequality coefficient was found 0.08 which means the error is very small and there is

a perfect fit between simulated and observed volumes.

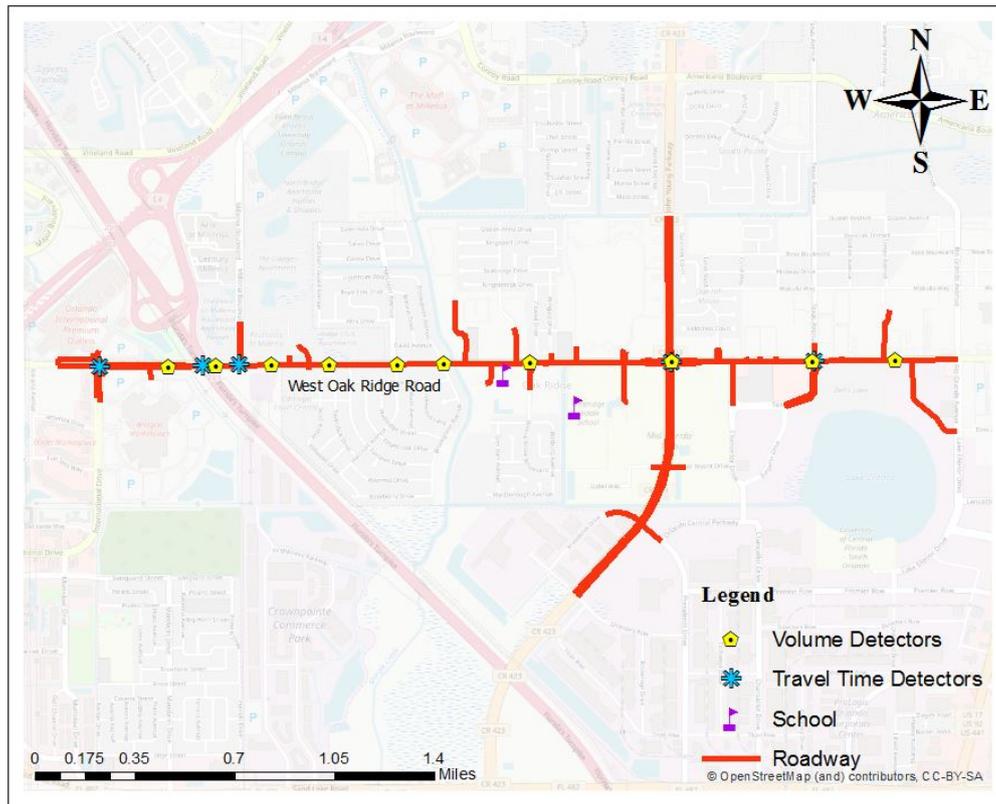


Figure 1: The study area showing school zone and detectors' location

For validating the network, the difference between field and simulated travel times should be within ± 1 minute for routes with observed travel times less than seven minutes and within $\pm 15\%$ for routes with observed travel times greater than seven minutes for all routes identified in the data (30). Though in this study, the travel time was less than seven minutes for all cases, both criteria were used for travel time validation. Hence, the result showed that 100% cases simulated travel time and the field travel time difference were less than 1 minute and 87.5% cases the difference between observed and simulated travel times was less than 15%. So, after calibration with volume and validating with travel time, there was no significant difference between the field and simulation network in terms of volume and travel time.

2.4 Proposed countermeasures

2.4.1 Two-step speed reduction (TSR)

Ellison et al. (3) showed that if the speed of the previous segment is higher than 70 km/h then it is difficult to reduce the speed with the posted speed limit (40 km/h). Thus, in this study, an intermediate zone was provided for the smooth reduction of speed instead of sudden change from higher speed limit of upstream section to lower speed limit of the school zone area and captured how this change improves safety in the school zone.

In the first part of Figure 2 it could be seen that the speed limit of the upstream section ahead of the school zone is 40 mph, which is reduced to 15 mph in the school zone area during school hours. This variation might result in a higher standard deviation of speed and increase the probability of rear-end crash occurrence. In order to address this problem, an advance speed reduction zone (second part of Figure 2) was created between the high and low speed limit section so that drivers can reduce the speed slowly instead of sudden change from upstream section to the school zone. Depending on the maximum speed limit (40 mph) on the main roadway, three different procedures (sub-scenario) of TSR was tested in microsimulation, which are:

- i. 40-25-15 (max. speed limit 40 mph, advance reduction 25 mph and school zone speed limit 15 mph)
- ii. 40-20-15 (max. speed limit 40 mph, advance reduction 20 mph and school zone speed limit 15 mph)
- iii. 40-30-15 (max. speed limit 40 mph, advance reduction 30 mph and school zone speed limit 15 mph)

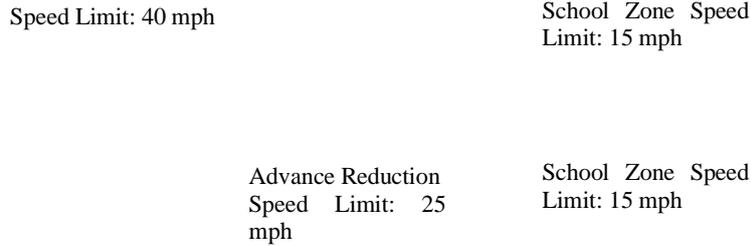


Figure 2: Two-step speed reduction procedure

2.4.2 Decreasing the number of driveways (DD)

Because the majority of the land-use at the study area is residential, there are a number of driveway accesses that are directly connected to the main road. Such large number of driveways might increase the crash frequency near the school zone area (31). Therefore, we suggested to reduce the number of driveway access by 25, 50, 75, and 100 percent by connecting them with the main road through a collector road and tested how this change affects the safety in the school zone. Four different sub-scenarios were introduced under this measure which is given by:

- i. DD 25% (driveway reduction by 25%)
- ii. DD 50% (driveway reduction by 50%)
- iii. DD 75% (driveway reduction by 75%)
- iv. DD 100% (driveway reduction by 100%)
- v.

2.4.3 Replace two-way left-turn lane (TWLTL) with raised median (RM)

There were too many TWLTL in the study area for access between the driveway and the main road which might create confusion to the drivers during turning movements and result in severe crashes. Hence, TWLTL was replaced by the RM and measured how this change improves safety in the school zone. Median and intersection U-turns were created so that the vehicle could move to their desired destination. Therefore, we tested two different sub-scenarios in this case i.e., 1. Intersection U-turn 2. Median U-turn.

2.5 Surrogate measures of safety

The surrogate measures of safety are widely used as indicators to evaluate the crash risk in the microsimulation software. In previous studies (32, 33) lots of surrogate safety measures i.e., time-to-collision, post-encroachment time, and rear-end crash risk index, etc. were used. In this study, three surrogate measures of safety were considered where two advanced surrogate safety measures are developed from Time to Collision (TTC) notations and denoted as time exposed time-to collision (TET) and time integrated time-to-collision (TIT) to evaluate the traffic safety in school zone area. The TTC concept was first introduced by Hayward (34) which is defined as the time that remains until a collision between two vehicles (following and leading) would occur if the collision course and speed difference are maintained. If the following and leading vehicle are denoted as n , $(n-1)$ respectively then TTC notion is expressed by:

$$TTC_n(t) = \begin{cases} \frac{y_{n-1}(t) - y_n(t) - L_{n-1}}{v_n(t) - v_{n-1}(t)}, & \text{if } v_n(t) > v_{n-1}(t) \\ \infty, & \text{if } v_n(t) \leq v_{n-1}(t) \end{cases} \quad (4)$$

where $TTC_n(t)$ = the TTC value of vehicle n at time t , y = the positions of vehicles, v = velocities of the vehicles, L_{n-1} = Length of leading vehicles.

Previously, many studies (25, 32) used two types of TTC for analyzing traffic safety where TTC_1 denoted that the leading vehicle always maintains its current speed without any change while TTC_2 explained the situation where leading vehicle stop suddenly. The later one is called TTC at brake (TTC_{brake}) which is defined as follows:

$$TTC_{brake}(t) = \frac{y_{n-1}(t) - y_n(t) - L_{n-1}}{v_n(t)} \quad (5)$$

Minderhoud et al. (35) developed TET and TIT based on TTC_{brake} and TTC^* which is expressed as:

$$TET(t) = \sum_{n=1}^N \delta_t \times \Delta t, \quad \delta_t = \begin{cases} 1, & 0 < TTC_{brake}(t) \leq TTC^* \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

$$TET = \sum_{t=1}^{Time} TET(t) \quad (7)$$

$$TIT(t) = \sum_{n=1}^N \left[\frac{1}{TTC_{brake}(t)} - \frac{1}{TTC^*} \right] \cdot \Delta t, 0 < TTC_{brake}(t) \leq TTC^* \quad (8)$$

$$TIT = \sum_{t=1}^{Time} TIT(t) \quad (9)$$

where t = time ID, n = vehicle ID, N = total number of vehicles, δ_t = switching variable, Δt = time step, which was 0.1 s in simulation, Time = simulation period, and TTC^* = the threshold of TTC. In general, the values of TTC^* threshold varies from 1 to 3 s which is used to differentiate between safe and unsafe car following condition (25, 36, 37).

Another surrogate safety measure, time exposed rear-end crash risk index (TERCRI) proposed by Rahman et al. (25) based on rear-end crash risk index (38) was used in this study which is defined as:

$$SD_L = v_L \times h + \frac{v_L^2}{2 \times a_L} + l_L \quad (10)$$

$$SD_F = v_F \times PRT + \frac{v_F^2}{2 \times a_F} \quad (11)$$

$$TERCRI(t) = \sum_{n=1}^N RCRI_n(t) \times \Delta t, \quad RCRI_n(t) = \begin{cases} 1, & SD_F > SD_L \\ 0, & \text{Otherwise} \end{cases} \quad (12)$$

$$TERCRI = \sum_{t=1}^{Time} TERCRI(t) \quad (13)$$

where SD_L and SD_F are the stopping distance of the leading and the following vehicles, respectively. PRT = perception-reaction time, h = time headway, l_L = length of the leading vehicle, v_L = speed of the leading vehicle, v_F = speed of the following vehicle, a_L = deceleration rate of the leading vehicle and a_F = deceleration rate of the following vehicle. In this study, the deceleration rate of PC was selected as 3.42 m/s^2 where for both HG and SB, the rates were selected as 2.42 m/s^2 . The value of PRT was used as 1.5 s which is used by the Green Book, A Policy on Geometric Design of Highways and Streets (39). In this paper, we analyzed these three surrogate safety measures for all scenarios and compared them.

3 RESULTS

As mentioned earlier, we introduced three different countermeasures i.e., two-step speed reduction, decreasing the number of driveways, replacing TWLTL to RM and analyzed TET, TIT, and TERCRI for each measure which is further compared with the field condition (base scenario). Each sub-scenario was simulated repeatedly 30 times in order to consider the randomness effect of simulation. At first, the TTC threshold was considered 1.5 seconds and further sensitivity analysis was conducted for different values of TTC thresholds from 1 to 3 seconds. The descriptive statistics of three surrogate safety measures (TET, TIT, and TERCRI) for all sub-scenarios are presented in Tables 2 and 3. Also, the average value of all sub-scenarios is shown in Figure 3.

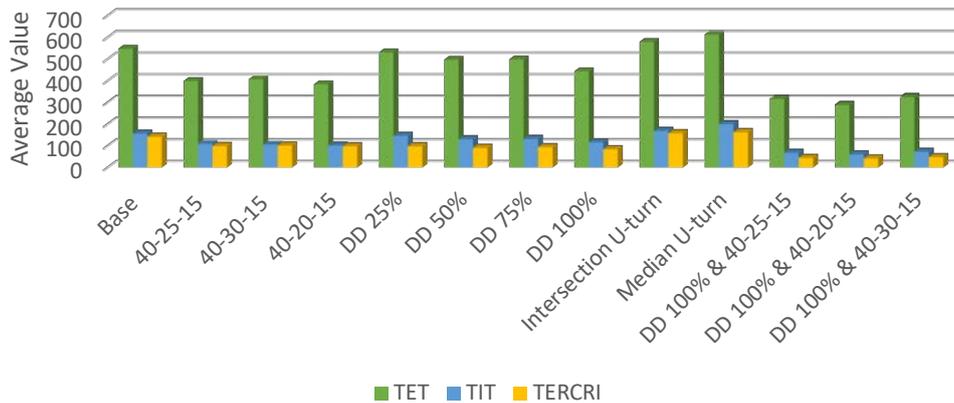


Figure 3: Average value of TET, TIT and TERCRI for all sub-scenarios

The higher values of TET, TIT and TERCRI imply more dangerous situations. Thus, the result showed that the crash risk is higher for the base scenario compared to all other sub-scenarios, except converting TWLTL to RM. For TSR, both 40-25-15 and 40-20-15 sub-scenarios showed the best result among the three of them while for DD, the value of surrogate safety measures decreases with the increase of the reduction percentage of the number of driveways (Figure 3). On the other hand, for TWLTL to RM, all the three measures for both sub-scenarios were higher than the base scenario which means higher probability of crash risk than the field condition. Also, the standard deviation of TET, TIT, and TERCRI was high for base scenario compared to all other sub-scenarios of TSR and DD, which is presented in Tables 2 and 3, respectively.

Moreover, we combined the best sub-scenarios (combinations of DD 100% with 40-25-15, 40-20-15, 40-30-15, separately) based on the above results for analyzing surrogate safety measures found that all three combined sub-scenarios outperformed all other sub-scenarios. The minimum, maximum, mean and standard deviation of TET, TIT, TERCRI values for three combined sub-scenarios were very low than the base scenario which is shown in Tables 3 and 4.

Table 3: Summary statistics of TET and TIT

TET					
Scenarios	Sub-Scenario	Mean(s)	Stdev (s)	Min (s)	Max (s)
Base	Base	548	43	444	620
Two-step speed Reduction	40-25-15	399	31	332	448
	40-30-15	407	31	337	457
	40-20-15	384	30	321	437
Decreasing the number of Driveways	DD 25%	531	45	432	612
	DD 50%	498	39	416	569
	DD 75%	499	37	428	557
	DD 100%	444	31	383	497
TWLTL to RM	Intersection U-turn	580	41	486	662
	Median U-turn	614	42	520	685
DD and TSR	DD 100% & 40-25-15	319	27	263	380
	DD 100% & 40-20-15	291	25	239	352
	DD 100% & 40-30-15	327	26	276	383
TIT					
Base	Base	158	40	113	345
Two-step speed Reduction	40-25-15	112	27	86	218
	40-30-15	108	10	91	130
	40-20-15	103	25	83	204
Decreasing the number of Driveways	DD 25%	148	16	117	200
	DD 50%	132	12	111	157
	DD 75%	134	10	117	153
	DD 100%	118	10	100	144
TWLTL to RM	Intersection U-turn	171	15	138	206
	Median U-turn	202	104	156	735
DD and TSR	DD 100% & 40-25-15	70	7	54	86
	DD 100% & 40-20-15	62	8	52	85
	DD 100% & 40-30-15	74	7	61	91

The one-way ANOVA analysis was also conducted among all thirteen sub-scenarios. The F-values for TET, TIT and TERCRI were 265.89, 44.47 and 870.54, respectively, which are considerably higher than the critical values at 95% confidence level. Therefore, we can conclude that there are significant differences among the thirteen sub-scenarios including the base. Moreover, we tested ANOVA, separately for TSR, DD, TWLTL to RM and combination of DD and TSR. The results indicated that the sub-scenarios are also significantly different from each other.

4 DISCUSSION

The main objective of this paper is to propose different countermeasures for school zones and evaluate them by using microsimulation. At first, the most crash-prone school zone was identified based on crash rates, which was further analyzed by VISSIM. The simulation experiments were designed by deploying sub-scenarios of three countermeasures i.e., two-step speed reduction, decreasing the number of driveways and replacing TWLTL to RM and three surrogate safety measures i.e. TET, TIT, and TERCRI were analyzed for all sub-scenarios separately and also their combined effects.

The results indicated that the implementation of TSR and DD significantly improve safety in the school zones. The value of TET, TIT, and TERCRI is larger for base scenario compared to all other sub-scenarios except converting TWLTL to RM. In TWLTL to RM, two sub-scenarios were tested which showed a larger value of surrogate safety measures than the base scenario because of the large number of traffic that made a U-turn both at the intersection and median. Moreover, the combined scenarios of TSR and DD outperformed all other scenarios. One-way ANOVA analysis showed that there was a significant difference among all thirteen sub-scenarios. Furthermore, the sensitivity analysis indicated that different value of TTC thresholds does not affect the results.

Table 4: Summary statistics of TERCRI

Scenarios	Sub-Scenario	Mean (s)	Stdev (s)	Minimum (s)	Maximum (s)
Base	Base	144	10	123	161
Two-step speed Reduction	40-25-15	101	6	91	113
	40-30-15	103	6	91	115
	40-20-15	100	6	89	111
Decreasing the number of Driveways	DD 25%	88	6	77	103
	DD 50%	93	7	79	108
	DD 75%	99	7	86	113
	DD 100%	86	7	75	100
TWLTL to RM	Intersection U-turn	160	9	143	176
	Median U-turn	165	9	147	183
DD and TSR	DD 100% & 40-25-15	46	4	39	58
	DD 100% & 40-20-15	44	4	38	56
	DD 100% & 40-30-15	50	4	43	65

Although this study proposed multiple countermeasures to improve traffic safety at school zones and confirmed their effectiveness there are remaining important issues, which are required to be investigated in follow-up studies. For DD scenarios, vehicles couldn't directly access to the main road as they need to use collector road first to access the main road and for TWLTL to RM scenarios, vehicles need to use intersection or median U-turn instead of using the center lane (TWLTL) for left turning movements. So, this might create some delay, which is not addressed in this paper. Thus, it is worth to study how to capture the delay. In addition, more innovative countermeasure that could improve traffic safety at school zones are proposed and evaluated. Also, additional research is needed to evaluate pedestrian and bicycle safety in school zones.

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MOBILE APPLICATION FOR MAPPING HAZARDOUS LOCATIONS IN THAILAND: CASE OF ATRANS SAFETY MAP

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1 INTRODUCTION

Road crash is a serious problem causing many deaths annually in the world. According to (1), Thailand was ranked as the second highest fatality rate worldwide. It was estimated that Thailand has the road crash fatality rate of 36.2 persons per 100,000 populations. Various road safety research and studies were conducted to tackle road crash problems, see for example (2-6). The development of road safety map is one of the effective tools for safety professionals to understand underlying issues and to propose active measures and actions in order to correct the unsafe problems efficiently, see for example (7-9).

In Thailand, various concerned authorities have developed a variety of road crash databases, e.g., (10-13). However, the developed databases have been used for different purposes in national and provincial levels (lack of an integration and difficulty to use by local users). In addition, most of the safety maps cannot present exact locations where people are being killed and seriously or slightly injured.

ATRANS (14) has launched a 4-year consecutive research project which focuses mainly on development and implementation of the interactive road safety map application, called “ATRANS Safety Map”. Goals of the application are:

- to allow concerned authorities to utilize crash and risk location data for enhancing road safety, e.g., identification of hazardous locations (passive approach), implementation of road safety audit (active approach);
- to allow anyone to easily access and perceive the incident and crash information for traveling daily or during national holidays, e.g. New year, Songkran (Thai new year) festival.

This paper presents the development of the ATRANS Safety Map which is the mobile application for mapping hazardous locations in Thailand. The results of data analysis and safety improvement of the hazardous locations identified by the application are also explained in the paper.

2 APPLICATION DEVELOPMENT AND IMPLEMENTATION

The design concept of the application (Figure 1) consists of four main features. The first feature allows local authorized users (police and rescue team) to input crash data and any persons to report risk data. The data include, for example, location, photo/video, type of road users and vehicles, and road related data. In the second feature, the data are then verified and stored in the server. The database administrator can verify the data and maintain the database. The third feature allows any user to retrieve the results of data analysis. The results include the details of black spot locations (high number of crash locations), hotspot locations (high number of risk locations), and hazardous locations (identified using the estimated cost of crash and risk locations). The last feature allows local officers in municipalities, road authorities, police officers, and related authorities to report safety improvements or countermeasures of black spot, hotspot, or hazardous locations identified to the application in order to inform road users.

The application was developed based on cross-platform mobile development, see details in (15). Thus, the application can be used on various platforms, including iOS, Android, and web browsers (Google Chrome, Firefox, and Microsoft Edge). The application (Figure 2) consists of four main functions, including crash location, risk location, report, and navigation. The first function allows the authorized users (police and rescue team) to identify location of crashes occurred in their area. The second function allows road users, including pedestrians, bike cyclists, motorcyclists, and car users, to identify risk locations those may affect them. For the third function, users can view the results of crash locations, risk locations, and hazardous locations analyzed

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from the application. For the last function, road users can use the navigation tool to check the risk and hazardous locations and prepare themselves through their desired traveling route.

Note that the risk locations were identified based on the black spot treatment guideline (16) and road safety audit manual (17). In addition, the data of risk locations reported to the system is only a part of hazardous location ranking subsystem developed in the application. The subsystem automatically identifies and ranks the hazardous locations mainly based on the accident costing technique (18) using the number of casualties (fatalities, serious injuries, slight injuries, no injuries, and damaged vehicles) from the crash location data. However, the hazardous locations and risk locations reported in the application are preliminary information for local safety professionals to understand underlying issues and to propose countermeasures in order to correct the unsafe locations efficiently.

The initial developed application was demonstrated to key persons and concerned agencies. Feedback was collected to assess level of satisfaction of the application and to obtain the recommendation for improving the application. After revision, the application was finally distributed to potential users (police, rescue team, road safety working groups) and students and staff in several schools and universities through the workshops in various provinces, see Figure 3 for example.

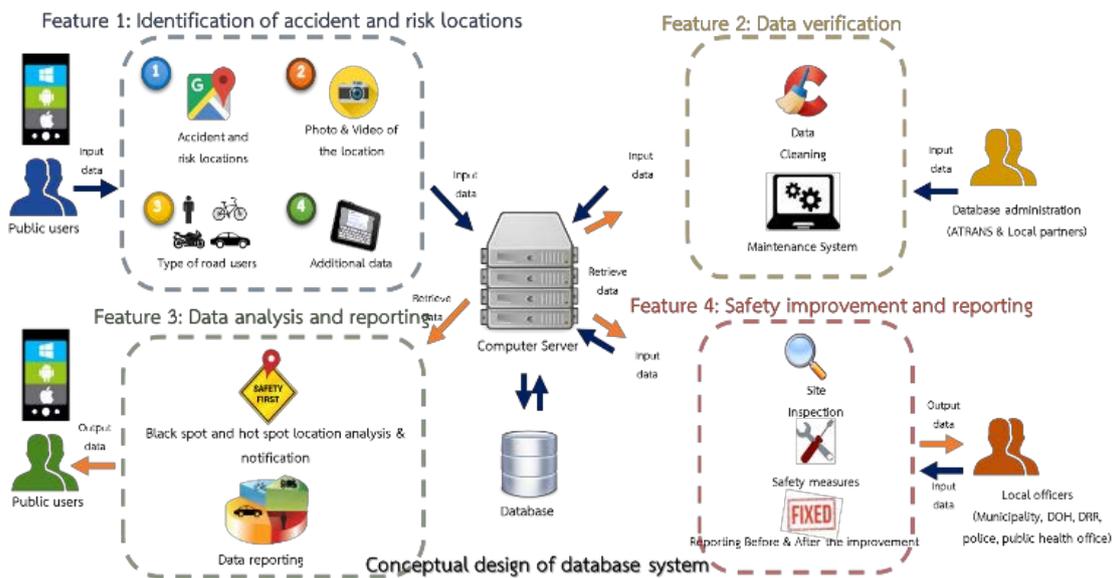


Figure 1. Design concept of the application



Figure 2. Four main functions in the application



3 RESULTS AND DISCUSSION

3.1 Results of crash locations

From the data collected between April 1st, 2017, and October 31st, 2018, there were a total of 928 crashes reported, which included 2,343 casualties and 1,622 vehicles involved. Figure 4 shows that among the casualties 46% were slightly injured, followed by no injured (26%), seriously injured (19%) and dead (11%). Regarding vehicles involved, top two vehicle types were a motorcycle (60%) and passenger car (25.9%), respectively. This shows that more than over half of the casualties are vulnerable road user (motorcyclists). Figure 5 shows the percentage of crashes classified by day and time. It was found that a number of crashes occurred on each day were almost similar. However, the crashes were more frequently occurred on Monday and Friday (16% each). Regarding time of day, the crashes often occurred during 15:01-18:00.

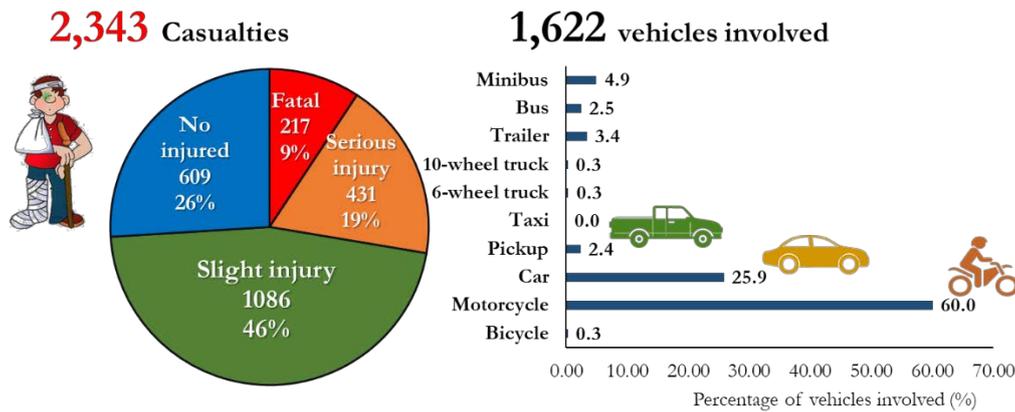


Figure 4. Percentage of casualties and vehicles involved the crashes

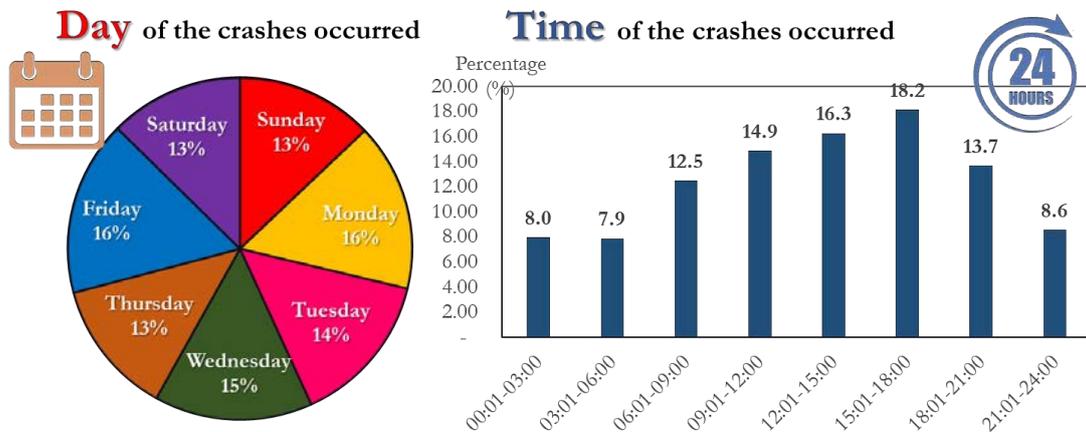


Figure 5. Percentage of crashes classified by day and time

Figure 6 shows details of crash locations. 56% were along the road sections (midblock). 39% were at the intersections. Only 5% were at the U-turns. Regarding the road sections, the majority (67%) was on the straight

sections. For the intersections, the top two locations were found at T intersections (48%) and 4-leg intersections (29%). Note that the crashes occurred at the 3-leg junctions (T and Y junctions) were accounted for 64%. For the U-turns, 60% occurred at the midblock opening and 40% occurred at the intersection.

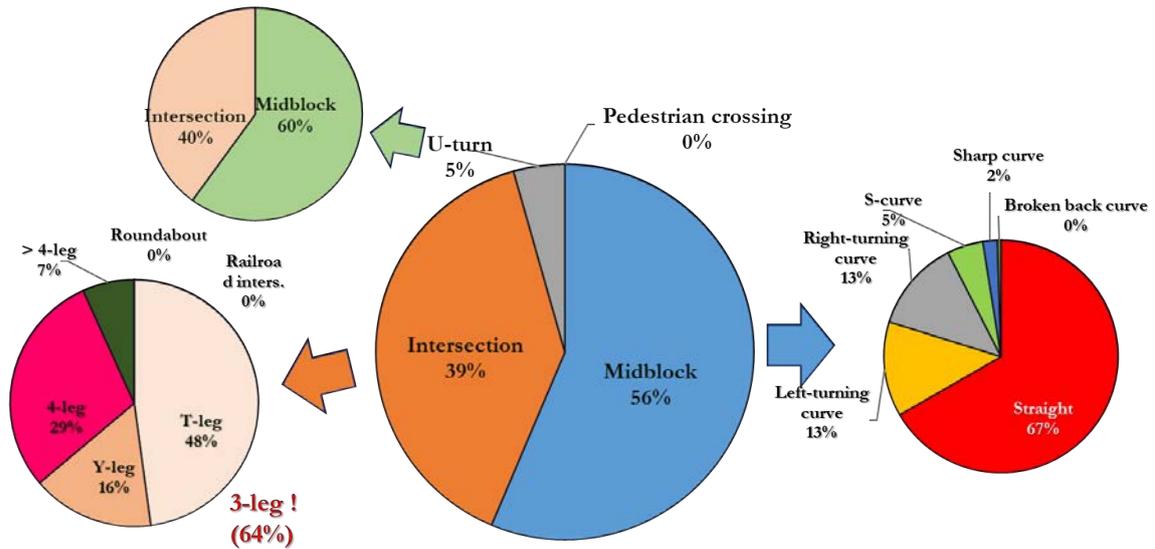


Figure 6. Crash locations classified by type of road section

3.2 Results of risk locations

From the database, there were a total of 959 risk locations reported. Figure 7 shows that more than three-quarter of the road users affected by the risk locations are vulnerable road users (i.e. motorcyclists 38%, pedestrians 26%, and bicyclists 13%) while 23% are car users.

Regarding the top five risk factors reported, Figure 8 shows that for pedestrians the obstacle on the walkway is a main risk factor (15.4%), followed by broken surface (13.0%), no crosswalk (9.9%), no crosswalk sign (8.6%), and walking behavior (8.0%), respectively. For the bicyclists, unsmooth drain cover is a top risk factor (15.2%), followed by unsmooth surface (10.6%), no bicycle warning sign (9.1%), no traffic light (7.6%), and guardrail (7.6%), respectively. Regarding the motorcyclists, no motorcycle lane is a main risk factor (6.3%), followed by over speeding (6.0%), no motorcycle warning sign (5.6%), broken surface (5.3%), and narrow traffic lane for bicycle (4.6%), respectively. Finally, for car drivers, no traffic light at intersection and non-reflective road surface marking are the top two risk factors (8.6% each), followed by no warning sign (7.0%), too wide traffic lane (6.3%), and over speeding (6.3%).



Figure 7. Percentage of road users affected by risk locations

3.3 Results of hazardous locations

The hazardous locations in the study areas were identified using the hazardous location ranking subsystem developed in this research. Examples of the hazardous locations (the top accident costs) found in Phuket province were illustrated in Figure 9.

3.4 Results of road safety improvement

Crash, risk, and hazardous locations reported in the database were used by local road authorities for road safety improvement. Some examples of road safety improvements are illustrated in Figure 10.

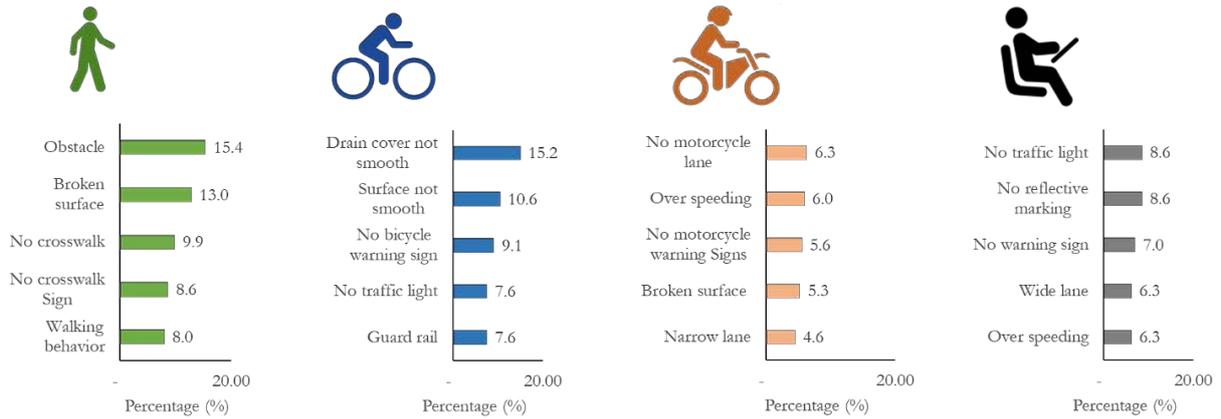


Figure 8. Top five risk factors related to road users

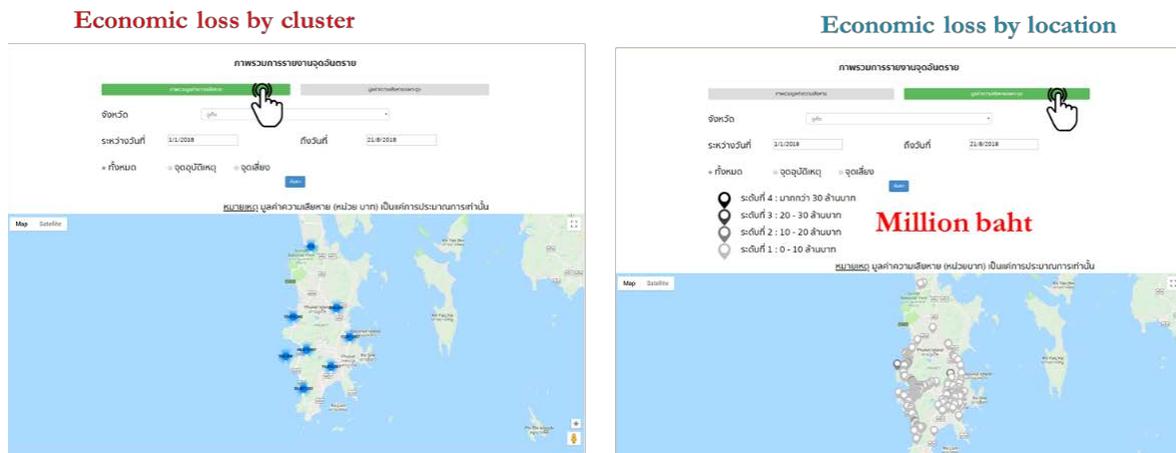


Figure 9. Examples of hazardous locations identified in Phuket province



a) Improvement of black spot location b) Improvement of hot spot location

Figure 10. Examples of road safety improvement

4 CONCLUSIONS

The ATRANS Safety Map application was developed based on the cross-platform mobile framework. There are four main functions, which include reporting crash location, reporting risk location, viewing the analysis report and navigating the desired route. The application was implemented in various study areas. From the data analysis, there were 928 crashes reported. Most of them (46%) were slightly injured, only 9% died. Regarding 1,622 vehicles involved the crashes, the motorcycle is the main group (60%). It was also found that the crashes most frequently occurred on Monday and Friday, during 3:01-6:00 p.m. Considering the road factors, most crashes occurred on the straight section (67%) and intersections (39%). At intersections, the 3-leg junctions (T and Y junctions) were accounted for 64%. From the risk locations, more than three-quarter affected to vulnerable road users (motorcyclists 38%, pedestrians 26%, and bicyclists 13%). Regarding the top risk factors, obstacle on walkway, unsmooth drain cover, no motorcycle lane, no traffic light at the intersection are the main reported risks for the case of pedestrians, bicyclists, motorcyclists, car users, respectively. Future research should consider, for example, development of a decision support tool for safety improvement programs. Implementation of the application across the country is also a big challenge.

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Determinants of congestion caused by a traffic accident in urban road networks

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1 INTRODUCTION

It has been widely recognized that about half of the traffic congestion can be attributed to non-recurrent traffic events (1-3). Therefore, it is of great importance to understand the causes of non-recurrent congestion. Major causes of non-recurrent congestion in urban road networks include weather conditions, natural hazards, and traffic accidents (4-7). There has been a proliferation of studies that investigate how the first two causes, that is, weather conditions (6-8) and natural hazards (9-11), impact the level of congestion in urban road networks. For example, (7) investigate the level of congestion with respect to rainfall, snowfall and temperature levels. (11) develop a simulation framework to measure the level of congestion caused by flood under different management strategies. (10) investigate the level of congestion caused by the Hurricane Sandy in 2012. Moreover, the impact of special events and infrastructures on traffic congestion are also considered (12, 13).

In this research, we propose to investigate how a traffic accident affect the level of congestion in urban road networks, which is new to the literature. When a traffic accident occurs on an urban link, the congestion would propagate to and affect adjacent links. We first develop a modified version of the Dijkstra's algorithm to identify the set of links in the neighborhood of the accident. We then measure the level of congestion caused by the traffic accident as the reduction in travelling speed on those links. As the level of congestion varies both in space and in time, we systematically vary the size of the neighborhood and time period, which results in a panel of congestion measurements. This data is then analyzed using a generalized linear mixed-effects model to quantify how the type of the accident, types of vehicles involved and occurrence time affect the level of congestion. Using real data in Beijing, we find that: (a) The level of congestion is mostly determined by the type of the traffic accident, the types of vehicles involved and the occurrence time; (b) For the three types of traffic accidents, namely, scrape among vehicles, collision with fixed objects, and rear-end collision, the level of congestion induced by the first two types are comparable, while that induced by the third type is 8.43% more serious; (c) For the types of vehicles involved, the level of congestion induced by the traffic accidents involving buses/trucks is 6.03% more serious than those involving only cars; (d) For the occurrence time, the level of congestion induced by traffic accidents occurring in morning peaks and afternoon peaks are 5.87% and 6.57% more serious than that induced by traffic accidents occurring in off-peak hours, respectively.

2 METHOD

In this section, we develop an approach to measure the level of congestion caused by a traffic accident in urban road networks. In Section 2.1, we measure the level of congestion as the reduction in travelling speed on a set of links in the neighborhood of the accident. In Section 2.2, we present our approach to identify the set of links to calculate the level of congestion.

2.1 Measurement of the level of congestion

We take the local urban road network in Figure 1 as an example to illustrate the congestion caused by a traffic accident. In this figure, the red mark O indicates the location of the accident. The arrow beside a link represents the direction and color of a link indicates the travelling speed. When the color of a link is green, it indicates that the travelling speed is not affected by the accident. When the color of a link is red, it indicates that the traffic accident results in the reduction on travelling speed. The links UV and YX are two overpasses that are not directly connected to the other links in the figure. It is found that the reduction in travelling speed propagates upstream from the location of the accident. According to the figure, we conclude that the traffic accident would reduce the travelling speeds of adjacent

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upstream links in its neighborhood, and therefore leads to the congestion in urban road networks.

Such congestion can be measured by the average reductions in travelling speeds on a set of links in the neighborhood of the traffic accident (12). For a given traffic accident, suppose that the set of links $1, \dots, n, \dots, N$ are identified in its neighborhood. The time period in a week is discretized into multiple intervals labelled as $1, \dots, m, \dots, M$. Let v_{nm} indicate the travelling speed on link n in time period m . Based on the historical observations of v_{nm} when there are not accidents, we can easily obtain the mean of v_{nm} , denoted as \bar{v}_{nm} , that is, the accident-free speed. When a traffic accident occurs, the v_{nm} is referred to as the accident-induced speed, denoted as \hat{v}_{nm} . The reduction in travelling speed on link n in time period m caused by the traffic accident is measured as follows:

$$y_{nm} = \frac{\hat{v}_{nm}}{\bar{v}_{nm}}. \quad (1)$$

Figure 1: Illustration of the congestion caused by a traffic accident in urban road networks.

Figure 1: Illustration of the congestion caused by a traffic accident in urban road networks.

We then measure the level of congestion caused by the traffic accident using the average weighted reductions in travelling speeds on the set of links. Let ω_n represent the weight of link n and it is measured by its length. Suppose that the level of congestion caused by the traffic accident is measured during the time period m . The level of congestion caused by the traffic accident is then measured as follows:

$$y_m = \frac{\sum_{1 \leq n \leq N} \omega_n y_{nm}}{\sum_{1 \leq n \leq N} \omega_n}. \quad (2)$$

When the value of y_m is large, it indicates that the level of congestion is slight. When the value of y_m is small, it indicates that the level of congestion is serious.

2.2 Identification of the set of links

According to Section 2.1, we know the key of measuring the level of congestion caused by a traffic accident is to identify the set of links, denoted as the link set L . We develop a modified version of the Dijkstra's algorithm to identify the L . Let the accident location O be the initial node and the distance of a node V be the shortest distance from node V to the accident location O . For a given link HI , we call node H the starting node and node I the ending node. The modified version of the Dijkstra's algorithm is used to find the link set L that each link in L satisfies the property that the distance of any point on the link is no more than r . The idea of this algorithm is to first find all nodes whose distance are no more than r . After obtaining these nodes, we put them into a node set S and record their distances. Next, the link n whose ending node V exists in S is put into the link set L . When the distance from node V to the accident location O is less than r , there must exist part of the link satisfy the property. If the whole link n satisfies the property, the following equation would be established:

$$dist(V) + len(n) \leq r,$$

where $dist(V)$ is the distance of node V and $len(n)$ is the length of link n . Otherwise there only exists part of the link n satisfying the property, we then truncate the link n at a point Z whose

distance is exactly r . In this case, we only keep the truncated link from the point Z to the ending node. Let \hat{n} denote the truncated link, the following equation would be established:

$$dist(Z) = dist(V) + len(\hat{n}) = r,$$

where $len(\hat{n})$ is the length of the truncated link. Finally, we define ω_n , the weight of link n , as the length of the link satisfying the property, which can be expressed as follows:

$$\omega_n = \min\{r, dist(V) + len(n)\} - dist(V). \quad (3)$$

We illustrate the algorithm in Figure 2. Assuming that the traffic accident occurs at the point O and $r = 500$. In addition, we replace the origin link HI with two new links HO and OI to implement the algorithm easily. The length of link HO is 250. We first find the nodes whose distances are less than 500 and put them into the node set S : $S = \{O: 0, H: 250, G: 450\}$. After that, we get the links whose ending node are O, H or G and put them into the link set L :

$$L = \{HO, GH, CH, MH, IH, BG, FG, LG, HG\}.$$

Figure 2: Illustration of the modified version of the Dijkstra's algorithm.

Finally, we calculate the weight of each link n in set L by Equation 5. If $dist(V) + len(n) \leq 500$, it means that the whole link satisfies the property, such as the link GH . In this case, the weight of link GH is its length (200). Otherwise it means that only part of the link satisfies the property, such as the link MH . We then truncate the link MH at a point Z whose distance is exactly 500. The truncated link from the point Z to the ending node H is kept, that is the link ZH . In this case, the weight of link MH is the length of the truncated link ZH (250). In Figure 2, all links in the link set L are blacked.

2.3 Generalized linear mixed-effects model for panel data

In the research of traffic accident analysis, various regression models are developed. Mixed models containing both fixed and random effects are widely used to capture the unobserved heterogeneity in traffic accidents which is particularly important in estimating the parameters (14-16). As the level of congestion varies both in space and in time, we systematically vary the size of the neighborhood and time period, which results in a panel of congestion measurements. Compared to cross-section data, panel data is able to control for spatial and time invariant individual heterogeneity, and also provides more informative data thus better estimating the parameters (17, 18). According to the detailed steps in Section 2.2, the congestion caused by a traffic accident k is measured in a spatiotemporal area that is characterized by the maximum distance r and time period m . When we systematically vary the distance r and time period m , the panel data can be obtained. The generalized linear mixed-effects model for panel data can be expressed as follows:

$$\log(y_{rmk}) = \beta \mathbf{x}_{rmk} + \mu_{rm} + \gamma_k + \varepsilon_{rmk},$$

where $\log(y_{rmk})$ is the logarithm of the level of congestion caused by the traffic accident k given the distance r and time period m ; \mathbf{x}_{rmk} is the vector of independent variables, such as the type of the accident, types of vehicles involved, the occurrence time and so on; β is the coefficient vector of the variables; μ_{rm} is a fixed term for distance r and time period m , which captures the spatial and

temporal congestion evolution; γ_k is a random term for accident k , which captures the unobserved heterogeneity in traffic accidents; and ε_{rmk} is a random term for extra interaction effects. The Akaike information criterion (AIC) and Bayesian information criterion (BIC) are used to measure the goodness of fit. Smaller values of AIC and BIC indicate that the model fits the data better.

3 RESULTS

The urban road network of northern Beijing is selected to conduct the case study. All the data are provided by the Beijing Transport Research Institute. All the computational programs are performed on a desktop computer with an Intel 3.70G Hz CPU and 16GB of memory. The independent variables and regression results are summarized in Table 1. Note the minor link indicates a link that composes of 2 or fewer traffic lanes and the secondary link indicates the class of a link is branch or bypass. The ratio of such links indicates the percent between the cumulative length of the secondary links and the cumulative length of all links in L . The coefficient of a variable can be regarded as the percentage increase in the dependent variable with 1 unit increase in the independent variable.

Table 1: Summary of the independent variables and regression results.

Category	Variables	Coefficient	Stand error
Types of the accidents	collision with fixed object	-0.0071	0.0178
	rear-end collision	-0.0843***	0.0122
	scrape among vehicles	-	-
Types of the vehicles	involved with buses/trucks	-0.0603***	0.0092
	involved with cars	-	-
Injury conditions	injuries	0.0008	0.0077
	property damage only	-	-
Occurrence times	morning peak (7:00-9:00)	-0.0587***	0.0072
	afternoon peak (17:00-19:00)	-0.0657***	0.0070
	off-peak hours	-	-
Occurrence days	weekdays	-0.0384***	0.0071
	weekends	-	-
Occurrence areas	in the 2nd ring	0.0045	0.0154
	between the 2nd and 3rd ring	0.0152	0.0108
	between the 3rd and 4th ring	0.0081	0.0098
	between the 4th and 5th ring	-0.0088	0.0100
Surface conditions	out of the 5th ring	-	-
	wet	0.0032	0.0069
Speed (km/h)	dry	-	-
	average speed before the accident	0.0402***	0.0028
	square of the average speed	-0.0009***	0.0001
Road types	ratio of the minor links (%)	-0.0006***	0.0001
	ratio of the secondary links (%)	-0.0001	0.0001

4 DISCUSSION

- When the traffic accidents are induced by the rear-end collision, the level of congestion would increase by 8.43% compared to that induced by the scrape among vehicles or collision with fixed object. The reason is that rear-end collision usually cause severe damage (19, 20), the vehicles would not be moved until the intervene of the traffic police.
- When the traffic accidents are involved with buses/trucks, the level of congestion would increase by 6.03% compared to that involving only cars. The traffic accident with buses/trucks involved results in longer congested time and affects more traffic lanes due to its weight and size and therefore causes more serious congestion (21, 22).
- Both the variables morning and afternoon peak are found to be statistically significant. Coefficient of the morning peak is -5.87%, which means the level of congestion caused by traffic accidents occurring in morning peak is 5.87% more serious than those occurring in off-peak hours. Coefficient of the afternoon peak can be interpreted similarly.

- When the traffic accidents occur in weekdays, the level of congestion would increase by 3.84% compared to those occurring in weekends. The reason is that lots of people are on duty in weekdays and therefore the traffic is heavier than that in weekends, which makes the level of congestion caused by traffic accidents occurring in weekdays more serious.
- We expect to see that the level of congestion would increase by 0.06% with 1% increase in the ratio of minor links in the neighborhood of the traffic accident. Increase of such ratio suggests the decrease of traffic capacity in the neighborhood of the accident, and therefore the level of congestion becomes more serious.

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Investigating varying effect of road-level factors on crash frequency across regions: A Bayesian hierarchical random parameter modeling approach

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1. INTRODUCTION

The aim of this study is to investigate the underlying variations in effects of road-entity related factors (roadway features and traffic volumes) on crash frequency across geographical regions. A hierarchical model with random parameters is proposed as a methodological alternative to account for the regional varying relationships between the crash frequency and road level factors by allowing the coefficients to vary among the highly aggregated geographic units (e.g., county). The data collected for urban two-lane two-way roadway segments in Florida are used as a case study for the proposed model and examine the varying safety effects of road level factors across counties. Road level factors including traffic volume, segment length, access density, surface condition and median type are examined in this study.

Traffic crashes are the result of combination of multiple factors (1-3). Many factors (especially related to region-level and individual-level factors) are usually unavailable or even unobservable (4, 5). As a result, many important factors have been often not considered in modeling crash frequency. From a statistical view, if these omitted variables are significantly correlated with selected variables, this omission could introduce variations in the effects of selected variables on crash likelihood (6). The omitted factors constitute the so-called unobserved heterogeneity. An overview of the potential for unobserved heterogeneity in the context of crash data and analysis has been highlighted by Mannering et al. (5).

Risk factors associated with crash frequencies exhibit a hierarchical structure (7). Road entities and their located geographic region could be viewed as a hierarchical system of the road entity nested within the geographic region. The road entities within the same region may be correlated with each other because they share similar unobserved (regional) characteristics (e.g. enforcement of driving regulations, land use patterns, socioeconomic characteristics, road density and traffic environments), and thus the traffic participants' characteristics and behaviors tend to be similar (3). The presence of these unobserved regional factors (or heterogeneities) and their interactions with observed road-entity-level factors can eventually result in variations in the effect of these factors on crash likelihood across different space unit. Consequently, the effects of the road-entity-level factors on crash frequency in the same region are seen to be more similar than the effects in different geographical regions (8, 9).

A vast array of studies has been devoted to utilize statistical and econometric models to account for unobserved heterogeneity (4, 10). The random parameter modeling approaches have gained considerable attentions in crash frequency analysis (11) and crash severity analysis (12). However, the traditional random parameters modeling approach assumes the sources of heterogeneity are independent over the sample population (13). Traditional random parameters modeling approach cannot provide parameter estimates that account for the possible spatial correlation effects among road entities in crash data with hierarchical structure (12, 13).

Recently, the hierarchical modeling technique is recommended application in traffic safety analysis (14, 15). In this study, a random parameter model is incorporated into the hierarchical modeling framework to account for regional-specific heterogeneity for investigating varying relationships between the crash frequency and road-entity-level factors across regions. The proposed model could distinctly address and properly estimate the hierarchical structure of data, but also mitigate the adverse impacts of these omitting variables (i.e., region-level and individual-level) by allowing the regression coefficients to vary with regions.

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2. METHODOLOGY

Poisson model and its variants (such as negative binomial and Poisson lognormal model), are widely used and proven to be successful as they are capable of effectively modeling the rare, random, sporadic, and non-negative crash data. Compared with Poisson model, Poisson lognormal model can provide a more credible estimation by incorporating random effects of the linear predictor to address overdispersion for unobserved heterogeneity (16). The formulation for Poisson lognormal model can be presented as follows:

$$Y_i \sim \text{Poisson}(\lambda_i) \quad (1)$$

$$\log \lambda_i = \beta_0 + \sum_{m=1}^M X_{mi} \beta_m + \varepsilon_i \quad (2)$$

where Y_i is the observed number of crash frequency for road entity i , and λ_i is the expectation of Y_i . X_{mi} is the m th factor for road entity i . β_0 and β_m are the intercept coefficient and the slope coefficient, respectively. ε_i denotes the random effect which is assumed to follow independently a normal distribution with zero mean and standard deviation $\sigma(\sigma>0)$, that is,

$$\varepsilon_i \sim N(0, \sigma^2)$$

The aforementioned Poisson lognormal model assumes safety effects of factors (regression coefficients) to be fixed. In fact, this fixed setting of regression coefficient builds on an underlying assumption that the observations should be mutually independent. However, as contended in the introduction, this fundamental requirement may always be violated. A hierarchical random parameter model is further proposed to model crash frequency for road systems with hierarchical structure. In the hierarchical model with random parameters, regression coefficients (the intercept coefficient and the slope coefficient) are not fixed but vary with regions. That is, the $(\beta_0, \beta_1, \dots, \beta_M)$ in Eq.(2) are set to be varying coefficient $(\beta_{0j}, \beta_{1j}, \dots, \beta_{Mj})$ as:

$$Y_{ij} \sim \text{Poisson}(\lambda_{ij}) \quad (3)$$

$$\log \lambda_{ij} = \beta_{0j} + \sum_{m=1}^M X_{mij} \beta_{mj} + \varepsilon_i \quad (4)$$

$$\beta_{0j} = \gamma_{00} + \mu_{0j} \quad (5)$$

$$\beta_{mj} = \gamma_{m0} + \mu_{mj} \quad (6)$$

where Y_{ij} is the observed number of crashes for road entity i (e.g., segment) in region j (e.g., county), γ_{00} is the mean of the intercept. γ_{m0} is the average effect of m th factor. ε_i is the random effect representing within-region variance. μ_{0j} and μ_{mj} are random effects representing between-region variances, which are consistent for road entity in the same region but vary between different regions. μ_{0j} and μ_{mj} reflect unique effects associated with region j . ε_i , μ_{0j} and μ_{mj} are generally assumed to follow normally distributed with mean zero, that is,

$$\begin{aligned} \varepsilon_i &\sim N(0, \sigma^2) \\ \mu_{0j} &\sim N(0, \delta_0^2) \\ \mu_{mj} &\sim N(0, \delta_m^2) \end{aligned}$$

A simplified equation of hierarchical random parameter model is to let the intercept vary ($\beta_{0j} = \gamma_{00} + \mu_{0j}$) with fixed slope ($\beta_{mj} = \gamma_{m0}$), forming a hierarchical random intercept model. This means that the between-region variance only works on the intercept β_{0j} . In this study, a hierarchical model with random intercept is also provided as a reference for model performance comparisons.

3. DATA

The collected for a specific roadway facility type, two-lane two-way urban road, in Florida are used to illustrate the proposed hierarchical random parameter model and examine varying effects of road level factors across regions. The road entity level is the two-lane two-way urban segment (level 1) and the region level under consideration is the county (level 2).

Three years of crash data (2005-2007) were obtained from the Florida Department of transportation (FDOT) Crash Analysis Reporting System. Meanwhile, the shape files of site characteristics were downloaded from the website of the FDOT Transportation Data and Analytics Office. Then, geographical information system (GIS) technique was used to extracted two-lane two-way urban road

segments according to the road characteristics including function class and number of lanes. Subsequently, GIS was used to map crashes and site characteristics to these segments. Since the number of investigated segment type in some counties of Florida is small, with consideration of simple size in hierarchical modeling, we extracted two-lane two-way urban segments in 34 counties which have relatively higher number of this road type among all of 67 counties of Florida. As a result, a total of 3,857 road segments with 38,938 crashes occurred were selected for our analysis, and the number of segments ranges from 26 to 337 within each selected county. The descriptive statistics of crash data in a three-year period (2005–2007) and factors related with traffic volumes and roadway features for these selected segments are provided as in Table 1.

Collinearity diagnose for the factors of segment was conducted in SPSS software. As the result, the eigenvalue of the variable “median” is 0.015, and its condition index is more than 17, indicating that the presence of the median is significantly collinear with other factors. Therefore, the variable “median” was excluded from the models.

Table 1. Summary of variable and descriptive statistics

Variable	Description	Mean	S.D.	Min.	Max.
Response variable					
Crash frequency	Number of crashes per segment from 2005 to 2007	10.090	15.965	0	323
Road level factors					
Length	Segment length (mile)	1.497	1.005	0.600	7.876
ADT	Average daily traffic (10^3 pcu ^a)	8.054	7.573	0.350	59.500
Access	Number of access roads/segment length	6.588	4.196	0	32.717
		Crash count (Proportion)		Segment count (Proportion)	
Median	Median barrier indicator:				
	Present	23401 (60.1%)		2991 (77.5%)	
	Otherwise	15537 (39.9%)		862 (22.5%)	
Surface Condition	Good	8173 (21.0%)		811 (21.0%)	
	Fair	28216 (72.5%)		2755 (71.4%)	
	Poor	2549 (6.5%)		293 (7.6%)	

^a pcu: passenger car units

4. RESULTS AND DISCUSSIONS

A significant advantage of the hierarchical random parameter model is that, in addition to the global regression coefficients, local coefficients in each county can also be estimated. The local coefficient estimates for selected factors in this study are plotted by the solid lines in Fig. 2(a–d). Furthermore, since the model has nonlinear coefficients, direct parameters could not show a unit effect of explanatory variables on the number of crashes. The marginal effects are thus computed at the sample mean of the explanatory variables, and shown by the dotted lines in Fig. 2(a–d). Marginal effects for continuous variables measure the impact of a unit change in the exogenous variable on the frequency of crashes and the marginal effect for a dummy variable indicates a change in the crash counts with and without the presence of the variable. As shown in Fig. 2, these local coefficient estimates and corresponding marginal effects reveal obvious patterns of regional variations. The red horizontal straight lines in each figure are marked for estimated global means of regression coefficients. It is apparent that the local means deviated significantly from the global means estimated in the hierarchical random parameter model. The information from Fig. 2 illustrates that the effects of the road level factors on crash frequency appear to vary with counties rather than the potential assumption of the safety effects being fixed. Specifically, the mean of the regression coefficient and the marginal effect of $\ln(\text{ADT})$ would be expected to vary in the range of (0.343, 0.823) and (0.867, 10.505) respectively, $\ln(\text{Length})$ would be in the range of (0.872, 1.063) and (1.552, 19.705), access density of (0.050, 0.127) and (0.136, 1.606), and surface condition of (-0.302, 0.134) and (-1.950, 0.243).

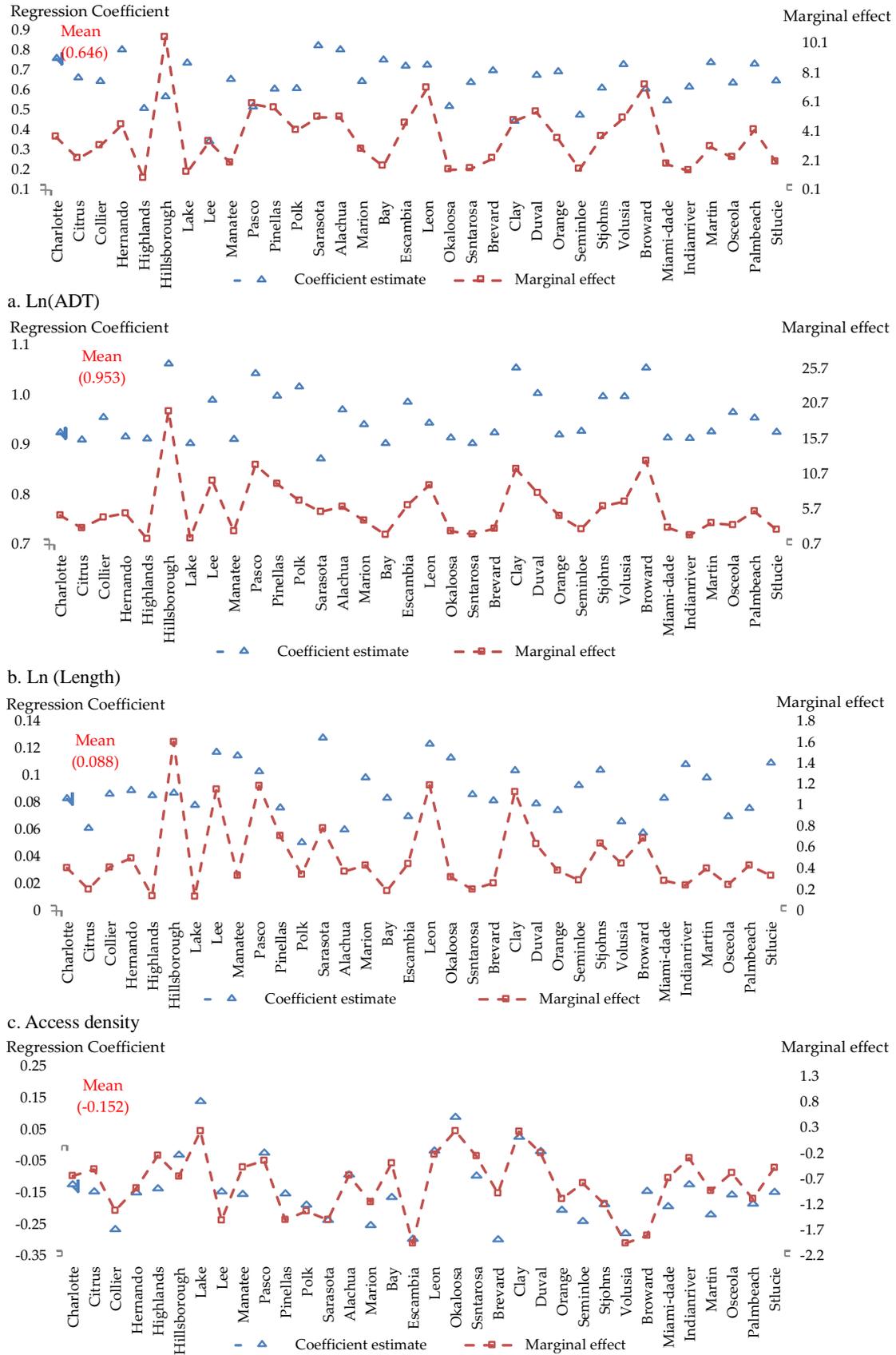


Fig. 2. Local regression coefficient estimates and marginal effects for selected road level factors in each

As shown in Fig. 2, the signs of local regression coefficients for three risk-factor variables including

$\ln(\text{ADT})$, $\ln(\text{Length})$, and access density are positive in all of selected 34 counties, indicating that these three variables have positive associations with crash frequencies in each county. But the magnitudes of positive effects are found to vary over a wide range in different counties. The global estimated mean of the regression coefficient for $\ln(\text{ADT})$ is 0.646 (Fig. 2a). The maximum value of the local coefficient estimation for this variable is 0.823 in Sarasota county, and the minimum is 0.343 in Lee county. Correspondingly, the global marginal effect of $\ln(\text{ADT})$ is calculated as 4.576, the local marginal effect in Sarasota county is 5.073, and is 3.385 in Lee county. These mean that one unit increase in $\ln(\text{ADT})$ will associate with a 1.525 ($= 4.576/3$) increase in average segment crash frequency per year, and with a 1.691 ($= 5.073/3$) increase in Sarasota county and a 1.128 ($= 3.385/3$) increase in Lee county. The positive effect of traffic volume is consistent with previous studies (14, 17) that greater traffic volumes present more opportunities for exposure to traffic conflicts, and thus are associated with more crashes. Our study further reveals that the magnitude of safety effect of traffic volumes can vary significantly from one county to another. Country.

The regional variation of coefficient estimation of $\ln(\text{length})$ is relatively less than that of $\ln(\text{ADT})$. The maximum value and minimum value of the local coefficient estimation of $\ln(\text{length})$ are 1.063 in Hillsborough county and 0.872 in Sarasota county, respectively (Fig. 2b). Their corresponding marginal effects are 19.705 in Hillsborough county and 5.379 in Sarasota county, indicating that one unit increase in $\ln(\text{length})$ would increase 6.568 ($= 19.705/3$) crashes in Hillsborough county per year and 1.793 ($= 5.379/3$) crashes in Sarasota county per year. The positive relationship between segment length and crash frequency is reasonable since a longer segment length is associated with the higher crash exposure, and thus increases the potential probability of crash occurrence.

With regard to the access density, this variable also exhibits an obvious pattern of regional inconsistency. The global estimated mean of the regression coefficient for the access density is 0.088 (Fig. 2c). County Sarasota has the maximum value (0.127) of the local coefficient estimation for this variable, and the minimum value (0.050) is in Polk county. Their marginal effects are 0.423 globally, 0.786 in Sarasota and 0.345 in Polk, respectively. It indicates that one unit increase in the access density associates with an approximate 0.141 ($= 0.423/3$) increase in average segment crash frequency per year, and with 0.262 ($= 0.786/3$) increase in Sarasota county and 0.115 ($= 0.345/3$) increase in Polk county per year. The positive effect of access density is generally expected and agrees with the preliminary studies (18, 19). This is because that more accesses may result in more conflict points and deteriorated safety.

What interesting to see are in Fig. 2d that the signs of local coefficients of the good surface condition are negative in most counties; but are positive in Lake, Okaloosa, and Clay. The global estimated mean of the regression coefficient for this factor is -0.152, and its corresponding marginal effect is -0.730. It indicates that urban two-lane two-way roadway segment with good surface condition would decrease crash frequency by -0.243 ($= -0.730/3$) in average per year. Overall, there is a negative association between the good surface condition and crash frequency (in 31 counties among 34 counties), which is consistent with prior studies (1, 20). The counterintuitive safety effects of this variable in Lake, Okaloosa and Clay may due to the fact that drivers reside in these three counties are generally likely to drive with higher speed and less cautiously on the pavement with good surface condition, which is a manifestation of risk-compensation behavior (21). This inconsistent sign of coefficient estimations among different counties strongly indicates the safety effect of some road level variables could be largely influenced by regional-level and individual-level factors.

5. CONCLUSIONS AND IMPLICATIONS

This study seeks to quantitatively investigate the underlying regional variations in effects of road level factors on crash frequency. The relationship between crash frequency and road level factors should not be considered spatially constant, since many regional-level and individual-level unobserved or uncollected factors may be correlated with these road level factors. In modeling crash frequency, these correlations would introduce variations in the effects of selected variables on crash likelihood. To this end, a hierarchical random parameter model is proposed to investigate the regional varying relationships between the crash frequency and road level factors. For the purpose of comparison, a Poisson lognormal model and a hierarchical random intercept model are also developed.

Using the crash data during three-year period and their related road level factors for urban two-lane two-way highway segments in Florida as a case study, the results of model parameter estimations demonstrate that regression coefficients of all investigated factors (i.e., traffic volume, road length,

access density and surface condition) and their corresponding marginal effects are significantly different over a wide range among different counties. In regard to the model comparison, the hierarchical random parameter model outperforms the hierarchical random intercept model and the Poisson lognormal model in terms of goodness-of-fit as measured by DIC. These results confirm the reasonability and necessity of the use of hierarchical random parameter model to analyze the crash frequency for road entities with hierarchical structure.

Several limitations should be noted for this study. First, region-level factors are not considered in this study. In the follow-up study, important region-level demographic and socioeconomic variables (e.g., population by age group, industry, income, employment) could be incorporated into hierarchical random parameter models to further explore these variability patterns of road-level factors. Second, there may be micro-level spatial correlations among adjacent road entities, which are caused by similar traffic volumes, traffic controls and road features of adjacent road entities. The modeling approach that incorporates the spatial correlation into the hierarchical random parameter model will be further explored to track the source of varying effects of road-level factors.

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Driver Physiology and Behavior Differences during Perpendicular Parking: A Real Vehicle Experiment

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Abstract

Based on a real vehicle experiment, this study investigated parking behavior differences in 26 Chinese drivers (21 men and 5 women) using different perpendicular parking space widths and passage widths. The results indicated that the driver working load score, number of trajectory adjustments and number of failures were not affected by age and driving experience. Parking speed was significantly affected by driving frequency. Additionally, the presence of parking references improved parking efficiency. A significant difference was observed in parking behavior on sunny and rainy days, indicating that changes in the external environment affect driver parking operation. During parking, driver behaviors were greatly affected by the parking space width, and the passage width also influence behavior. Increasing the passage width appropriately was an effective way to relieve pressure due to a limited parking width and improve parking efficiency.

Keywords: parking behavior; perpendicular parking; real vehicle experiment; heart rate variability; parking speed

1 INTRODUCTION

Parking is an essential part of everyday driving and vehicle travel. Safely and efficiently parking a car is important for drivers and transportation systems. Driver gaze movement and steering wheel rotation are more complicated during garage parking than driving on the road. Drivers must precisely control the position and direction of their vehicles because of the limited space. Therefore, operational errors are more likely to occur during parking, which can lead to accidents.

Usually, parking spaces are categorized as parallel parking, perpendicular parking and diagonal parking. Parallel parking was considered the most difficult way to park a car (1). Previous studies on parallel parking are abundant, but research on perpendicular parking is limited. However, perpendicular parking still has many problems to be studied, and perpendicular parking is frequently used. Douissembekov et al. found that perpendicular parking was the most common manoeuvre for parking at home (2). Parking behavior is related to driver spatial perception (3, 4).

Subjective factors also affect driver parking behavior. Driver emotions while driving are important factors affecting traffic safety (5). Driver psychology, cognitive ability and stress response have significant differences (6). Emotion and personality mainly affect driving behavior by affecting the driving attitude. Drivers with unstable emotions often have erratic driving operations and engage in risky driving behavior, causing traffic infringements and accidents and severely affecting road traffic safety (7). Physiological indicators can be used to more intuitively examine driving behaviors and physiological changes (8). Heart rate variability is thought to reflect the driver stress response and driving behavior (9-11). However, heart rate variability as an important indicator of driver psychological response has not been used to study driver psychological and physiological changes during parking. Additionally, only a few studies on different parking space widths and passage widths in perpendicular parking have been reported.

Based on a physiological evaluation method, a real vehicle experiment was used to study the changes in heart rate variability and parking speed of drivers for different perpendicular parking space widths and passage widths. In addition, the study also compared the differences in driver parking behavior during different weather and analysed the impact of parking references and gender on driver parking behavior. Hypothesis 1: The presence or absence of a parking reference has an effect on parking behavior, and the driver has a higher parking efficiency when a reference is present. Hypothesis 2: The sizes of the parking spaces and passages have a

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significant effect on driver heart rate variability and parking speed. When the sizes are small, the driver RR interval is relatively large and the speed is low.

2 METHOD

2.1 Measures and Design

According to China’s code for parking space design, midsize car parking spaces should be approximately 4.8 m long and 1.8 m wide (12). To eliminate the influence of manual gear shifting and parking sensors on driver parking behavior, a 2008 Toyota Camry (4.85 m long and 1.825 m wide) with an automatic transmission but without parking sensors or a rear-view camera was chosen for the experiment. The driver heart rate variability during parking was measured by the ECG module of an MP150 physiological tester produced by American Biopac. The parking speed was measured by a high-precision GPS.

The perpendicular-parking space designed for this experiment was in a clearing at Hefei University of Technology with almost no pedestrian and student traffic. The experimental conditions are shown in Table 1. Marked poles with a height of 0.9 m were set around the parking space and the passage boundary as parking references (red dot in the figure), as shown in Fig 1. Every participant completed a series of 25 parking conditions in the experiment. As a control, participants parked without references in a fixed parking space with a width of 2.4 m and fixed parking passage 5.5 m wide.

Table 1. Experimental design

Experimental design		Parking space width (m)				
		2.3	2.35	2.4	2.45	2.5
Passage width (m)	5.0	W2.3P5.0	W2.35P5.0	W2.4P5.0	W2.45P5.0	W2.5P5.0
	5.25	W2.3P5.25	W2.35P5.25	W2.4P5.25	W2.45P5.25	W2.5P5.25
	5.5	W2.3P5.5	W2.35P5.5	W2.4P5.5	W2.45P5.5	W2.5P5.5
	5.75	W2.3P5.75	W2.35P5.75	W2.4P5.75	W2.45P5.75	W2.5P5.75
	6.0	W2.3P6.0	W2.35P6.0	W2.4P6.0	W2.45P6.0	W2.5P6.0
No reference		NW2.4P5.5				

W: Width, P: Passage Width, N: No reference.

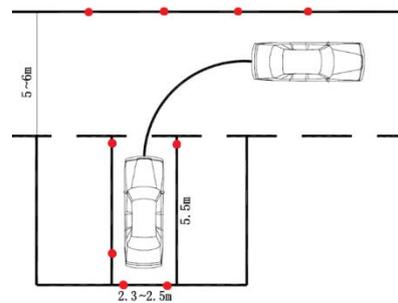


Fig 1. Perpendicular parking sketch

The NASA Task Load Index questionnaire adapted from English was used for this experiment. According to the introduction of the NASA-TLX by Douissembekov, a driver self-assessment was collected after parking. Twelve items are included in this questionnaire, involving mental, physical and time requirements of the parking process. The self-rating scales for each item range from 1 (low) to 5 (high). (Coefficient of internal consistency α is 0.796)

2.2 Participants and procedure

Skilled drivers (i.e., with more than 5 years driving experience) were selected for this experiment to reduce the impact of driving skill on parking efficiency. A total of 26 drivers (23 to 60 years of age, 40.0 ± 10.9) with driver’s licenses participated in the real vehicle experiments.

Participants drove 20 minutes with the relevant instruments to become familiar with the experimental car and parking space to reduce the effect of the vehicle equipment and facilities on the driver. They parked the car in the parking passage outside of and perpendicular to the parking space at the beginning of the experiment. Participants were required to back the car into the parking space. First, the length of the parking space was changed, and then, the width of the parking passage was changed. Participants could adjust the car forward more

than once. Participants were encouraged to immediately stop the parking test and report to staff if they felt uncomfortable.

When a wheel went over the line or the car body touched the line or crashed into a reference, a parking failure was recorded. Participants reported the failures themselves as well. The experiment would then start again under the same conditions with the car back at the starting location, and the participant was marked as failing one time. Participants filled out the NASA-TLX and basic information (driving frequency, annual average driving mileage, etc.) after finishing all the parking experiments. We paid participants 200 RMB as a reward.

3 RESULTS

3.1 Parking behavior differences

A correlation analysis was performed between the descriptive variables and parking behavior. Parking speed was significantly affected by driving frequency ($p < 0.05$). There were no significant correlations between the total workload score, number of trajectory adjustments and number of failures and driver age, driving experience and driving frequency ($p > 0.05$).

An independent t-test was used to check the differences in the total workload score, number of trajectory adjustments, number of failures and parking speed and between gender and weather. The results show a significant difference in the number of trajectory adjustments between sunny and rainy days ($p = 0.036$), and drivers had fewer trajectory adjustments on sunny days than rainy days. Drivers also had fewer failures and a lower parking speed on sunny days than on rainy days, but a significant difference was not observed. Similarly, no significant difference was observed in parking behavior between genders.

A paired-sample t-test was used to analyse the effect of a parking reference on driver parking behavior. A non-significant difference was found in the RR interval for parking with references and without ($t = -0.601$, $p = 0.559$). The driver RR interval was higher in the absence of references than that in the presence of references. The parking speed was significantly faster in the presence of references than that in the absence of references ($t = 3.047$, $p = 0.017$). The number of failures in the presence of references was also significantly lower than that in the absence of references ($t = -2.760$, $p = 0.024$). However, no significant difference was observed in the number of trajectory adjustments for the presence and absence of a parking reference ($t = -1.00$, $p = 0.337$).

3.2 The effect of the parking space width and passage width on heart rate

Table 2. Paired-sample t-test results for the RR interval

Passage width (m)	Space width (m)	RR interval		Space width (m)	Passage width (m)	RR interval	
		t	p			t	p
5	2.3 vs. 2.35	-3.172	.004	2.3	5 vs. 5.25	-2.262	.032
	2.35 vs. 2.4	-2.253	.033		5.25 vs. 5.5	-1.288	.209
	2.4 vs. 2.45	-1.967	.053		5.5 vs. 5.75	-0.460	.649
	2.45 vs. 2.5	-0.089	.929		5.75 vs. 6	-0.230	.820
5.25	2.3 vs. 2.35	-3.002	.007	2.35	5 vs. 5.25	-1.759	.041
	2.35 vs. 2.4	-1.733	.045		5.25 vs. 5.5	-0.215	.832
	2.4 vs. 2.45	-1.625	.119		5.5 vs. 5.75	-0.116	.909
	2.45 vs. 2.5	-0.371	.714		5.75 vs. 6	-1.625	.119
5.5	2.3 vs. 2.35	-1.265	.018	2.4	5 vs. 5.25	-1.471	.154
	2.35 vs. 2.4	-2.258	.033		5.25 vs. 5.5	-0.788	.438
	2.4 vs. 2.45	-0.899	.377		5.5 vs. 5.75	-0.480	.626
	2.45 vs. 2.5	-0.478	.637		5.75 vs. 6	-0.732	.470
5.75	2.3 vs. 2.35	-2.324	.029	2.45	5 vs. 5.25	-1.107	.279
	2.35 vs. 2.4	-2.374	.026		5.25 vs. 5.5	-0.347	.732
	2.4 vs. 2.45	-1.637	.114		5.5 vs. 5.75	-0.465	.646
	2.45 vs. 2.5	-0.734	.470		5.75 vs. 6	-0.107	.524
6	2.3 vs. 2.35	-3.017	.006	2.5	5 vs. 5.25	-1.746	.043
	2.35 vs. 2.4	-1.950	.062		5.25 vs. 5.5	-1.184	.219
	2.4 vs. 2.45	-1.547	.134		5.5 vs. 5.75	-0.496	.624
	2.45 vs. 2.5	-0.361	.715		5.75 vs. 6	-0.133	.895

3.2.1 The effect of the parking space width on the RR interval

A paired-sample t-test was used to analyse the difference in the RR interval for different parking space widths with a fixed passage width (Table 2). The results show that for all passage widths, the RR interval decreased significantly as the parking space width changed from 2.3 m to 2.35 m. When the passage width was 5 m, 5.25 m, 5.5 m or 5.75 m, there was a significant difference in the RR interval as the parking space width changed from 2.35 m to 2.4 m. For 6 m, no significant difference was observed in the RR interval as the parking space width changed from 2.35 m to 2.4 m. However, when the parking space width was greater than 2.4 m, the RR interval decreased with the increase in the parking space width, but the decrease was not significant.

3.2.2 The effect of the passage width on the RR interval

A paired-sample t-test was used to analyse the difference in the RR interval for different passage widths with a fixed parking space width. The results of the differential test showed that when the parking space width was small (2.3 m, 2.35 m or 2.5 m), the RR interval decreased significantly as the passage width changed from 5 m to 5.25 m. As the passage width increased, a decrease in the RR interval was observed but was not significant.

3.3 The effect of parking space width and passage width on parking speed

3.3.1 The effect of the parking space width on the parking speed

A paired-sample t-test was used to analyse the difference in the parking speed for different parking space widths with a fixed passage width (Table 3). The results show a significant difference in the parking speed between any two parking space widths with a fixed parking passage width of 5 m. With an increase in the parking space width, the parking speed also increased. However, the rate of increase in the speed levelled off. A significant difference was also observed in the parking speed between any two parking space widths with a fixed parking passage width of 5.5 m and 5.75 m, which was the same tendency previously observed. When the passage width was 5.25 m, a significant difference was observed in the parking speed between any two parking space widths, except as the parking space width changed from 2.4 m to 2.45 m. For 6 m, the parking speed significantly increased as the space width increased from 2.35 m to 2.4 m and from 2.4 m to 2.45 m.

Table 3. Paired-sample t-test results for the parking speed

Passage width (m)	Space width (m)	Speed		Space width (m)	Passage width (m)	Speed	
		t	p			t	p
5	2.3 vs. 2.35	-5.251	.000	2.3	5 vs. 5.25	-4.721	.000
	2.35 vs. 2.4	-3.653	.001		5.25 vs. 5.5	-1.652	.111
	2.4 vs. 2.45	-2.676	.013		5.5 vs. 5.75	-2.772	.010
	2.45 vs. 2.5	-3.687	.001		5.75 vs. 6	-3.210	.004
5.25	2.3 vs. 2.35	-3.012	.006	2.35	5 vs. 5.25	-3.440	.002
	2.35 vs. 2.4	-6.108	.000		5.25 vs. 5.5	-3.497	.002
	2.4 vs. 2.45	-0.045	.964		5.5 vs. 5.75	-5.674	.000
	2.45 vs. 2.5	-4.530	.000		5.75 vs. 6	1.785	.086
5.5	2.3 vs. 2.35	-4.145	.000	2.4	5 vs. 5.25	-5.749	.000
	2.35 vs. 2.4	-3.739	.001		5.25 vs. 5.5	-1.626	.116
	2.4 vs. 2.45	-2.818	.009		5.5 vs. 5.75	-0.655	.518
	2.45 vs. 2.5	-2.990	.006		5.75 vs. 6	-1.190	.245
5.75	2.3 vs. 2.35	-6.143	.000	2.45	5 vs. 5.25	-3.345	.002
	2.35 vs. 2.4	-0.967	.043		5.25 vs. 5.5	-4.799	.000
	2.4 vs. 2.45	-2.702	.012		5.5 vs. 5.75	-1.669	.108
	2.45 vs. 2.5	-4.245	.000		5.75 vs. 6	-2.849	.009
6	2.3 vs. 2.35	-1.656	.110	2.5	5 vs. 5.25	-5.957	.000
	2.35 vs. 2.4	-2.090	.047		5.25 vs. 5.5	-2.776	.010
	2.4 vs. 2.45	-4.909	.000		5.5 vs. 5.75	-2.632	.015
	2.45 vs. 2.5	-1.578	.127		5.75 vs. 6	-0.105	.917

3.3.2 The effect of the passage width on the parking speed

A paired-sample t-test was used to analyse the difference in the parking speed for different passage widths with a fixed parking space width. When the parking space width was 2.3 m, there was a significant difference in the parking speed between any two passage widths, except as the passage width changed from 5.5 m to 5.25 m. When the width was 2.35 m, a significant difference was observed between any two passage widths, except as the passage width changed from 5.75 m to 6 m. When the parking space was 2.45 m, the parking speed was significantly different for each passage width except 5.5 m and 5.75 m. For 2.5 m, the parking speed significantly changed as the passage widths varied from 5 m to 5.75 m. However, when the parking space width was 2.4 m, the speed increased significantly when the passage width changed from 5 m to 5.25 m.

3.4 **The effect of the parking space width and passage width on the number of trajectory adjustments**

This experiment measured the number of trajectory adjustments for different parking space widths and passage widths. With an increase in the parking space width, the number of trajectory adjustments decreased, but the rate of decrease plateaued. The passage width also had an impact on the number of trajectory adjustments. The number of trajectory adjustments significantly decreased as the passage width changed from 5 m to 5.25 m and from 5.25 m to 5.5 m. As the passage width increased, there was no significant difference in the number of trajectory adjustments.

4 **DISCUSSION**

According to the results of the NASA TLX questionnaire, this study compared the correlation between demographic variables (age, driving experience, etc.) and parking behavior. These factors were found to have a certain relationship with the selected sample, i.e., skilled drivers. With an increase in driving age, driving experience increases. However, an increase in driving experience had a minimal impact on skilled driver parking skills. Drivers with experience and skill feel less pressure during parking, and demographic variables did not affect their parking ability, which was like the results reported by Holland (13).

The independent t-test results showed that the number of trajectory adjustments on rainy days was significantly less than that on sunny days. This result might be because the drivers were more inclined to complete parking with fewer operations to achieve one-time parking on rainy days. The results showed that the deterioration of the external environment directly affects driver parking operation, indicating that the environment has an important influence on driving operations. Bad weather did not directly affect the parking results. The number of failures and parking speed were not significantly different on rainy and sunny days. However, the conclusion of this study was not like that of Bergdahl who reported differences in the emotional psychology, cognitive ability and stress response between male and female drivers (1). This difference may be due to the special nature of parking.

The study also validated the impact of parking references on drivers during parking. The results showed that the presence of a parking reference had no obvious effect on the driver heart rate during perpendicular parking but slightly increased the parking speed. Drivers determined the exact location of the car body with effort only by adjusting the field of view without a reference, which caused the number of failures to increase, i.e., the wheel went over the line or the car body touched the line or collided with the reference. Therefore, installing references for limited parking spaces could significantly increase the efficiency of parking. These findings on parking references fully confirm the results of Michael (4).

During improper operation, the wheel and car body might cross the line. Therefore, drivers remained highly stressed. Once the parking space widths increased, the driver psychological pressure decreased significantly. The angle between the car and the parking space increased with the widths, reducing the difficulty of the operation. The RR interval also decreased, and a significant difference was no longer observed. When the parking space width and passage width are small, the driver RR interval during parking decreased significantly with an increase in the passage width. When the width of the parking space was large, there was also a significant difference in the heart rate between passage widths of 5 m and 5.25 m. Thus, parking space width is the dominant factor affecting driver psychology, while passage width affected drivers only in small parking spaces. Appropriately increasing the passage width could effectively alleviate the stress caused by small parking space widths.

Drivers accelerated their parking speed as the parking space width and passage width increased. There was a significant difference in the parking speed for each combination of parking space widths and passage widths. Drivers were cautious, and the speed was lower in the smaller spaces. Increasing the widths of the parking spaces and passages could significantly increase the parking efficiency. When the parking space width is

limited, the passage width can be appropriately increased to improve the parking efficiency.

This study also analysed the number of adjustments as another indicator of parking efficiency. The results showed that as the parking spaces widths increased, the number of adjustments decreased. Driver parking behavior was affected by the passage width when the width was small. However, as the passage width increased, the number of adjustments was not substantially limited. Increasing the width of parking spaces is a good way to effectively improve parking efficiency. After reaching 5.5 m, the effect of further increasing the passage width on the number of adjustments was not obvious.

This study has some limitations. Because parking parameters cannot be endlessly tested, this experiment selected five parking space widths and five parking passage widths. Subsequent research should examine additional combinations of parking space lengths and passage widths to further refine these conclusions. Moreover, the location of the parking reference was fixed in this experiment. Thus, the study did not examine the effect of different positions on driver parking behavior. Subsequent studies should focus on the effect of a dynamic person or reference.

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Progress in Pedestrian Safety Research

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Abstract

This study looks at the pedestrian safety issue and the research that has followed to understand and solve the problem of pedestrian safety in the last 120 years - since the time of the first reported pedestrian fatality in the US. Researches have studied the epidemiology of pedestrian crashes, pedestrian behaviour, pedestrian movements and pedestrian flows. The suggested strategies to reduce pedestrian crashes have ranged from controlling vehicular speeds to controlling pedestrian behaviour. This study presents a summary of the progress we have made in understanding pedestrian crash patterns. Pedestrian behaviour observed in different regions of the world tend to have similarity in terms of gap acceptance, preferences of route choice and location for crossing roads. High income countries (HIC) have reported reduction in pedestrian fatalities as compared to low- and middle-income countries (LMIC), however pedestrian trips have also reduced in these countries leading to concerns about effectiveness of “known” strategies. Speed control through active measures has been found to have maximal benefit and education and training program the least. Low and middle income countries face pedestrian exposure on high speed roads. New research efforts are required address pedestrian safety in HIC and LMICs both.

Keywords: Pedestrian safety, pedestrian risk, traffic risk, pedestrian behaviour

1 INTRODUCTION

Henry Bliss was America’s first recorded pedestrian fatality. On September 18, 1899, The New York Times headline read “fatally hit by automobile”. Henry Bliss was hit by an electric taxi as he was alighting from a street car (1). Since then in US alone more than 300,000 pedestrians have died in traffic crashes. Historical records show that the first ever recorded pedestrian fatality was a British woman Bridget Driscoll more than 120 years ago². Bridget Driscoll was hit on the grounds of Cristal Palace by an experimental vehicle—a horseless car—the experimental automobile which could go at a maximum speed of 8 mph (13 km/h).

In the years to follow, automobiles and other forms of motorized vehicles grew all over the world. In some parts of the world more than the others. Today we have countries labelled as motorized countries and less motorized countries. Less motorized countries are the low and middle-income countries (LMIC) having different traffic patterns and crash patterns (2).

Road traffic fatalities continued to rise all over the world for the next 70 years since the first reported road traffic fatality. However, motorized countries started reporting reduction in RTIs 1970 onwards. The rate of traffic fatalities have stabilized, however, the number of road traffic deaths continues to increase, reaching 1.35 million in 2016 (3). The WHO report on Road Traffic Injuries notes that “progress has been achieved in important areas such as legislation, vehicle standards and improving access to post-crash care. This progress has not, however, occurred at a pace fast enough to compensate for the rising population and rapid motorization of transport taking place in many parts of the world” (3). Most motorized countries have reported reduction in fatalities, less motorized countries continue to report increase in road traffic fatalities.

However, pedestrian safety has been a difficult issue in all countries. European Union countries report “Deaths of unprotected road users have been decreasing at a slower rate than those of vehicle occupants. In the last ten years deaths among pedestrians decreased by 41%, those among cyclists by 37% and those among power two wheeler (PTW) users by 34% compared to a 53% decrease for vehicle occupants.” (4). NHTSA report stated for USA “Although pedestrian deaths were 20 percent lower in 2017 than in 1975, they have increased 45

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² Fatal crash with self-driving car was a first — like Bridget Driscoll’s was 121 years ago with one of the first cars. <https://www.washingtonpost.com/news/tripping/wp/2018/03/22/>

percent since reaching their lowest point in 2009".³ Low income countries continue to report increase in traffic fatalities and proportion of pedestrian fatalities have remained high (3).

This study looks at the pedestrian safety issue and the research that has followed to understand and solve the problem of pedestrian safety in the last 120 years. Section 2 presents number of pedestrians lost in different regions of the world. Pedestrian fatalities have reduced in high income countries, however at the same time number of pedestrians, school going or to work, have also reduced. Section 3 presents summary of research studies since 1950 that focused on understanding pedestrian behaviour. Section 4 presents a comparison of pedestrian crash patterns observed in earlier studies to what is observed in recent studies from different regions of the world. Section 5 summarize the suggested strategies to reduce pedestrian crashes which have ranged from controlling vehicular speeds to controlling pedestrian behaviour. Final section discusses the challenges to address pedestrian safety and new research areas.

2 NUMBER OF PEDESTRIANS LOST IN ROAD TRAFFIC CRASHES

In terms of pedestrian crashes on a worldwide scale, over 400,000 pedestrians die every year with over half of these deaths occurring in low-income countries (3). This may be an under estimation by at least 20 percent (5, 6). The latest WHO Global Status Report on Road Safety (3) has listed road traffic crashes (RTC) as the leading cause of death for the age group 5-29 years. With progress made in reducing deaths from communicable diseases, proportion of deaths from non-communicable diseases-injures has increased. Large variation has been observed in fatality rates amongst different regions of the world. Low and middle-income countries continue to report high fatality rates as compared to high income countries. The variation in death rates observed across regions and countries also corresponds with the differences in types of road users most affected (3). Globally pedestrians and bicyclists comprise of 26% of all road traffic deaths and MTW comprise of 28%. The report states 44% pedestrian fatalities in Africa and 14% for South East Asia. These numbers are based on government statistics. Bhalla, Khurana (6) have highlighted the underreporting of pedestrian crashes in India in government statistics. Other detailed studies (5) have reported at least 35% pedestrian share in fatalities in India. It is possible that the pedestrian deaths have higher underreporting as compared to other road users in other South Eastern countries too.

Around 138,400 pedestrians and cyclists lost their lives on EU roads between 2001 and 2013. 7,600 were killed in 2013 alone (4). Pedestrian and cyclists together accounted for 29% of the road traffic deaths in EU countries in 2016 (4). Pedestrians killed represent 21% and cyclists 8% of all road deaths. But big disparities exist between countries. ETSC reports that there is a high level of underreporting of collisions involving pedestrians and cyclists.⁴ ETSC reports show concern over the slow pace of decrease in the deaths of unprotected road users as compared to that of vehicle occupants. In the last ten years deaths among pedestrians decreased by 41%, those among cyclists by 37% and those among power two wheeler (PTW) users by 34% compared to a 53% decrease for vehicle occupants.

US reported an average of 6,000 pedestrian fatalities in 2016-17. The proportion of pedestrian fatalities increased from 14% in 2008 to 19% in 2017. The proportion of people killed "inside the vehicle" (passenger car, light truck, large truck, bus, and other vehicle occupants) declined from a high of 80% in 1996 to 67% in 2017. Conversely, the proportion of people killed "outside the vehicle" (motorcyclists, pedestrians, pedalcyclists, and other nonoccupants) increased from a low of 20% in 1996 to a high of 33% in 2017).⁵

3 PEDESTRIAN CRASH INVESTIGATIONS AND RESEARCH METHODS

First reported pedestrian crash of Bridget Driscoll was not a road traffic crash. It was in an exhibition ground. However, it was so unusual that the incident was sent to the Coroners court for full investigation. The investigation included the testimonies in the court of various witnesses. The witnesses were questioned and reported their observations about the vehicle speed "Florence Ashmore, a domestic servant who had witnessed the crash, said the vehicle had come on "at a tremendous pace, in fact, like a fire engine".⁶ The perception speed of this witness is interesting to note because the vehicle was designed for a maximum speed of 8 mph (13 km/h) and for demonstration the speed had been restricted to 4 mph (6.5 km/h).

³ 2017 Fatal Motor Vehicle Crashes Overview, <https://www.nhtsa.gov/press-releases/us-dot>

⁴ ETSC Report: Making Walking and Cycling on Europe's Roads Safer, www.pacts.org.uk/.../

⁵ U.S. DOT Announces 2017 Roadway Fatalities Down | NHTSA, <https://www.nhtsa.gov/press-releases/>

⁶ Fatal crash with self-driving car was a first — like Bridget Driscoll's was 121 years ago with one of the first cars. <https://www.washingtonpost.com/news/tripping/wp/2018/03/22/>

There were statements about the driver's abilities and training, "Witnesses testified that Edsall had been driving for all of three weeks time and had not even been told which side of the road he should stay on. (Perhaps unsurprising, he also had no license.)". Driscoll's daughter testified that he (the driver) didn't seem to know what he was doing — that he had zigzagged toward her mother and her — just before the crash. Witnesses were questioned whether the public had been given enough warning about the demonstration vehicle. John Wood, a foreman for workers at the Crystal Palace, testified that there were sufficient public notices in the area warning people of the automobile demonstration.⁷ The driver testified that he was going less than 4 mph (6.5 km/h). When he saw the lady in the path of the vehicle he had shouted "Stand back!", while ringing the car's bell. The vehicle hit the lady and the blow knocked Bridget Driscoll down, inflicting a fatal head injury. The driver right away hit the brakes. The jury deliberated for six hours and concluded that this was an "accidental" incident and hoped that this would not be repeated in future.

The framework of the investigation of this first pedestrian crash influenced the process of investigation for many years. Researchers and policy makers focused on "investigating" the role of driver, skills of driver, and "awareness or information" given to the road users to induce safe behaviour on the road. Some other observations from this incident included the possibility of fatality even at a low speed, consequences of head hitting a hard surface. For the next sixty years the role of speed, environment around the road user and road user behaviour after knowing the "correct information" continued to be ignored by most researchers.

Since 1950s some original experimental studies were done to understand pedestrian behaviour on the road (7, 8). Cohen, Dearnaley (8) observed the behaviour of pedestrians in the face of oncoming traffic. Measurements were made between the time elapsing between the pedestrian first observed the oncoming vehicle and the arrival of the vehicle at the crossing. The researchers studied the differences in crossing behaviour with age and sex. Haddon Jr, Valien (9) studied adult pedestrians who were fatally injured by motor vehicles in New York. The study was published in 1961 and it reported that of all the people who died in road traffic crashes in New York city in the years 1955-59, seventy percent were pedestrians. The study focus was to find out the characteristics of pedestrians who are involved in fatal crashes as compared to the ones who were not involved in such events though were similarly exposed. The study also noted that "despite this lack of scientifically gathered information large sums are spent annually throughout the United States in 'pedestrian control' programs, public exhortations, and other measures which though often reasonably have not been the subject of adequately designed evaluations. To the contrary, much has been made of short term fluctuations in incidence, both as evidence of the efficacy of such measures where the changes have been downward and, where the reverse has been the case, as evidence for their need."

The study was based on the premise that it was more important to understand the pedestrian characteristics and socio economic status of the pedestrian rather than the "pedestrian actions" (for example, 'disobeying given traffic regulation') which had been the focus of discussion for pedestrian safety. The study included investigation of post-mortem records of pedestrians involved in fatal crashes controlling for age. A control group was obtained by visiting the accident site on the same day of the week and as close to the time of reported crash to interview similar age people present on the location. Breath samples were also taken of the persons who were interviewed. The study resulted in a control or comparison group of 200 individuals. The results included purely descriptive and controlled observations. The study had noted the time period when majority of the crashes were taking place, weather was not found to explain the differences in patterns of the case and the control group, and presence of alcohol was more in the case group. Neither commuters nor visitors contributed to the fatally injured pedestrians and many of those killed were close to their residence.

These two studies made valuable contribution to the scientific study of cognitive and judgmental factors in traffic crash causation. Cohen, Dearnaley (7) noted the usefulness of models of decision making in risk situations which could help organize many diverse findings concerning individual behaviour in hazardous environment. These studies established methodology of conducting controlled observational studies which approach those of real life situations. The results included maximum risk taking behaviour (no one crossed the road when the vehicle was 1.5 seconds away and fifty percent of the sample crossed when the vehicle was 4.5 seconds away. Similar results have been found in later studies from many other regions of the world (10-12). Ishaque and Noland (13) reviewed a large number of studies of pedestrian crossing behaviour from different regions and different time periods. They conclude "The crossing of streets, which in some cases can be a risky endeavor for pedestrians, is clearly controlled by a consciousness of what those risks are. Gap acceptance rates suggest that pedestrians tend to choose safe crossing gaps and that individual gap acceptance levels are strongly

⁷ Fatal crash with self-driving car was a first — like Bridget Driscoll's was 121 years ago with one of the first cars. <https://www.washingtonpost.com/news/tripping/wp/2018/03/22/>

mitigated by individual capabilities. For example, older people, who walk slower, will select longer gaps. The width of the crossing point also affects gap acceptance rates, clearly showing awareness on the pedestrian's part of the risks they are taking (or in most cases, risks that are avoided through rational decisions)."

In the following decades researchers focused on studying pedestrian risk-taking behaviour by observing pedestrian behaviour while crossing the road (gap acceptance) or interviewing pedestrians regarding the perception of risk at various facilities. Researchers continued to observe pedestrians and young pedestrians (children) behaviour in traffic to suggest how the risk-taking behaviour could be altered. Sandels (14) published a seminal study in Sweden in 1968. This study tried to answer the question "What happens if children are too immature to be able to derive any benefits from the traffic instructions that is given to them?". Sandels attempted to answer this question because "when accidents involving children are discussed it is often said that these accidents are caused by children's carelessness, incautiousness, and rashness,"... "this identification of children with adults has produced the belief that the behaviour of young children in traffic could be made perfect by instruction, ...". The study focused on understanding the cognitive skills of children and limitations of young children. The main conclusion of this study was that children below the age of approximately 10 years do not have sensory or cognitive ability to cope up with modern traffic. Consequently, the remedial measures will have to be aimed primarily at segregating children and traffic. Sweden is the only country at present where children's traffic education is not part of the national traffic safety strategy (15). The finding was accepted and questioned at the same time. Van Der Molen (16) noted in 1981 "children can and do in fact, negotiate modern traffic to a considerable extent and that taking the full consequences of Sandels' solution would be both very expensive and socially disruptive".

Schieber and Thompson (17) reviewed a large number of studies on children's behaviour and traffic focusing on "the developmental attributes affecting the behavior of children that make them more likely to be struck by a vehicle." The study focused on normal developmental stages of children, how children of various ages behave in traffic, what tasks and skills are needed to negotiate traffic successfully and which are deficient, and the effectiveness of school-based methods intended to correct such deficiencies. The authors concluded "For a young child, the act of crossing a street is a conscious, problem solving situation, with each circumstance appearing to be unique". Authors posed the question: "Is a child ready and able to acquire the necessary skills through education or training, or should these approaches be made secondary to efforts designed to change driver behaviour, adult supervision, or the roadway environment?" After considering several factors to answer this question the conclusion was "A developmental perspective suggests that traditional pedestrian traffic education has limited value for young elementary school children, and that most efforts targeting this age group should be directed towards improving the roadway, vehicles, drivers, and adult supervision." The conclusions of this review perhaps have influenced many safe school programs, however attempts to modify education programs and methods to teach school children for improving traffic safety has continued.

With advancements in data collection and statistical techniques, researchers have focused on collecting more data of pedestrian behaviour in different environment and developed models to predict pedestrian risk-taking behaviour. Video cameras have been extensively used to monitor pedestrian behaviour (18-21). Pedestrian movements are being tracked using image processing techniques. Micro simulation techniques have been used to model and predict pedestrian behaviour (22). More advanced microscopic simulation techniques are exploited, namely multi-agent simulation systems, which are based on artificial intelligence concepts. In these systems, pedestrians are treated as fully autonomous entities with cognitive and often learning capabilities (23). Majority of the studies have focussed on pedestrian crossing behaviour in urban settings. Researchers have suggested to combine road crossing behaviour models with route choice behaviour to present a more comprehensive pedestrian behaviour (24-26). In one of the recent studies(27, 28) theory of planned behaviour has been applied to explain the pedestrian route choice behaviour.

Overall data collection techniques have changed, computational techniques and statistical methods have advanced. However, broad understanding of pedestrian behaviour that was reported in 1950-60s and 70s has more or less remained unchanged. More studies continue to be published on pedestrians differentiated by age and gender crossing urban roads.

4 PEDESTRIANS CRASH PATTERNS THEN AND NOW

Pedestrian crashes have been understood as an urban problem primarily. Waller (29) reported injury patterns of pedestrian in US and few other selected countries in 1980 . Pedestrians fatalities represented 18% of the total highway fatalities, whereas same year Kuwait share of pedestrian fatality was 58% , Nigeria 36%, and Malaysia 22%. In contrast to this, Sweden reported 10%. In US, 72% of the pedestrian fatalities were in urban areas. Havard showed that age specific fatality rates per 100,000 inhabitants were highest between age 6 and 9 (29). A

Swedish study found similar results between age 3 and 8 (29). These details were not available for low income countries in 1980.

Waller also reported that the risk of crashes and injuries was highest in dense areas, however, risk of fatal and serious injuries was higher in low density areas (29). This finding has been confirmed by many other researchers thirty years later (30, 31). US data showed in 2007 approximately 73% of pedestrian fatalities occurred in urban areas, largely because of the greater number of pedestrian trips in urbanized areas (32). Similar patterns were observed almost three decades back and reported by Waller (29). Zegeer and Bushell (32) reported although fewer pedestrian fatalities occur in rural areas, pedestrians are more than 2.3 times more likely to die from a pedestrian crash in rural areas than in urban areas. This is because rural areas have higher vehicle speeds combined with fewer separated facilities for pedestrians, such as sidewalks, trails, and paths, compared to urban areas.

In the EU, the risk of being killed as a pedestrian is consistently lowest for children, with 3.4 deaths per million child population, about half that for adults under 50 with 7.5 deaths per million adult population. The greatest risks of being killed as a pedestrian are for people aged 50-64 and especially for those over 65 with 13 and 28 deaths per million population in the age group respectively.

For the EU as a whole, over the period 2011 to 2013, 69% of all pedestrian deaths occurred on urban roads (4, 33). Given the high level of urbanization in Europe and frequent interaction between pedestrians and motorized transport in cities and towns, such a figure is not unexpected. In the EU, another 27% of pedestrian deaths occur on rural roads and 4% on motorways. Pedestrians are legally not allowed to use motorways, so the ones killed might be vehicle users who have left their vehicles for some reason or workers in work zones, along with some individuals who entered the motorway on foot illegally. There is extensive evidence to show that more males than females are being killed in road collisions in Europe which is also the case for pedestrians, but to a lesser degree than for all road users (4).

Large proportion of pedestrian deaths are reported in urban areas in LMICs (3). Unlike North America and Western Europe, pedestrian and motorcyclist involvement in fatal crashes on rural highways is greater than that of other road users.⁸ These highway crash patterns are similar to those observed in urban areas.

Some common patterns of pedestrian crashes were identified by Waller (29). These include: a small child darts into the road from between two cars or other obstacles on the road, clustering of fatally injured elderly pedestrians when they have to cross a road for essential shopping, higher proportion of pedestrian fatally injured with high blood alcohol levels. Hunter investigated pedestrian crashes in 1996 (34). Some of the most frequent pedestrian crash types include dart-out in first half of the street (24%), intersection dash (13%), dart-out in second half of the street (10%), midblock dart (8%), walking along roadway (7.4%), and turning-vehicle crashes (5%). Similar patterns have been reported from China (35), Turkey(36), and Israel (37).

Prato, Gitelman (37) reviewed studies on pedestrian crash patterns in 2012 and reported that the main interest had shifted from analysing child pedestrian and elderly to patterns of pedestrian vehicle interaction. The most common factors used to characterize pedestrian accidents have been age, gender, intoxication of pedestrians by alcohol or drugs, location in urban residential areas, fault of pedestrians and drivers and type of vehicle involved. The study applied neural network technique to find out most recurring patterns in pedestrian crashes. The results showed 72 percent crashes in urban areas in Israel. Five distinct clusters were identified- pedestrian urban elderly, pedestrian two-wheel vehicles, pedestrian rural night, pedestrian youngsters night, pedestrian rural children. The study confirmed the patterns found earlier: (i) elderly pedestrians crossing on crosswalks in metropolitan areas, mostly far from intersections; (ii) pedestrians crossing suddenly or from hidden places and colliding with two-wheel vehicles on urban road sections; (iii) male pedestrians crossing at night and being hit by four-wheel vehicles on rural road sections; (iv) young male pedestrians crossing at night wide road sections in both urban and rural areas; (v) children and teenagers crossing road sections in small rural communities.

Recent studies have reported pedestrians facing high risk near bus stops in urban areas (38-40). Some new emerging patterns of pedestrian crashes which have not been reported in published studies include pedestrian fatalities on access control expressways in India, pedestrians waiting along the shoulder of a high-speed road to board buses.

⁸ Principles for development of safer rural highway systems for conditions prevailing in low and middle-income countries, <https://www.icorsi.org/scientific-papers-international-sym>

Overall, pedestrian death reduced in the US, EU countries and Australia as compared to LMICs. However, travel surveys from Australia, EU and US also show decrease in pedestrian trips at the same time. School active transport generally declined for males and older female children (19 and 20 percentage points per decade, respectively) between 1985 and 2003 and 2013 in Australia (41). Estimates from the UK suggest that the number of trips on foot per person fell by 20% between 1985/86 and 1997/99 (42). Stewart, Moudon (43) report that active travel to school in the U.S. have declined, from 47.7 percent in 1969 to 12.7 percent in 2009, while rates of students being driven to school in the family car have increased in mirrored proportions. According to US Department of Transportation's 2001 National Household Travel Survey only a small percentage of the population reported any walk trips during the sample day; about 84% listed no walk trips in their daily trip diary. A separate question on the number of walk trips made in the past week revealed that Americans on average take 3.8 walk trips per week (44). The Swedish national travel survey 2015–2016 shows that for all types of travel (business, work and study-related, service and shopping, leisure and other purposes) walking and cycling trips were only 27% of all trips.

Reduction in pedestrian trips is a matter of concern both from lack of active transport resulting in adverse impacts of health (45) and also the effectiveness of strategies which have been implemented for improving pedestrian safety.

5 SUGGESTED STRATEGIES – WHAT HAVE WE LEARNT

5.1 Speed control

Speed is an important factor affecting road accidents both in terms of accident occurrence and severity (46). It seems reasonably safe to assume that increased speed would mean that the accidents that have occurred would be more severe, if other factors (e.g., environment and vehicle design) remain the same. Large number of studies have shown this by both Newtonian physics and empirical data (47-50). Pedestrians, bicyclists and motorcyclists are more vulnerable to impact speeds as compared to vehicle occupants. For many years 30 km/h was considered the safe speed for pedestrians with less than 10 percent chance of fatal injury (51). A recent study analysed Swedish data and reported “the data indicates that fatal accidents (excluding runover accidents) are rare at mean travel speeds below 40 km/h, while severe injury accidents are quite frequent at mean speeds below 35 km/h but rare at mean travel speeds below 25 km/h (51). Therefore, the current speed policies (frequently 30 and 50 km/h speed limits in urban areas) might need revision.”

We recall the details of the first reported pedestrian crash where the victim was hit at a speed of 4 mph (6.5 km/h) as reported by the witnesses. Current research shows impact of several other factors such as the vehicle design, impact surface properties, victim age etc. With the increase in the presence of elderly pedestrians on the road, perhaps there is a need to rethink urban speed limits.

5.2 Environmental factors

One of the earliest study on pedestrian crashes reported “Pedestrians are often asked to decide between the easy and quick way to safe way” (29). Repeated empirical studies have shown that pedestrians chose the former. Often grade separation between pedestrian and vehicular movement has been suggested in urban area as well as on highways in LMICs to improve pedestrian safety. This involves constructing foot over bridges or underpasses. Empirical studies have been carried out in different regions and settings to understand pedestrian behaviour at zebra crossings at grade, foot over bridges and under passes. Cantillo, Arellana (52) reviewed a large number of studies on pedestrian crossing behaviour in urban environments and concluded pedestrian crossing behaviour is affected by socioeconomics (e.g. age, gender), traffic characteristics (e.g. speed and flow), the road environment (e.g. crossing walking distance, presence of traffic/pedestrian control devices and signals, presence of crossing facilities), and subjective factors (e.g. perceptions and attitudes). This study found that additional walking distance to cross the road over the pedestrian bridge is less appealing than using a zebra when available; even if it is less attractive when compared to crossing directly somewhere on the road. This effect could be explained by the additional effort needed to climb and descend stairs in a pedestrian bridge. Cantillo, Arellana (52) reported that “the respondents state a general dislike to walk additional distances to cross the street using the ‘safer’ alternatives (i.e. pedestrian bridge and crosswalk at the intersection). To some extent, respondents prefer to walk towards an intersection rather than going towards a pedestrian bridge to cross.” Model results suggest that pedestrians are willing to take less risk when traveling with a minor. The presence of a minor increases the probability of using safer crossings; in fact, the direct crossing alternative became less attractive. The probability of being delayed also has an important effect on the decision. Pedestrians are more prone to use the alternative route involving less walking distance (crossing directly). The authors concluded that “...a largest distance diminishes the probability for the individual to choose safer alternatives. It is observed that

this effect is more relevant for the case of the pedestrian bridge than for the signal crossing, which may be explained by the extra effort involved in climbing stairs. This finding suggests that pedestrian bridges should only be considered in extreme cases, as they seem to be a non-effective crossing facility. To solve conflicts between traffic and pedestrian flows it is preferable to propose at level signalized crossings along with underpass/overpass roads, when necessary.”

The conflict of pedestrian and vehicular traffic on high speed roads observed in LMICs and also the presence of pedestrians along the high speed roads require further research and understanding for a successful strategy.

5.3 Training and education

Several detailed studies have repeatedly highlighted the limitation of school education and training programs, yet a 2004 report prepared by EU experts (15) noted “Traffic and pedestrian safety education were a part of the school programs for children (ongoing throughout their school years) in some of these countries, and government-sponsored marketing and safety education campaigns were a high priority. In countries like England, traffic safety campaigns are unified under a single national brand for numerous safety focus areas.” Pucher and Dijkstra (53) examined safety trends in both the Netherlands and Germany and came to a similar conclusion; both of these nations provide very successful examples that strict traffic law enforcement and rigorous traffic education for drivers and pedestrians can increase pedestrian and bicycle safety dramatically. The report also mentioned long list of measures which were implemented to create safe infrastructure in these countries, active traffic calming measures introduced to control speeds of vehicular traffic. Separate impact of different measures on safety outcome is not discussed and it is difficult to make a case for prioritizing different measures as required by most LMICs due to limited resources. In fact, education and training is often considered as a low hanging fruit requiring less resources and becomes the priority for many national strategies (32).

There are few attempts to add qualifiers to the success of training strategies and therefore the importance of education and training programs.⁹ The WHO manual on pedestrian safety mentions “Changing the attitudes and behaviour of drivers and pedestrians is a complex, long-term undertaking that requires a variety of interventions to be implemented. Measures commonly used to raise awareness and modify behaviour are discussed in the following sections. These measures are most effective when implemented alongside other measures described in this module such as speed management and reducing pedestrian exposure to vehicular traffic”.¹⁰

The limitations of human cognitive skills and capability of judging risk was established almost fifty years back (7, 8, 14). Recent studies have mentioned the limitations and effectiveness of education programs. However, researchers and policy makers continue to include education and training as a possible strategy to reduce pedestrian crashes.

6 CHALLENGES

Much progress has been made in understanding pedestrian behaviour and risk that pedestrians are exposed to in traffic, however not enough success has been achieved in reducing pedestrian crashes both in motorized as well as less motorized countries. Motorized countries continue to report high proportion of pedestrian fatalities in urban areas. These patterns have not changed since 1970s. There is a large body of research available on understanding pedestrian behaviour and exposure to risk from these countries. Researchers made valuable contribution in documenting characteristics of pedestrians, and location of pedestrian crashes in urban settings. More importantly, limitations of cognitive skills of children pedestrian and elderly pedestrians were documented. Since 1990 we find similar research studies coming from less motorized countries also. Studies from China, India, Israel show similar results of gap acceptance by pedestrians while crossing the road, reluctance to use grade separated pedestrian facilities. There seems to be little difference in cognitive skills of pedestrians across different regions of the world. There are differences in location of pedestrian crashes in less motorized countries as compared to motorized countries. Pedestrian are fatally injured on highways in less motorized countries in much higher proportion as compared to motorized countries. Presence of pedestrians is much higher on high speed road in less motorized countries.

New research is required to make cities safer for pedestrians in all countries- revisiting current speed limits, lower speed limits, and active measures to control speeds. There is consensus on urban design principles which can lead to safer cities - higher mixed land use density - the condition already present in less motorized

⁹ Pedestrian safety: a road safety manual for decision-makers ..., <https://www.who.int/roadsafety/projects/manuals/pedestrian/en/>

¹⁰ *ibid.*

countries. New research is required to get insights from these settings and understanding of barriers to implementation of these principles.

Less motorized countries have to make greater efforts to understand the requirements of pedestrians along high-speed roads and develop new standards for ensuring pedestrian safety in such locations. Despite continuous efforts of over more than a century, the first reported accident of pedestrian continues to pose challenges to the researchers.

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China Powered-Two-Wheeler (PTW) Accident Investigation and Analysis

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Abstract

An e-bike is a powered two-wheel vehicle (PTW). It has been reported that more than 180,000 PTW users die in traffic accidents annually throughout the world, with most deaths occurring in middle income countries. Since 1994, many cities in China have successively banned/limited motorcycles in urban areas. As a substitute, electric two-wheelers (E2W, e-bikes or e-scooters) prevail. In China, nearly 70% of traffic fatalities are vulnerable road users (VRUs), of which two wheelers account for nearly 40%, and pedestrians, 25%. Rapid development of both pedestrian passive and active countermeasures, such as pedestrian bonnets/airbags, night vision and autonomous braking, is under way. In China, a conservative estimate shows that roughly 140 million e-bikes are in service, for transportation rather than recreation. According to national regulations (GB17761-1999), an e-bike is required to have a bicycle-style design with functioning pedals, a weight of less than 40kg, and a maximum speed of 20 km/h.

This classification allows an e-bike to run on bicycle lanes, and is considered a bicycle from a regulatory perspective (i.e. registration, helmets and driver's licenses are not required). However, regulations are poorly enforced. Faster and heavier e-bikes that mimic gasoline-driven mopeds are now prevalent. Most e-bike drivers in China are untrained, uneducated and unlicensed. Nevertheless, e-bikes are momentarily the best and most affordable transportation options for normal income families. According to official Chinese data, deaths of e-bike drivers increased from 589 to 4,029 from 2004 to 2010.

The aim of this study was, therefore, to investigate e-bike road traffic safety based on real accidents from China In-depth Accident Study (CIDAS) database. An overview of the findings and a case-by-case reconstruction was conducted. An analysis was carried out based on the results from the overview of the findings and reconstruction of pre-crash and crash parameters. Accident scenarios, traffic control, road and junction type, accident causation, injury severity, and distribution of injury by body part were evaluated. Head contact points against windscreen and screen frame were plotted schematically on a standard vehicle. According to pre-crash parameters, detection of motion in the field-of-view was studied by the sampled accidents.

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Second Thoughts on Safety-in-Numbers Phenomenon: Counterevidence from an Area with Low Pedestrian Activities

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Abstract

The safety-in-numbers effect has been found, which is a phenomenon that when the number of pedestrians or cyclists increases, their crash rates decrease. The previous studies used data from highly populated areas. It is questionable that the safety-in-numbers effect is still observed in areas with a low population density and small number of pedestrians. Thus, this study aims at analyzing pedestrian crashes in a suburban area in the United States and exploring if the safety-in-numbers effect is also observed. We employ a Bayesian random-parameter Poisson-lognormal model to evaluate the safety-in-numbers effects of each intersection, which can account for the heterogeneity across the observations. The results show that the safety-in-numbers effect were found only at 32 intersections out of 219. The intersections with the safety-in-numbers effect have relatively larger pedestrian activities whereas those without the safety-in-numbers effect have extremely low pedestrian activities. It is concluded that just encouraging walking might result in serious pedestrian safety issues in a suburban area without sufficient pedestrian activities. Therefore, it is plausible to provide safe walking environment first with proven countermeasures and a people-oriented policy rather than motor-oriented. After safe walking environments are guaranteed and when people recognize that walking is safe, more people will consider walking for short-distance trips. Eventually, increased pedestrian activities will result in the safety-in-numbers effects and walking will be even further safer.

Keywords: pedestrian safety, pedestrian activities, safety-in-numbers

1. INTRODUCTION

Recently, walking and cycling have been encouraged because not only they are economically and environmentally sustainable but also they can improve public health of the society. Nevertheless, the high crash risk of the pedestrians and cyclists have been a deterrent for people to select walking and cycling as their major transportation mode. Thus, there have been many efforts to identify factors increasing crashes involving vulnerable road users, and suggested countermeasures to improve their safety. Some previous studies have found that when the number of pedestrians or cyclists increases, their crash rates (i.e., the number of crashes involving pedestrians or cyclists per the number of pedestrians or cyclists) decrease. It means that the probability of crash involvements per vulnerable user would be decreased if the number of pedestrians or cyclists increases. This phenomenon is called safety-in-numbers (SIN). There had been difficulties to analyze the SIN effect because the number of pedestrian trips is hard to obtain in the previous studies. For this reason, some used population, population density, or land-use (e.g., residential, commercial) as a surrogate measure for pedestrian trips (1-7). In the recent two decades, several researchers successfully collected pedestrian trip data and explored the SIN effects. Jacobsen (8) found the SIN effect for walking and cycling. He discussed that pedestrians and bicyclists are not supposed to be more cautious if their numbers are larger. Instead, it is plausible that the behavior of drivers control the probability of crashes with pedestrians and bicyclists. It indicates that drivers change their behavior in the presence of many pedestrians and bicyclists. Elvik (9) also argued that if there are many pedestrians or cyclists, drivers would expect to encounter them and interact with them, which could strengthen the SIN effect. In the recent two decades, the SIN effects for pedestrian safety have been confirmed in multiple studies (8-19).

The following equation shows the relationship between the number of pedestrian crashes and vehicle and pedestrian exposure:

$$Y_i = \exp^{\beta_0} Veh_i^{\beta_1} Ped_i^{\beta_2} \exp(\beta X_i) \quad (1)$$

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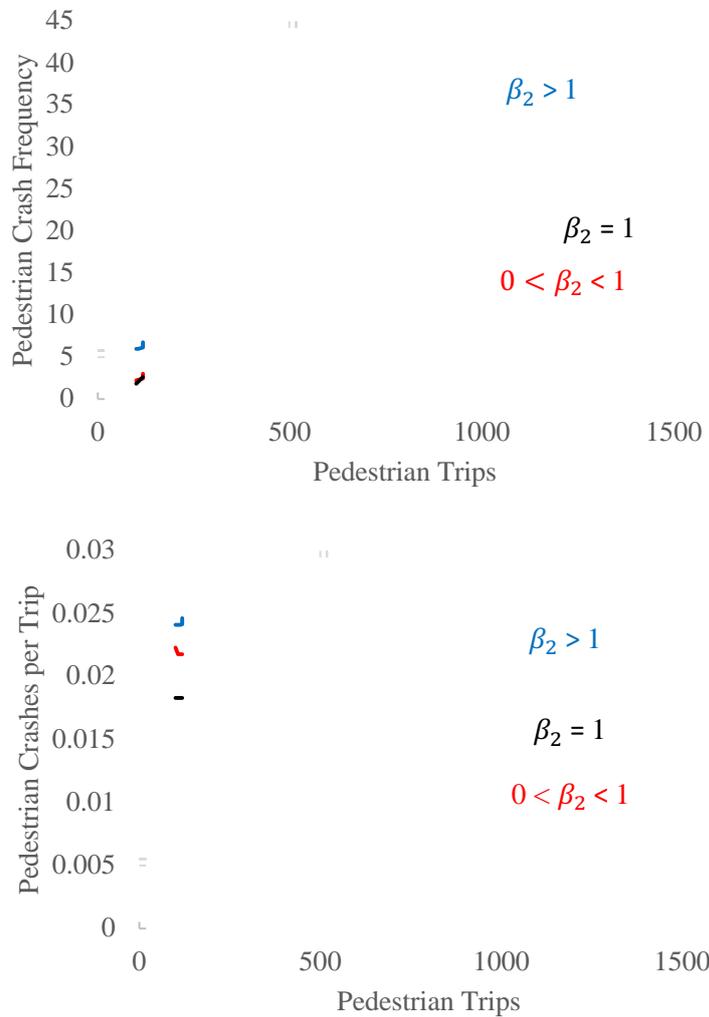
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where,

- Y_i is the number of pedestrian crashes,
- β_0 is the intercept,
- β_1 is the exponential coefficient of vehicle volume,
- β_2 is the exponential coefficient of pedestrian trips,
- β is a vector of parameters to be estimated,
- and X_i is a vector of independent variables.

As shown in Figure 1, the shape of the curves is determined by the range of β_2 . The upper graph of Figure 1 indicates the relationship between the number of pedestrian crashes and pedestrian trips, and the lower graph illustrates the relationship between the pedestrian crash rate (pedestrian crashes per trip) and pedestrian trips. If β_2 is greater than one, the pedestrian crash rates would increase as pedestrian trips increase. On the other hand, if β_2 is exactly one, the crash rate is constant. Lastly, if β_2 is less than one (and greater than zero), the crash rate would decrease as pedestrians increase, which is the SIN effect. Table 1 summarizes the studies that found the SIN effects for pedestrian safety in the past two decades. As seen in the previous studies, the findings are quite consistent. However, those studies used data from metropolitan areas with a high population density. Therefore, a question arise: is the effects of the safety-in-numbers observed in less populated areas as well? In order to answer the research question, we have collected data from a suburban area in Central Florida of the United



States: Seminole County.

Figure 1: Graphical description of safety-in-numbers for pedestrian safety

Table 1: Studies reporting the safety-in-numbers (SIN) effects in the recent two decades

Study	Region	Study period	Observations	Outcome measures	Confounders controlled					
					Motor vehicle	Pedestrian	Geometric design	Traffic control	Land use	Demographic
Leden (10)	Hamilton, Ontario, Canada	1983-1986	749 signalized intersection approaches	Crashes between pedestrians and left-turning vehicles	1.19**	0.33**				
			126 signalized intersection approaches	Crashes between pedestrians and right-turning vehicles	0.86**	0.48**				
Jacobsen (8)	68 cities in California	2000	68 cities	Pedestrian injuries per capita		0.41** (0.066)				
	47 Danish towns	1993-1996	47 towns	Pedestrian injuries per capita		0.36 (0.235)				
	8 European countries	1998	8 countries	Pedestrian fatalities per capita		0.13 (0.434)				
Zegeer et al. (11)	28 cities	1994-1998	1,000 marked crosswalks	Pedestrian-vehicle crashes	0.99** (0.17)	0.33** (0.06)	✓			
			1,000 unmarked crosswalks		0.55** (0.26)	0.64** (0.13)	✓			
Geyer et al. (12)	Oakland, California	2000-2002	247 intersections	Pedestrian-vehicle crashes	0.15 (0.12)	0.61** (0.12)	✓		✓	
Daniels et al. (13)	Flanders, Belgium	1996-2004	90 roundabouts	Crashes involving injured pedestrians	2.77**	0.27**	✓			
Schneider (14)	Alameda, California	1998-2007	81 intersections	Pedestrian-vehicle crashes	1.50** (0.43)	0.58** (0.16)	✓	✓	✓	✓
Miranda-Moreno et al. (15)	Montreal, Quebec, Canada	1999-2003	519 signalized intersections	Pedestrian-vehicle crashes	0.90**	0.26**		✓	✓	✓
Elvik et al. (16)	Oslo, Norway	2004-2008 2006-2010	159 marked pedestrian crossings	Pedestrian-vehicle crashes	0.53** (0.17)	0.76** (0.11)	✓			
Kröyer (17)	6 cities, Sweden	2008-2012	113 intersections	Pedestrian-vehicle crashes	0.65 (0.53)	0.55** (0.27)	✓			
Tasic et al (18)	Chicago, Illinois	2005-2012	801 census tracts	Pedestrian-vehicle crashes	0.049* (0.028)	0.295* (0.036)	✓	✓	✓	✓
Xu et al. (19)	Hong Kong, China	2010-2012	288 signalized intersections	Pedestrian-vehicle crashes	0.271** (0.078)	0.213* (0.051)	✓	✓		

Note: S.D. refers to the standard deviation. In Leden (10), Daniels et al. (13) and Miranda-Moreno et al. (15), the standard errors of the corresponding coefficients were not reported. ** and * denote statistical significance at the 95% and 90% confidence levels, respectively.

In Seminole County, most of the households have at least one available vehicle (96.4%) and very few people choose walking as the commute mode of transportation (0.7%) compared to the whole United States, Florida, and other counties (see: Figure 2). In the United States, about 91% of households have an available vehicle and 2.8% of people walks to their workplace. In Florida, the higher percentage of household have an available vehicle (93.1%) and the lower percentage of people choose walking for commute (1.5%). Thus, Seminole County is an appropriate study area to investigate the SIN effects of an area with a small number of pedestrians.

2. METHOD

2.1 Data collection

The data were collected from 219 intersections in Seminole County in Central Florida, United States. Crash data of 2014-2017 (four years) were acquired from the Signal Four Analytics archived by the University of Florida GeoPlan Center. Land-use data of 2017 were acquired from the Florida Department of Revenue. The proportion of each land-use type within a half mile radius from the center points of the intersections was calculated and attempted in the crash model. Speed limit data were collected from NAVTEQ, and all other information (e.g., legs, crosswalks, skew angle, curve, ramp) were manually collected using Google Earth.

Pedestrian and traffic data of 2017 were collected from the Automated Traffic Signal Performance Measures (ATSPM) system of Seminole County. The ATSPM is promoted by the Federal Highway Administration as a mean to enhance the traditional retiming process by providing continuous performance monitoring capability (20). Pedestrian related data were collected from the ATSPM: “Pedestrian Logs” which is the number of actual pedestrian phases activated. The average pedestrian phases provided (ADPP) were calculated from “Pedestrian Logs”. In this study, ADPP was used as an exposure for pedestrian trips. Average daily traffic volume of the intersections in this study is total entering vehicles, which was also collected from ATSPM. The descriptive statistics of the collected and processed data are summarized in Table 2.

Table 2: Descriptive Statistics

<i>Continuous variables</i>	Mean	Std Dev	Min	Max
Pedestrian crashes	0.288	0.732	0.000	7.000
Average daily pedestrian phases requested (ADPR)	41.372	39.923	4.844	240.832
Average daily pedestrian phases provided (ADPP)	44.490	40.995	5.830	243.964
Average daily traffic volume (ADT)	53888	34627	2131	183155
Proportion of residential land-use within a half mile radius	0.338	0.153	0.008	0.699
Proportion of commercial land-use within a half mile radius	0.183	0.131	0.000	0.606
Proportion of industrial land-use within a half mile radius	0.030	0.053	0.000	0.331
Proportion of institutional land-use within a half mile radius	0.025	0.031	0.000	0.165
Proportion of governmental land-use within a half mile radius	0.053	0.049	0.000	0.328
Proportion of agricultural land-use within a half mile radius	0.016	0.035	0.000	0.206
Proportion of school land-use within a half mile radius	0.021	0.035	0.000	0.189
<i>Categorical variables</i>	Category	Frequency	Percent	
Number of legs	3	35	15.98%	
	4	184	84.02%	
Number of pedestrian crosswalks	1	12	5.48%	
	2	52	23.74%	
	3	48	21.92%	
	4	107	48.86%	
Speed limit category of the major approach	55-64 mph	2	0.91%	
	41-54 mph	152	69.41%	
	31-40 mph	53	24.20%	
	21-30 mph	12	5.48%	
Speed limit category of the minor approach	41-54 mph	11	5.02%	
	31-40 mph	36	16.44%	
	21-30 mph	134	61.19%	
	6-20 mph	32	14.61%	
	Less than 6 mph	6	2.74%	
Whether the speed limit categories of major and minor approaches are same	Yes	24	10.96%	
	No	195	89.04%	
Skewed intersection	Yes	56	25.57%	
	No	163	74.43%	
Curved intersection	Yes	102	46.58%	
	No	117	53.42%	
Located at an interchange ramp	Yes	11	5.02%	
	No	208	94.98%	

2.2 Statistical methodology

This study employed a Bayesian random-parameter Poisson-lognormal model to explore the SIN effects in the study area. Poisson-lognormal models have been used as an alternative to Poisson models to account for the over-dispersed crash data (1, 3, 4, 21-26). A Poisson-lognormal model is specified as follows:

$$y_i \sim \text{Poisson}(\lambda_i) \tag{2}$$

$$\lambda_i = \exp(\beta X_i + \theta_i) \tag{3}$$

$$\theta_i \sim \text{Normal}(0, 1/\tau_\theta) \tag{4}$$

where X_i is a vector of independent variables,
 β is a vector of parameters to be estimated,

θ_i = error component of the model, and
 τ_θ = precision parameter (inverse of the variance), which follows a prior gamma (0.001, 0.001).
 The variance, $1/\tau_\theta$, provides the amount of variations that is not explained by the Poisson assumption (27).

In order to account for heterogeneity across observations, random parameters were estimated for intercept and the log of the average daily pedestrian phases provided (ADPP). The random parameters are formulated as follows (26, 28-31):

$$\beta_i = \beta + \varphi_i \tag{5}$$

where φ_i is a random distribution term following $Normal(0, \sigma^2)$.

The model was run considering informative normal priors for β s using MCMC (Markov Chain Monte Carlo) method. The informative priors were obtained from the preliminary non-Bayesian negative binomial models that were estimated by maximum likelihood estimation (32). The significance of the parameters was determined based on Bayesian confidence interval (BCI). The BCI infers on the true parameter value. For example, a 95% BCI contains the true parameter value with approximately 95% certainty. The final model was chosen based on deviance information criterion (DIC) as follows (33):

$$DIC = 2 \times \bar{D} - \hat{D} \tag{6}$$

where, \bar{D} is the posterior mean of deviance D , $\hat{D} = 2 \times p(y|\bar{\theta})$, and $\bar{\theta}$ is the posterior mean of θ .

3. RESULT

3.1 Modeling result

Table 5 presents the modeling results. The final model was chosen based on the value of DIC (255.357) and its R^2 was 0.558. ‘Log of average daily pedestrian phases provided (ADPP)’ has a positive association with the number of pedestrian crashes, with 95% Bayesian credible interval. The variable led to a random parameter with a mean of 1.014 and a standard deviation of 0.092. It indicates that the SIN effects vary from intersection to intersection. More detailed discussions on the SIN effects are provided in the discussion. ‘Log of daily average traffic volume (ADT)’ was found credible at 95% and has a positive effect, as expected. In addition, ‘Number of pedestrian crosswalks’ and ‘Located at an interchange ramp’ are positively associated with the number of pedestrian crashes. On the other hand, ‘Whether the speed limit categories of major and minor approaches are same’ and ‘Curved intersection’ are negatively associated with the number of pedestrian crashes. None of land-use variables were included as they are either highly correlated with the ADPP or insignificant.

Table 5: Bayesian random-parameter Poisson-lognormal model for pedestrian crashes

Variable	Mean	S.D.	Bayesian Credible Interval			
			2.5%	5.0%	95.0%	97.5%
Intercept	-9.849**	1.211	-13.130	-12.510	-8.048	-7.377
<i>random parameter: s.d. of intercept</i>	0.234**	0.211	0.027	0.033	0.685	0.788
Log of average daily pedestrian phases provided (ADPP)	1.014**	0.221	0.585	0.630	1.346	1.413
<i>random parameter: s.d. of average daily pedestrian phases provided (ADPP)</i>	0.092**	0.052	0.025	0.029	0.192	0.216
Log of daily average traffic volume (ADT)	0.310**	0.130	0.028	0.090	0.531	0.577
Number of pedestrian crosswalks	0.408**	0.220	-0.004	0.056	0.774	0.852
Whether the speed limit categories of major and minor approaches are same	-0.867*	0.599	-2.118	-1.900	0.057	0.201
Curved intersection	-0.767**	0.328	-1.425	-1.316	-0.238	-0.128
Located at an interchange ramp	1.230**	0.705	-0.236	0.045	2.318	2.543
<i>s.d. of θ</i>	0.250**	0.228	0.027	0.033	0.726	0.849
DIC	255.357					
R^2	0.558					

** credible at 95% level, and * credible at 90% level.

3.2 Analysis of the safety-in-numbers for pedestrian safety

From the modeling result, the coefficient of ADPP each intersection was obtained. If the coefficient of ADPP is one or greater at an intersection, the intersection does not show the SIN effect. On the other hand, if the coefficient is smaller than one, we can determine that the SIN effect was observed at the intersection. As shown in the modeling results, the SIN effects for pedestrian safety was not observed in all intersections in the study area. Out of 219 intersections, only 32 intersections had the SIN while 187 did not. We made an assumption that the SIN effects are not shown because the pedestrian activities in the study area are very low. We conducted two statistical tests to prove the assumption: t-test and Chi-square test with contingency table. The following t-test compared the numbers of ADPP between the two types of intersections (No SIN vs. SIN) (Table 6). The test

indicates that the mean ADPP of the intersections without the SIN effect (37.781) is significantly smaller than that of the intersections with the SIN effect (83.701), as t-statistics is -4.849 ($p < 0.001$).

Table 6: t-test comparing the average daily pedestrian phases provided (ADPP) between the intersections without and with the safety-in-numbers (SIN) effects

Statistics	No SIN observed	SIN observed
Mean	37.781	83.701
Variance	1216.397	2661.164
Observation	187	32
d.f.		36
t-statistics (p)	-4.849 ($p < 0.001$)	

From the previous t-test, we found that the intersections with the SIN effect tend to have higher pedestrian volumes while those without SIN are likely to have lower pedestrian volumes. We further conducted a Chi-square test with contingency table to confirm the finding. Intersections in the study area have been classified into three groups based on their pedestrian volumes. The SIN effect by the intersection classification was summarized in the contingency table and the Chi-square value was presented accordingly (Table 7).

Table 7: Chi-square test with contingency table

Classification	ADPP Range	No SIN	SIN	Sum	Percentage of the intersections with no SIN effect
High pedestrian volumes (> 75 percentile)	ADPP > 60.31	37	18	55	67%
Medium pedestrian volumes (Between 75 percentile and 25 percentile)	16.91 < ADPP ≤ 60.31	96	13	109	88%
Low pedestrian volumes (≤ 25 percentile)	ADPP ≤ 16.91	54	1	55	98%
Sum		187	32	219	85%
$\chi^2=2.311$ ($p < .0001$)					

The Chi-square test showed that the proportions of the SIN effects are significantly different by the classification. Among the intersections with high pedestrian volumes, 67% of them did not show the SIN effects. The percentage of the intersections with non-SIN effects is higher at those with medium pedestrian volumes, 88% (97/109). Furthermore, among those low pedestrian volumes, the percentage of non-SIN effect intersections is 98% (54/55).

From these results, it could be concluded that it is not always true that intersections with high pedestrian activities have the SIN; but there is a tendency that intersections with lower pedestrian activities to not have the SIN effects, in most of the cases. The intersections classified by pedestrian volume and the SIN effects are illustrated in the map in Figure 3.

4. DISCUSSION

The safety-in-numbers is a phenomenon that when the number of pedestrians or bicyclists increases, their risk (or crash rate) decreases. In other words, pedestrians or bicyclists would be safer from traffic crashes if their number increases as drivers would be more cautious for them. The SIN effects for active modes of transportation have been confirmed by many previous studies. In this study, we focused on the SIN effects for pedestrians in areas with a low population density and low pedestrian activities. We collected data from a suburban county of Central Florida of the United States. A Bayesian random-parameter Poisson-lognormal model was estimated to account for the possible different SIN effects across the intersections. The modeling results revealed that the natural logarithm of pedestrian activities led to a random parameter with a mean of 1.014 and a standard deviation of 0.092, which shows that the SIN effects vary from intersection to intersection. It was shown that only 32 intersections among 219 had the SIN effects. The intersections with the SIN have relatively larger pedestrian activities whereas those without the SIN have very low pedestrian activities, which were confirmed by the t-test and Chi-square tests.

The findings from this study have an important policy implication that just aiming to encourage people to walk in a regions with an extremely low pedestrian activities cannot reduce the pedestrian safety risk until the pedestrian activities increase to a sufficient level. Therefore, on one hand, it is required to encourage more people to walk. On the other hand, it is also required to establish and implement an effective plan and

engineering treatments to minimize traffic crashes involving pedestrians, especially in areas with small number of pedestrians. Nevertheless, further follow-up studies might be needed to confirm the findings using data from other regions with various levels of pedestrian activities.

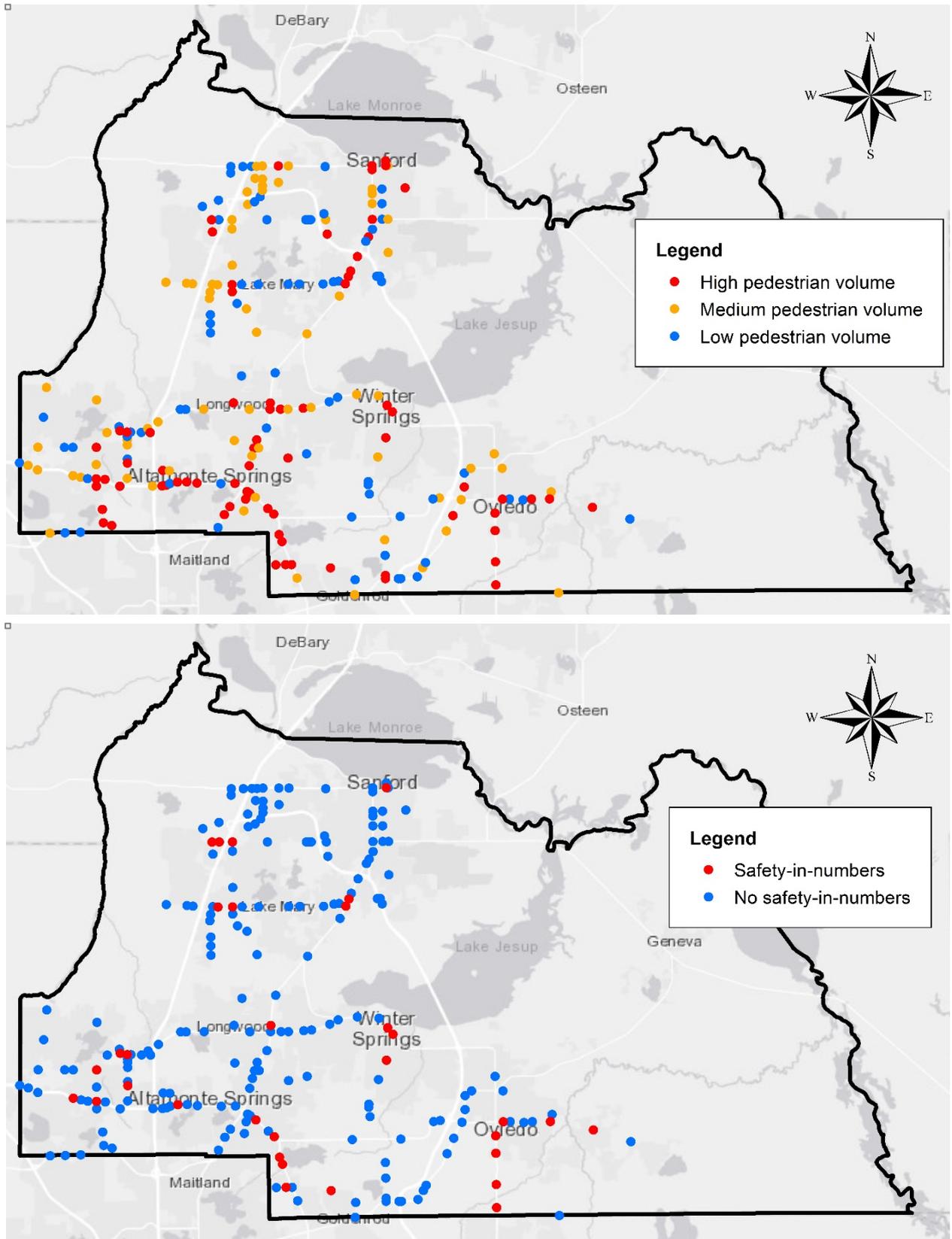


Figure 3: Intersections classifications (upper) and SIN effects (lower) in Seminole County

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Risk perception and responsibility attribution concerning pedestrian-vehicle crashes among children, adolescents and young adults in China

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Abstract

Objective. Child pedestrian injuries in China result from crashes not just with cars. We considered how Chinese youth and young adults perceive pedestrian risk from four vehicle types—bicycles, electric bicycles, cars, buses—evaluating perceptions for two factors that may influence pedestrian behavior and risk-taking: perception of road environment risk and responsibility to avoid crashes. *Methods* 383 children (grades 3-4, 5-6, 8) and university students completed self-report surveys. We analyzed overall responses, plus age/gender differences in risk perception and responsibility attribution, across vehicle types and number of vehicles approaching, using MANOVA and GEE models. *Results* Overall, larger vehicles were perceived as more risky ($p<.001$). Compared to children, university students perceived bicycles and electric bicycles as less risky ($Mean=2.66$ vs. 3.69 , 3.34 vs. 3.62 , respectively, $p<.05$). Cars and buses were perceived as equally risky across age groups. Across all vehicle types and number of vehicles traversing the road, both children and young adults perceived more pedestrian responsibility to avoid collisions relative to drivers ($p<.001$). Children attributed less personal responsibility to avoid pedestrian-vehicle crashes than university students (e.g., buses $OR=0.20$, $p<.001$; $OR=0.26$, $p<.01$; $OR=0.28$, $p<.01$ for third/fourth, fifth/sixth, eighth graders, respectively). University students and fifth/sixth graders also identified greater pedestrian responsibility to avoid collisions with multiple vs. one vehicle approaching (e.g., university students/cars $OR=4.17$, $p<.001$). *Conclusions* We discuss cognitive and perceptual development factors in childhood, adolescence, and young adulthood that may contribute to differences in risk perception and responsibility attribution among Chinese pedestrians and suggest future research should explore those processes and subsequently develop evidence-based interventions to reduce pedestrian injury risk.

Keywords: unintentional pedestrian injuries; risk perception; child traffic safety

1 INTRODUCTION

Compared to high-income countries (8.2 mortalities per 100,000), China experiences high traffic injury rates (19.4 mortalities per 100,000 in 2015) (1). In fact, road traffic injuries represent the leading cause of injury death in China (2). Pedestrians are particularly vulnerable to road traffic crashes, accounting for 25% of traffic fatalities in China (3). The economic and social implications of pedestrian-related injuries in China are significant. For example, in 2006, 13.5% of healthcare, social security and welfare expenditures in Shanghai were dedicated to pedestrian-related injuries (3).

While many people assume pedestrian injuries are caused only by crashes between pedestrians and large vehicles, almost half of nonfatal pedestrian injuries in urban Guangdong Province originated not from collisions with cars, but from other moving vehicles, including bicycles (26.3%), motorcycles/electric bicycles (19.0%), and tricycles (13.8%) (4). How pedestrians perceive and respond to various types of moving vehicles is poorly understood but merits exploration because underestimation of risk may lead to riskier behaviors (5) and may contribute to pedestrian injuries, including those resulting from collisions between pedestrians and smaller vehicles like bicycles and electric bicycles.

As such, this study examines how Chinese children and young adults perceive pedestrian risk from various types of vehicles. In particular, we evaluated perceptions of two factors that may influence pedestrian behavior around vehicles: risk perception in the road environment and perception about responsibility to avoid crashes.

Risk perception, conceptualized as the perceived vulnerability to a threat, drives a wide range of health promotion behaviors (6, 7), including road traffic behaviors (5), and develops as children grow into adolescence

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and adulthood (8). Risk perception influences pedestrian safety because pedestrians who perceive risk may be more attentive and reactive to potential road hazards, whereas those who do not perceive risk may engage with traffic conditions beyond what they can manage safely (9).

Perception about a pedestrian's responsibility to avoid crashes may also influence pedestrian behavior and risk. Responsibility and risk judgments, which also evolve as individuals grow older and gain greater cognitive sophistication (8), motivate a wide range of behavioral reactions. For example, charity giving is more likely among adults if recipients are perceived as not responsible for their suffering, such as for hurricane victims rather than drug abusers (10). Pedestrians may therefore take more risk if they feel they are not responsible to keep themselves safe and may behave more cautiously if they judge themselves responsible to maintain their own safety. Legally, Chinese policy requires drivers to yield to pedestrians in marked crosswalks, although such yielding is rarely practiced (11) and the law is poorly enforced (12). road-crossing skill to judge oncoming traffic (13), but children's perception of risk in pedestrian environments, has not been explored carefully in previous research, nor has the process of how child and adolescent development may influence children's perception of risk in pedestrian environments. We addressed these research questions in the present study, hypothesizing that young adults and older children, who have more advanced cognitive processing skills and also more experience in traffic, would correctly recognize larger vehicles as more dangerous than smaller vehicles given the large vehicles' greater mass, lack of maneuverability and need for greater braking distances.

Moreover, we hypothesized that young adults and older children would attribute more responsibility for crash avoidance to themselves than would younger children. In particular, those children who do not have sophisticated perspective-taking skills (or experience) to consider the driver's perspective, including the capacity of a driver to manipulate or stop the vehicle, might inaccurately presume drivers can easily avert pedestrian crashes. We also hypothesized that pedestrians would perceive more responsibility to avoid collisions with many vehicles approaching toward them than when there was just one vehicle approaching, across all vehicle types, as it is easier to negotiate a road-crossing safely with a single oncoming vehicle than with densely approaching traffic. Last, we considered pedestrian gender. We hypothesized females would assign greater responsibility for pedestrian-vehicle crashes to pedestrians than males because previous research suggests that females are more likely to blame themselves for injuries than males (14), and that men may have more optimistic judgments of risk, including in traffic (15).

In summary, we evaluated two perceptual factors that may influence pedestrian behavior and therefore pedestrian injuries and deaths: perception about risk in the road environment, especially with respect to different types of vehicles, and perception about motorist vs. pedestrian responsibility to avoid crashes. We considered both perceptions overall among Chinese children and young adults as well as considering age- and gender-specific differences in those perceptions. We studied three age groups of children, those who are still learning to be safe pedestrians (grades 3-4), those who are beginning to master pedestrian safety (grades 5-6), and those who should have nearly mastered the capacity to engage safely in traffic (grade 8), plus a group of young adults presumed to be fully safe pedestrians. We posited three primary hypotheses: 1) young adults and older children will rate larger road vehicles as more risky than smaller vehicles but younger children will not; 2) perception of pedestrian responsibility to avoid collision with road vehicles will increase with age; and 3) across all age groups, greater pedestrian responsibility to avoid pedestrian-vehicle crashes will be perceived when multiple vehicles are approaching compared to when just one vehicle (of the same type) is approaching.

Epidemiological data offer evidence of age-related differences in pedestrian mortality and morbidity (3), with child-related differences typically attributed to a range of cognitive, perceptual, and exposure-related factors (10) that may not be fully developed until about age 14 (16, 17). Children likely overestimate their ability to keep safe in traffic given overestimation in other domains of functioning, including

2 METHOD

2.1 Participants

A total of 395 participants were recruited from a public primary school (grades three through six), a public middle school (eighth grade) and a university (university students) in Changsha, China. Data from two participants were dropped from analysis due to incomplete demographic information and data from 10 participants were excluded due to invalid completion of questionnaires (e.g., answering with the same response for all items). The final sample consisted of 383 participants. The sample was 94% Han Chinese ethnicity and 55% male, and included 97 third- and fourth-grade children (age *Mean*=9.18 years; *SD*=0.60), 111 fifth- and sixth-grade children (*Mean*=11.10 years; *SD*=0.79), 107 eighth-grade children (*Mean*=13.60 years; *SD*=0.43), and 68 university students (*M*=19.39 years; *SD*=0.55). The study protocol was approved by the Institutional

Review Boards at both University of Alabama at Birmingham, USA and Central South University, China. All participants provided informed consent.

2.2 Measures

All participants completed a self-report survey composed of 3 parts: (a) demographics, (b) risk perception, and (c) perception of responsibility in pedestrian-vehicle crashes. Surveys were completed in group format in classroom settings. Demographic information included gender, age, grade (omitted for university students), and ethnicity. Risk Perception was measured through questions that asked “How risky is it to step in front of X vehicle?” with different items for bicycles, electric bicycles, cars and buses, respectively. For the last three vehicle types, which are capable of traveling fast, participants rated riskiness for the specific vehicle traveling at fairly slow (20 kilometers per hour [kph]) or moderately fast (30 kph) speeds. Responses were provided using a 5-point scale ranging from 1 (not risky at all) to 5 (extremely risky). There were no statistically significant differences between perceptions of risk at 20 kph versus 30 kph, so the responses for those items were averaged to form a composite variable for each vehicle type.

Perception of pedestrian responsibility was assessed via photographs of scenes on Chinese roadways that showed pedestrian crossings. Each picture differed across two variables: the type of vehicle traveling on the road (bicycle, electric bicycle, car, or bus) and the number of vehicles traveling on the road (one or many). Eight photographs in total were used therefore (4 types of vehicles \times 2 numbers of vehicles), and participants responded to the question, “Who would be more responsible for avoiding collision?” with two options as answers: pedestrian or riders/drivers, for each photograph. Potential covariates such as background scenery and distances of the vehicle to the crosswalk were similar across all photographs.

Questionnaire items were developed by the research team and reviewed by multiple content experts for face validity prior to implementation. Translation from English to Chinese was conducted using standard translation/back-translation processes and all surveys were completed in Chinese.

2.3 Data Analysis

2.3.1 Preliminary analyses

Descriptive statistics were generated overall as well as across grades and gender to assess perception of risk and pedestrian vs. driver responsibility to avoid traffic crashes for the four types of vehicles. Perceptions of risk across the four vehicle types were compared with paired samples t-tests. Attributions of responsibility (pedestrian vs. driver) for all vehicle types and number of vehicles were tested with binomial tests to indicate whether they differed from equal responsibility (50% each pedestrian and driver).

2.3.2 Risk perceptions

To evaluate age and gender differences in risk perceptions, a two-way multivariate analysis of variance (MANOVA) was computed with gender and grade as independent variables and the four perceived risk variables (bicycles, electric bicycles, cars, and buses) as dependent variables. Both main effects and interactions of grade and gender were tested. Significant effects were followed up with univariate ANOVAs, with post-hoc comparisons across grades using Tukey HSD tests.

2.3.3 Responsibility attributions

To test grade and gender differences in the categorical indices of responsibility attributions (pedestrian vs. rider/driver), generalized estimating equation (GEE) models with binomial distribution were utilized to account for the repeated nature of the data. The GEE models were conducted separately for each vehicle type, with pedestrian responsibility as the dependent variable, age group and gender as between-subject predictors, and number of vehicles and the interaction of grade and number of vehicles as within-subject predictors. The interactions of grade with number of vehicles were interpreted using simple slopes (i.e., the main effect of number of vehicles for the reference age group; Aiken & West, 1991). The interaction between age and gender was also explored, but it was not significant in any of the models and thus was removed from the final analyses. Analyses were conducted using SPSS Version 25 and SAS 9.4.

3 RESULTS

3.1 Preliminary analyses

Descriptive statistics are presented in Table 1. Across the full sample, perception of pedestrian risk increased with increasing vehicular size. Based on paired samples t-tests, all pairwise comparisons across the four vehicle types were significant ($t(382) \geq 6.19$, $p < .001$). Participants gave bicycles the lowest average score of 3.32 ($SD = .99$) for riskiness, followed by 3.62 ($SD = .74$) for electric bicycles, 3.96 ($SD = .81$) for cars, and 4.22 ($SD = .89$) for buses. For responsibility attributions, participants were more likely to perceive pedestrians as responsible to avoid collisions instead of drivers across all vehicle types and number of vehicles approaching

Table 1. Descriptive and Inferential Statistics—Risk Perception and Responsibility Attribution of Chinese Pedestrians

<i>Mean (SD) unless otherwise noted</i>	Total	Third/Fourth Grades	Fifth/Sixth Grades	Eighth Grade	University	Males	Females
Participants (N)	383	97	111	107	68	211	172
Age	12.85 (3.55)	9.18 (0.60)	11.10 (0.79)	13.60 (0.43)	19.39 (0.55)	12.74 (3.46)	12.97 (3.67)
Risk Perception Rating¹							
Bicycle	3.32 (0.99)	3.69 (0.10) ^a	3.42 (0.09) ^{ab}	3.33 (0.09) ^b	2.66 (0.11) ^c	3.29 (1.06)	3.36 (0.90)
Electric Bicycle	3.62 (0.74)	3.62 (0.07) ^a	3.73 (0.07) ^a	3.67 (0.07) ^a	3.34 (0.09) ^b	3.65 (0.81)	3.59 (0.64)
Car	3.96 (0.81)	4.01 (0.08) ^a	3.96 (0.08) ^a	3.99 (0.08) ^a	3.79 (0.10) ^a	4.00 (0.83)	3.91 (0.78)
Bus	4.22 (0.89)	4.27 (0.09) ^a	4.12 (0.08) ^a	4.36 (0.09) ^a	4.05 (0.11) ^a	4.22 (0.92)	4.22 (0.85)
Pedestrian vs. Driver Responsibility Rating²							
Bicycle - One	0.74 (0.44)	0.74 (0.44)	0.62 (0.49)	0.79 (0.41)	0.84 (0.37)	0.72 (0.45)	0.76 (0.43)
Bicycle - Many	0.75 (0.43)	0.72 (0.45)	0.80 (0.40)	0.72 (0.45)	0.84 (0.37)	0.79 (0.41)	0.74 (0.44)
Electric Bicycle - One	0.66 (0.47)	0.61 (0.49)	0.54 (0.50)	0.77 (0.42)	0.72 (0.45)	0.63 (0.48)	0.69 (0.47)
Electric Bicycle - Many	0.77 (0.42)	0.71 (0.46)	0.80 (0.40)	0.71 (0.46)	0.90 (0.31)	0.75 (0.43)	0.79 (0.41)
Car - One	0.59 (0.49)	0.60 (0.49)	0.50 (0.50)	0.61 (0.49)	0.68 (0.47)	0.57 (0.50)	0.61 (0.49)
Car - Many	0.74 (0.44)	0.61 (0.49)	0.80 (0.40)	0.67 (0.47)	0.90 (0.31)	0.72 (0.45)	0.75 (0.43)
Bus - One	0.75 (0.43)	0.66 (0.48)	0.73 (0.44)	0.74 (0.44)	0.91 (0.29)	0.71 (0.45)	0.80 (0.40)
Bus - Many	0.80 (0.40)	0.65 (0.48)	0.83 (0.38)	0.79 (0.41)	0.99 (0.12)	0.79 (0.41)	0.82 (0.38)

Note: ¹Risk perception was coded on 5-point scale; 1 signified not risky at all and 5 signified extremely risky;

^{abc}Age cohort groups with different superscripts differed from each other on risk perceptions of vehicle in that row

²Pedestrian responsibility to avoid collision was coded as 1; driver coded as 0

on the roadway (ranging from 59% pedestrian responsibility with one car approaching to 80% pedestrian responsibility with many buses approaching). Binomial tests suggested all of the proportions differed from 50% (all $p < .001$).

3.2 Risk perceptions

Next, the effects of age and gender on risk perceptions were examined. The MANOVA produced a statistically significant interaction effect between age group and gender on the combined dependent variables, $F(12, 985) = 1.80, p = .043$, Wilks' $\Lambda = .94$. Statistically significant interaction effects between age and gender were observed for risk perception of electric bicycles ($F(3, 375) = 4.09, p = .007$), cars ($F(3, 375) = 4.47, p = .004$), and buses ($F(3, 375) = 3.40, p = .018$), but not bicycles ($F(3, 375) = 1.30, p = .275$). Follow up tests indicated that males and females did not differ in their risk perceptions in third/fourth and eighth grade (all $p > .05$), but in fifth/sixth grade, males reported greater risk for cars than females ($p = .036$) but did not differ in risk perceptions of electric bikes and buses ($p > .09$), and among university students females reported greater risk perceptions than males for all three vehicle types (all $p < .007$).

Additionally, there were statistically significant differences among age groups in the risk perceptions of bicycles ($F(3, 375) = 16.87, p < .0005$) and electric bicycles ($F(3, 375) = 4.56, p = .004$), but not cars ($F(3, 375) = 1.23, p = .300$) or buses ($F(3, 375) = 2.32, p = .075$). Table 1 indicates pairwise differences in the risk perception scores for the four age cohorts. While no significant differences emerged among age groups for cars and buses, both adolescents and young adults judged the smaller bicycles and just young adults judged the electric bicycles as less risky compared to the younger children. There was no significant main effect of gender in the MANOVA, $F(4, 372) = 16.87, p = .540$, Wilks' $\Lambda = .992$.

3.3 Responsibility attributions

GEE models examining age differences for pedestrian responsibility to avoid collision separately for each type of vehicle also showed no gender differences (all $p > .085$) and no interactions of gender with age, indicating that males and females across all ages made similar attributions of pedestrian responsibility. However, a number of age differences and interactions between age and the number of vehicles emerged for each vehicle type (See Table 2).

Table 2. GEE Analyses of Pedestrian Responsibility Across Vehicle Types

	Bicycle		Electric Bicycle		Car		Bus	
	b (SE)	OR	b (SE)	OR	b (SE)	OR	b (SE)	OR
Third & Fourth Grades	-0.65 (0.40)	0.52	-0.47 (0.34)	0.62	-0.29 (0.34)	0.75	-1.59 (0.48)***	0.20
Fifth & Sixth Grades	-1.07 (0.38)**	0.34	-0.73 (0.33)*	0.48	-0.70 (0.32)*	0.49	-1.33 (0.48)**	0.26
Eighth Grade	-0.40 (0.40)	0.67	0.26 (0.36)	1.30	-0.30 (0.33)	0.74	-1.28 (0.48)**	0.28
University	ref		ref		ref		ref	
Female	-0.01 (0.17)	0.99	0.19 (0.19)	1.21	0.16 (0.19)	1.18	0.38 (0.22)	1.46
Many	0.00 (0.49)	1.00	1.22 (0.40)**	3.38	1.43 (0.43)***	4.17	1.87 (0.93)*	6.51
Third & Fourth Grades*Many	-0.06 (0.58)	0.95	-0.80 (0.48)	0.45	-1.36 (0.50)**	0.26	-1.93 (0.95)*	0.15
Fifth & Sixth Grades*Many	0.64 (0.58)	1.90	-0.03 (0.49)	0.97	-0.03 (0.50)	0.97	-1.24 (0.96)	0.29
Eighth Grade*Many	-0.39 (0.56)	0.68	-1.57 (0.48)***	0.21	-1.13 (0.48)*	0.32	-1.61 (0.96)	0.20
Third & Fourth Grades	ref		ref		ref		ref	
Fifth & Sixth Grades	-0.42 (0.30)**	0.66	-0.26 (0.29)	0.77	-0.42 (0.29)	0.66	0.26 (0.31)	1.30
Eighth Grade	0.25 (0.33)	1.28	0.74 (0.34)*	2.09	-0.02 (0.29)	0.98	0.31 (0.31)	1.36
University	0.65 (0.40)	1.92	0.47 (0.34)	1.61	0.29 (0.34)	1.33	1.59 (0.48)***	4.90
Many	-0.06 (0.32)	0.95	0.42 (0.27)	1.52	0.07 (0.26)	1.07	-0.06 (0.23)	0.95
Third & Fourth Grades*Many	0.70 (0.44)	2.00	0.77 (0.39)*	2.16	1.33 (0.36)***	3.78	0.69 (0.35)*	1.99
Fifth & Sixth Grades*Many	-0.33 (0.42)	0.72	-0.77 (0.37)*	0.46	0.23 (0.33)	1.26	0.32 (0.34)	1.38
Eighth Grade*Many	0.06 (0.58)	1.06	0.80 (0.48)	2.22	1.36 (0.50)**	3.91	1.93 (0.95)*	6.88
Third & Fourth Grades	0.42 (0.30)	1.52	0.26 (0.29)	1.29	0.42 (0.29)	1.52	-0.26 (0.38)	0.77
Fifth & Sixth Grades	ref		ref		ref		ref	
Eighth Grade	0.67 (0.30)*	1.95	0.99 (0.30)**	2.70	0.40 (0.28)	1.49	0.04 (0.31)	1.05
University	1.07 (0.38)**	2.92	0.73 (0.33)*	2.08	0.70 (0.32)*	2.02	1.33 (0.48)**	3.78
Many	0.64 (0.30)*	1.90	1.19 (0.28)***	3.28	1.40 (0.24)***	4.04	0.63 (0.26)*	1.88
Third & Fourth Grades*Many	-0.70 (0.44)	0.50	-0.77 (0.39)*	0.46	-1.33 (0.36)***	0.26	-0.69 (0.35)*	0.50
Fifth & Sixth Grades*Many	-1.03 (0.40)*	0.36	-1.54 (0.38)***	0.21	-1.10 (0.32)***	0.33	-0.37 (0.36)	0.69
Eighth Grade*Many	-0.64 (0.57)	0.53	0.03 (0.49)	1.03	0.03 (0.50)	1.03	1.24 (0.96)	3.46
Third & Fourth Grades	-0.25 (0.33)	0.78	-0.74 (0.31)*	0.48	0.02 (0.29)	1.02	-0.31 (0.31)	0.73
Fifth & Sixth Grades	-0.67 (0.30)*	0.51	-0.99 (0.30)**	0.37	-0.40 (0.28)	0.67	-0.04 (0.31)	0.96
Eighth Grade	ref		ref		ref		ref	
University	0.40 (0.40)	1.49	-0.26 (0.36)	0.77	0.30 (0.33)	1.35	1.28 (0.48)**	3.60
Many	-0.39 (0.27)	0.68	-0.35 (0.26)	0.70	0.29 (0.20)	1.34	0.26 (0.25)	1.30
Third & Fourth Grades*Many	0.33 (0.42)	1.39	0.77 (0.37)*	2.16	-0.23 (0.33)	0.79	-0.32 (0.34)	0.73
Fifth & Sixth Grades*Many	1.03 (0.40)*	2.80	1.54 (0.38)***	4.66	1.10 (0.32)***	3.00	0.37 (0.36)	1.45
Eighth Grade*Many	0.39 (0.56)	1.48	1.57 (0.48)***	4.81	1.13 (0.48)*	3.10	1.61 (0.96)	5.00

Note: * $p < .05$; ** $p < .01$; *** $p < .001$. Significant results are bolded.

Gender and grade are between-subject predictors. Vehicle type, number of vehicles (many vs. one), and interactions between vehicle type and number are within-subject predictors.

Note that each segment of the table presents analyses with different grades used as reference groups. All pairwise comparisons and simple slopes are reported for analyses of interaction effects.

For bicycles, eighth graders and university students were more likely to attribute responsibility to pedestrians than fifth/sixth graders ($OR=1.95$ and 2.92 respectively). Pedestrian responsibility was increased by the presence of multiple bicycles (vs. one bicycle) for fifth/sixth graders only ($OR=1.90$). For electric bicycles, greater pedestrian responsibility was also reported by older individuals: eighth graders reported more pedestrian responsibility than both third/fourth graders and fifth/sixth graders ($OR=2.09$ and 2.70), and university students more than fifth/sixth graders ($OR=2.08$). Multiple vs. one electric bicycle increased pedestrian responsibility perceptions in fifth/sixth graders ($OR=3.28$) and university students ($OR=3.38$), but not in third/fourth or eighth graders. For cars, university students were more likely to endorse pedestrian responsibility than fifth/sixth graders ($OR=2.02$). The presence of multiple vs. one car increased pedestrian responsibility perceptions for fifth/sixth graders ($OR=4.04$) and university students ($OR=4.17$), but not third/fourth or eighth graders. Finally, for buses, university students were more likely to attribute responsibility to pedestrians than all three youth groups ($OR=4.90$ vs. third/fourth grades; $OR=3.78$ vs. fifth/sixth grades; and $OR=3.60$ vs. eighth grade); the other three groups did not differ from one another. The presence of multiple buses vs. one bus increased pedestrian responsibility attributions for fifth/sixth graders ($OR=1.88$) and university students ($OR=6.51$), but not for third/fourth and eighth graders.

4 DISCUSSION

Our analysis yielded numerous noteworthy results. First, study participants in all age groups perceived that the smaller vehicles we considered, bicycles and electric bicycles, were less risky vehicles on the roads compared to cars and buses, although young adults tended to perceive all vehicles as less risky than children. Second, across all vehicle types and number of vehicles traveling on the road, both children and young adults perceived more responsibility on the part of pedestrians to avoid collisions relative to drivers. Children tended to ascribe less responsibility to pedestrians to avoid crashes than young adults did. Last, we found that university students and fifth/sixth graders identified greater pedestrian responsibility to avoid collisions when there were multiple vehicles approaching rather than just one vehicle for most vehicle types. We discuss each of these findings below.

We hypothesized that young adults and older children would judge larger road vehicles as more risky than smaller vehicles, whereas younger children might rate all vehicles similarly. Our results suggest this hypothesis was not supported. In fact, all participants identified higher risk from larger vehicles compared to smaller vehicles, although adolescents and young adults judged the smaller bicycles and young adults judged the electric bicycles as less risky compared to the younger children. Our results may reflect the possibility that even the youngest children in the sample – those in third and fourth grade – were able to perceive the risk of experiencing a crash with a large vehicle like a bus. The fact that the older participants rated bicycles and electric bicycles as less risky may reflect their ability to deduce the mass, maneuverability and yielding ability of smaller vehicles, recognizing that they could avert crashes more easily than large vehicles and that they might cause less severe injuries (18,19).

As hypothesized, perception of pedestrian rather than driver responsibility to avoid collisions tended to increase with age. Although the data patterns were not entirely consistent, GEE models offered a pattern of results suggesting young adults and older children attributed greater responsibility to avoid a crash to the pedestrian rather than the driver. This result is sensible: young adults and older children have greater capacity to avoid crashes while walking on the street and therefore might judge crash avoidance as their responsibility to a greater degree than younger children. They may also have a better sense of the ability of drivers to avoid crashes, having driving experience themselves and/or elevated cognitive understanding of the capacity of vehicles to stop and swerve in attempts to avert crashes. Age-graded increases in responsibility may also arise through language and socio-cognitive development, including greater consideration of situational factors (20) and more developed cognitive judgment, decision-making, impulse control, and understanding of horizontal projectile motion (21-23).

Our final hypothesis was that participants might judge greater pedestrian responsibility to avert crashes when many vehicles were approaching on the road rather than just a single vehicle. This hypothesis proved true for all vehicle types among fifth/sixth graders, and for all vehicle types except bicycles for university students. The higher risk with multiple vehicles versus a single vehicle approaching reported by fifth/sixth graders but not younger or older children is a bit perplexing, but may possibly result from their rapidly-emerging cognitive ability to distinguish and consider the risk consequences of many approaching vehicles instead of a single approaching vehicle. In fact, perceptions may be exaggerated in this young adolescent age group as the relevant cognitive skills to judge traffic are emerging and they struggle through the adolescent patterns of calibrating risk-taking behavior, both in traffic and more generally in life decisions (17,24). The perceptions among

university students may reflect their accurate comprehension of the risks involved and the maneuverability capacities of the oncoming vehicles.

5 CONCLUSIONS

Study results suggest participants of all ages perceive that bicycles and electric bicycles pose less risk in pedestrian settings than cars and buses, although children perceived greater risks from all vehicles than young adults. We also found that all participants attribute more responsibility to avoid pedestrian-vehicle crashes to pedestrians, although children ascribed less responsibility to pedestrians than did young adults. These findings are valuable to guide design and implementation of age-specific interventions to reduce pedestrian-vehicle crashes. With continued research on the topic, a better understanding of pedestrians' perception of risk, and ways to alter those perceptions could contribute to efforts to mitigate the frequency and severity of unintentional traffic injuries in China and worldwide.

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Empirical Analysis of Expressway Long Tunnels using a Seven-Zone Analytic Approach

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Abstract

Research efforts have been made to understand the traffic safety of tunnels. Most of the previous studies did not consider the different features of tunnels with different range of length comprehensively. Three or four-zone approach has generally been adopted, with which the entrance and exit parts of a tunnel are considered symmetrical in the safety analysis. This study employed a seven-zone analytic approach for the safety investigation of 18 expressway tunnels with length ranging from 2 to 3 km. Results reveal that the crash rate first increases for the entrance zone, then decreases for the mid-zone and again increases at the exit zone. High crash rates at the access, entrance and transition zones are attributed to rear-end crashes. While single-vehicle crashes take place in the mid-zone and exit of the tunnel. At the tunnel entrance – failure to maintain safe distance; in the mid-area – failure to maintain safe distance, fatigue driving, over speeding and improper lane change; and at the tunnel exit – over speeding and improper lane change mainly contribute to crashes. Crash occurrence mechanism is briefly discussed for the selected long tunnels. Engineering and policy countermeasures are recommended to raise traffic safety in expressway tunnels.

Keywords: Tunnel safety, Expressway tunnel, Three or four-zone approach, Seven-zone approach

1. INTRODUCTION

Tunnels, being an integral part of expressway network, reduce travel time, protect ecological environment and play a significant role in the expressway operation safety. The limited inner space and confined environment of expressway tunnels make it hard to rescue and evacuate people in the event of crash. Particularly, for a crash resulting in a fire, the consequences can be more severe due to the expansion of heat and smoke (1, 2). In recent years, the number of expressway tunnels has increased significantly, that result in an increase in the tunnel-related traffic crashes. For example, the number of expressway tunnel crashes in China has increased from 244 (2012) to 305 (2016) resulting in 685 fatalities, making up to 60% of all road tunnel fatalities (3). Therefore, it is essential to examine the crash characteristics of tunnels to find effective measures to improve the tunnel safety.

Previous studies (1, 2, 4 – 8) investigated the crash rates of the tunnels to evaluate the tunnel features that could mainly affect the safety. Taking the discrepancy of the driving environment in different tunnel sections into account, these studies have further divided the tunnel into different zones (see Table 1) and determined crash rates in each zone (see Table 2). Without differentiation for entrance and exit of the tunnel, the studies (1, 2, 4 – 8) has reached to a general conclusion that crash risk is higher in the entrance zone than inside the tunnel and declines as the drivers continue driving. As an exception, Ma et al. (2) highlighted the tunnel transition zone (zone 3 as in Table 1) as the most crash-prone zone, using four freeway tunnels data in China.

However, first, each zone (portal, entrance, transition, mid-area and exit) has its own independent characteristics that affect the crashes in the tunnel. The tunnel lighting guidelines (9) also divide the single tunnels into access, threshold, transition, interior and exit zones. But the studies (1, 2, 4 – 8) merely divided the tunnels into three or four zones, by considering the entrance and exit of the tunnel symmetrical in the safety performance. Besides that, using the above zoning definition, it is difficult to identify and adequately address the effects of the “black-hole and white-hole” phenomena. As the black-hole effect exists at the tunnel entrance while the white-hole phenomenon occurs at the tunnel exit. Second, the long tunnels have each zone while short and medium tunnels may not have some zones given their length (1, 2, 7, 8). Therefore, for long tunnels, the crash rate and the contributing crash factors should be different. The design specification for highway tunnels in China (10) also classified the single tunnels into four categories: short tunnel ($L < 500\text{m}$), medium tunnel ($500\text{m} \leq L < 1000\text{m}$), long tunnel ($1000\text{m} \leq L < 3000\text{m}$) and extra-long tunnel ($L > 3000\text{m}$). But, most of the studies considered all types of tunnels aggregately and did not define the tunnel groups specifically.

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From the contributing crash factors standpoint, the studies (2, 5, 7) mentioned that for tunnels, the main reasons for crashes are lacking vigilance (e.g., fatigue, distraction and inattention) and behavioral aspects (e.g., safety distance, lane keeping and overtaking). However, due to the limitation of the zoning approach, without significantly defining the different groups of tunnels and datasets with limited information about the specific factors, these studies failed to explain that how tunnels can affect the driving performance, the tunnel features that have the highest impact on drivers and the key contributing factors for the different parts of the tunnel.

As discussed, there is a lack of understanding that how the tunnel environment affects the tunnel crashes and the crash occurring mechanism, this paper is set to (1) propose a seven-zone analytic approach for the expressway long tunnels, (2) evaluate the crash rate and crash type in different zones of the expressway long tunnels and (3) explore the key contributing factors in different zones of the selected long tunnels.

Table 1. Division of tunnel into the different zone by different studies

Authors	Tunnels type (Country)	Zone 1	Zone 2	Zone 3	Zone 4
Amundsen et al. (1)	All tunnel (Norway)	First 50m before/after tunnel	First 50m inside tunnel	Next 100m inside tunnel	Remainder of tunnel
Ma et al. (2)	Freeway tunnel (China)	First 100m before/after tunnel	First 100m inside tunnel	Next 300m inside tunnel	Remainder of tunnel
Yeung et al. (7)	Expressway tunnel (Singapore)	First 250m outside the tunnel	First 250m inside the tunnel	Remainder of tunnel	
Lu et al. (8)	River crossing tunnels (urban expressway) (China)	First 50m before/after tunnel	First 50m inside tunnel	Next 100m inside tunnel	Remainder of tunnel

Table 2. Comparison of tunnel crash rates

Authors	Tunnels type (Country)	Crash rate			
		Zone 1	Zone 2	Zone 3	Zone 4
Amundsen et al. (1) (Person injury veh. Km) *	Crash/mill. All tunnel (Norway)	0.30	0.10	0.16	0.10
Ma et al. (2) (Crash/mill. veh. Km) *	Freeway tunnel (China)	0.56	0.53	0.58	0.45
	Tunnel longer than 500m	0.30	0.32	0.18	0.08
Amundsen et al. (4) (Person injury veh. Km) *	Crash/mill. Single Tube Unidirectional tunnel	0.175	0.15	0.12	0.03
	Single Tube Bidirectional tunnel	0.24	0.26	0.19	0.07
	Urban Unidirectional tunnel	0.31	0.38	0.16	0.12
	Rural Unidirectional tunnel	0.27	0.06	0.06	0.03
Nussbaumer (5) (Person injury veh. Km) *	Crash/mill. Unidirectional and (Austria)	0.30	0.05	0.09	
	Bidirectional tunnels (Austria)	0.30	0.10	0.07	
Brandt et al. (6)	Single Tube Unidirectional tunnel	0.175	0.15	0.12	0.03
	Single Tube Bidirectional tunnel	0.24	0.26	0.19	0.07
Yeung et al. (7) (Crash/km/year) *	Expressway tunnel (Singapore)	52	35	5	
Lu et al. (8) (Crash/km/year) *	River crossing tunnels (urban expressway) (China)	700	500	370	150

*Different measurement units of crash rates.

2. METHOD

2.1 Data Preparation

A dataset consisting of five years (2012–2016) of tunnel crashes was collected from Hunan Province, China. The final dataset contained 18 tunnels with length ranging from 2000m to 3000m. All the tunnels have unidirectional traffic flow in two tubes. Each tube carries two lanes with a speed limit of 80km/hr. The design speed of the expressway outside the tunnel is 100km/hr. Traffic crash data was obtained from the Hunan Traffic Management Sector-Specific Incident Case Data Report. The data covers various aspects of a traffic crash, including driving behaviors, temporal, vehicle, crash and environmental characteristics. The final dataset

consists of 255 unique crashes, reported to occur in the selected long tunnels during 2012-2015. Traffic volume data was also obtained for the selected tunnels from Freeway Management Bureau of Hunan Province.

2.2 Zoning definition

The tunnel lighting guidelines (9) divide the single and unidirectional traffic tunnels into five zones namely access zone, threshold zone, transition zone, interior zone and exit zone. But most of the prior studies (1, 2, 4 – 8) divided the tunnels into three or four zones and didn't consider the entrance and exit part of the tunnel, separately, in the safety analysis of the tunnels. In addition, using this approach, it is very difficult to capture the effects of the various sections of tunnel on traffic crashes, particularly the exit part of the tunnel. Therefore, considering the deficit mentioned above in the prior studies and using the tunnel lighting guidelines, this study divided the tunnels into seven zones (Fig. 1). Tunnel zones in this study are defined as follow;

- Zone 1 and Zone 2, access zone and entrance zone, respectively: The design speeds outside and inside the tunnel sections are 100km/hr and 80km/hr, respectively. If the reaction time is 4sec, the braking distances are 111.1m and 88.9m, respectively. For the sake of analysis, zone 1 and 2 are round to 100m. The purpose of zone 1 and 2 is to look into the effects of the access and entrance zones on the tunnel crashes, respectively.
- Zone 3, transition zone: According to the tunnel lighting guidelines (9), the length of the transition zone is approximately 300 m. Therefore, the length of the transition zone is 300m.
- Zone 4, mid-zone: It is the mid-zone of the tunnel. For the selected long tunnel this zone is very long; therefore, it was further divided into 10 equal sections to deeply analyse the key crash factors and how these factors change as the driver moves towards the tunnel exit.
- Zone 5 and Zone 6, exit-zone: The exit part of tunnel is divided into two zones i.e. zone 5 and 6. It is to understand how the driver behavior changes as the driver sees and gets closer to the tunnel exit and to capture the crash factors at the tunnel exit more effectively. The length of the zone 5 and zone 6 are defined as 300m and 100m, respectively.
- Zone 7, outside the tunnel: It is the first 100m outside the tunnel exit. This zone was considered to study the effect of vital change in light conditions (white-hole phenomena) on crashes as the driver comes out of the tunnel.

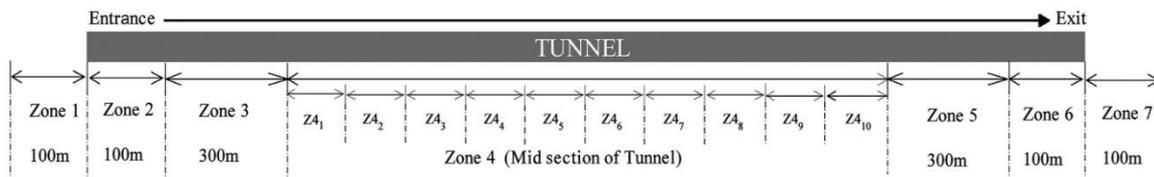


Fig.1. Zone definition for the selected long tunnels

3. RESULTS AND DISCUSSION

Based on the zone definition as explained above, the selected tunnels were classified into seven zones. According to the location (dataset has the precise location information of each crash) of the crashes, the 255 crashes were matched with their respective tunnels and then crashes in tunnels for the same zone were merged. The crash rates were calculated by dividing the number of crashes with the number of vehicle kilometres driven.

3.1 Crash rate in each zone

The crash rate for the seven zones of the selected long tunnels is shown in Fig. 2. It can be observed from the figure that the crash rate first increases for the entrance zone (zone 2) then it slowly decreases as the driver precedes into the tunnel and finally increases again as the driver leaves the tunnel (zone 7). The high crash rates at the tunnel entrance and exit are due to the black-hole and white-hole phenomena, respectively. Both of these effects reduce the driver's emergency response time and may lead to crashes (11, 12). In addition, the crash rate of the tunnel entrance is higher than that of the tunnel exit which shows that crashes are more likely to occur due to the black-hole effect. The study (13) also found similar results using experimental data. They found that driver experiences more difficulties to adapt to the black-hole effect than the white-hole effect.

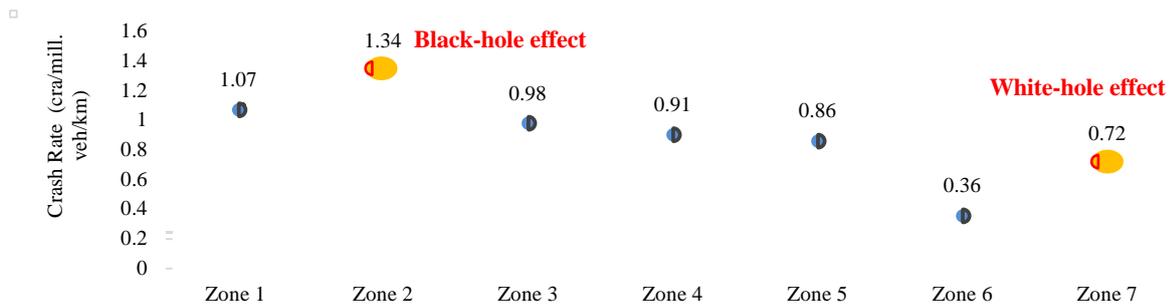


Fig.2. Crash rate in each zone from entrance to exit

3.2 Crash type in each zone

The distribution of the crashes by crash type is shown in Table 3. It can be observed that the proportion of rear-end crashes is the highest, which accounts for 44.31% and mainly occur due to the failure to maintain a safe distance from the front vehicle, which is consistent with the previous research (1, 2, 7, 8, 14). Rear-end crashes occur most frequently around the entrances, but inside the tunnel decreases with the distance from the tunnel entrance which is in contrast with the findings of Ma et al. (2). Single-vehicle crashes (collision with fixture and rollover) increases with the distance from the tunnel entrance, take place most frequently in the mid-zone and at the tunnel exit. The in-depth analysis of the data shows that these crashes were mostly occurred due to over speeding and fatigue driving. Therefore, the differences in the crash rate among different zone can be attributed to the crash types. Most of the rear-end crashes occurred in the access, entrance and transition zone which suggest that these zones appear to impair driver’s ability to cope with the inter-vehicle interaction. While single-vehicle crashes occurred in the middle and exit part of the tunnel which leads to the fact that driving in long tunnels makes the driver tired as well as force him to change his driving speed.

Table 3. Types of crashes in different zone of tunnel

Crash Types	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Total	Inside Tunnel
Rear-end	75.00%	60.00%	51.52%	40.65%	41.38%	33.33%	25.00%	44.31%	43.40%
With Fixed Objects	25.00%	26.67%	39.39%	40.65%	27.59%	33.33%	62.50%	38.04%	37.87%
Rollover	0.00%	0.00%	9.09%	7.10%	13.79%	0.00%	0.00%	7.06%	7.66%
Sideswipe	0.00%	13.33%	0.00%	5.81%	3.45%	33.33%	12.50%	5.49%	5.53%
Other	0.00%	0.00%	0.00%	5.81%	13.79%	0.00%	0.00%	5.10%	5.53%

3.3 Contributing crash factors

The database has the information of the contributing factors which are: failure to maintain a safe distance, improper braking, over speeding, improper steering, fatigue driving, improper lane change, breaking the rule and other. Friedman test was applied to examine the relationship between the contributing crash factors and different zones of the tunnel using statistical software (SPSS). The test results for the seven zones of the selected tunnels showed that at 95% confidence interval, the observed p-value is 0.01 as shown in Table 4. A similar analysis was conducted for the zone 4 (mid zone) of the tunnel and yielded a similar conclusion at a 95% confidence level. The observed p-value was 0.00. The results lead to the conclusion that the crash factors in the different zones of the whole tunnel and zone 4 are significant.

The results (Table 5) showed that the failure to maintain a safe distance is the main contributing crash factor at the access, entrance and transition zone, which is consistent with the prior studies (1, 2, 7). In the mid-zone, along with failure to maintain safe distance, fatigue driving, over speeding and improper lane change also contribute to crashes. At the exit zones, over speeding, improper lane are the main contributing factors. As zone 4 is very long for the selected tunnels, it was further analyzed to understand the crash factors. The results for zone 4 are shown in Table 6. Analysis of zone 4 shows that the failure to maintain a safe distance from the front vehicle decrease as the drivers move into zone 4, but the effect of over speeding remains almost constant in the zone 4. However, the drivers seem to be less involved in wrong driving behaviour as they proceed into the zone 4. With the increase in distance from the start of zone 4, the rear-end crashes decreases and in the last half part of the zone the rollover and sideswipe collisions increases.

Table 4. Friedman test results

Contributing crash factors	Whole Tunnel	Zone 4
Fail to maintain safe distance	7.57	7.05
Breaking the rule	4.93	5.05
Over speed	4.29	5.55
Improper steering	4.07	3.20
Improper braking	3.71	4.20
Improper lane change	3.36	2.50
Fatigue driving	3.07	3.00
Other	5.00	5.45
Test Results		
N	7	10
Chi Sq.	18.13	31.27
Df	7	7
Sig.	.01	.00

Table 5 Contributing crash factors in different zone of tunnel

Contributing crash factors	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Fail to maintain safe distance	58.33%	53.33%	45.45%	34.19%	27.59%	33.33%	25.00%
Improper braking	16.67%	0.00%	9.09%	10.32%	3.45%	0.00%	12.50%
Improper steering	8.33%	6.67%	12.12%	5.16%	0.00%	0.00%	25.00%
Over speed	0.00%	6.67%	3.03%	14.19%	18.79%	33.33%	0.00%
Fatigue driving	8.33%	0.00%	3.03%	5.16%	10.34%	0.00%	0.00%
Breaking the rule	8.33%	6.67%	15.15%	10.97%	26.03%	0.00%	0.00%
Improper lane change	0.00%	6.67%	0.00%	3.87%	6.90%	33.33%	12.50%
Other	0.00%	20.00%	12.12%	16.13%	6.90%	0.00%	25.00%

Table 6 Contributing crash factors in different sections of zone 4

Contributing crash factors	Z4 ₁	Z4 ₂	Z4 ₃	Z4 ₄	Z4 ₅	Z4 ₆	Z4 ₇	Z4 ₈	Z4 ₉	Z4 ₁₀
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Fail to maintain safe distance	18.18	44.44	45.00	52.94	42.31	31.58	15.38	11.11	11.11	30.77
Improper braking	9.09	0.00	15.00	5.88	11.54	26.32	7.69	0.00	11.11	7.69
Improper steering	9.09	0.00	5.00	11.76	3.85	0.00	7.69	11.11	11.11	0.00
Over speed	9.09	16.67	0.00	17.65	7.69	15.79	38.46	11.11	22.22	15.38
Fatigue driving	9.09	0.00	10.00	5.88	3.85	5.26	0.00	0.00	11.11	7.69
Breaking the rule	9.09	22.22	10.00	5.88	0.00	5.26	15.38	22.22	22.22	15.38
Improper lane change	0.00	5.56	0.00	0.00	7.69	5.26	7.69	0.00	0.00	7.69
Other	36.36	11.11	15.00	0.00	23.08	10.53	7.69	44.44	11.11	15.38

3.4 Crash Occurrence Mechanism

The study divided the long tunnels into seven zones to quantify the effect of driving direction and length of the tunnel on tunnel safety and found that the contributing crash factors for different zones of tunnel changes as the driver move from the entrance to the exit of the tunnel. It is because as the drivers approach the tunnel entrance, they adjust their speed because of the difference in the speed limit outside and inside the tunnel. According to Zhao et al. (15) research, the drivers normally decelerate as they approach the tunnel entrance. These large speed fluctuations of different vehicles (car, bus, truck, van) have a deleterious impact on the traffic safety and result in a high rear-end crashes in zone 1 as shown in Table 3. The crash rate for zone 2 increases because in zone 2 along with the fluctuations in the speed of different vehicles, the “black-hole phenomenon” will affect the driver and crash factors. Previous studies (16, 17) also found that black-hole phenomena affect the drivers at the tunnel entrance and causes a high number of crashes.

In zone 3, the combined effect of wrong driving behaviors (improper braking, improper steering and breaking the rules) is almost the same as the failure to maintain a safe distance. This suggests that the drivers start feeling more anxious due to the tunnel environment upon entering zone 3. In zone 4, the results showed that the effect of the failure to maintain safe distance decreases, the combined effect of wrong driving behaviors remains same and the effect of over speeding increases. This suggests that due to the tunnel environment the drivers feel anxious, so the drivers adopt wrong driving behaviors, but at the same time, they want to go out of the tunnel as soon as possible which affect their driving speed. Zhao et al. (15) also found that after entering the tunnel, the drivers accelerate to higher speeds. Further analysis of zone 4 shows that the failure to maintain a safe distance from the front vehicle decreases as the drivers move into the zone 4, but the effect of over speeding remains

almost constant in the zone 4. This shows that the drivers do over speeding in zone 4 that on one side help them to maintain a safe distance from the front vehicle but on the other side resulting in a collision with fixed objects and rollover. However, the drivers seem to be less involved in wrong driving behaviour as they proceed into the zone 4. Same results can be seen from the crash type perspective. With the increase in distance from the start of zone 4, the rear-end crashes decrease, but in the last half part of the zone the rollover and sideswipe collisions increases.

In zone 5, the effect of the failure to maintain safe distance decreases but the effects of over speeding, improper lane change and breaking the rule increases. This leads to the fact that as the drivers get closer to the tunnel exit, they want to go out of the tunnel resulting in over speeding that consequently causes breaking the rule and improper lane changes. The increasing effect of fatigue driving can also be seen in zones 3, 4 and 5. This is because the drivers are fatigue easily in a long tunnel with monotonous environment for a long time. In addition, with the increase of the tunnel length, the vehicle flow also increases in the tunnel which leads to the increase of smoke concentration and visibility reduction. Zone 6 is the last 100m at the tunnel exit. The contributing factors for zone 6 are over speeding, improper lane change and failure to maintain a safe distance, as shown in Table 5. When drivers enter in zone 6, they might see the tunnel exit. This leads them to do over speeding that results in improper lane change and failure to maintain a safe distance from the front vehicles. The over speeding results in higher single-vehicle crashes as shown in Table 3. Zone 7 is the first 100m outside the tunnel exit. Here the design speed is 100km/hr and crashes that occur due to speed between 80km/hr to 100 km/hr were not recorded as over speeding crash. Therefore, the results show that in zone 7 no crashes were occurred due to over speeding. However, this study believes that along with improper lane change and white-hole phenomena (16), over speeding (speed between 80km/hr to 100 km/hr) also contributes to the crashes in zone 7.

4. CONCLUSION AND IMPLICATIONS

This study aimed to investigate the characteristics of traffic crashes in the expressway long tunnels. Considering the entrance and exit of the selected long tunnels separately and the zone definitions in the tunnel lighting guidelines for single tunnels, a seven-zone approach was proposed for safety analysis of expressway long tunnels. A total of 18 expressway long tunnels in Hunan Province, China were studied using the police-reported crash data. The analysis reveals that the method (seven-zone method) provide better understating of the crash characteristics of expressway long tunnels. The crash rate was found the highest in the entrance zone (zone 2), followed by the access zone (zone 1) as the second highest among all the zones defined. Upon disaggregation by crash type, rear-end collision represent the major type of crashes, especially at the access, entrance and transition zones of the tunnel. But in the mid-section and exit part of the tunnel, single-vehicle crashes (collision with fixed object and rollover) increases. The study also found that in the access, entrance and transition zones, failure to main safe distance, improper braking and breaking the rule mainly contribute to crashes. In the mid-zone, along with failure to maintain safe distance, fatigue driving, over speeding and improper lane change also contributes to crashes. At the exit zones, over speeding, improper lane are the main contributing factors. This zoning approach finds that the crash factors for different zones of the tunnel are different, which is crucial to provide better countermeasures to improve tunnel safety.

The empirical results of the present study have the following implications. It is recommended to set up a buffer zone of gradually varying speed to eliminate the difference in the speed limits between the open stretch of road and the tunnel. Thus, drivers can adapt the tunnel's design speed without reducing the headway and can avoid a lot of rear-end crashes. Second, due to a large speed variation in the tunnel (resulting in the high rate of the rear-end crashes), advanced speed management system like a variable speed limit system (VSL) can be introduced. VSL have been proven effective in increasing average headways and reducing variances in speed and therefore reducing freeway crashes (18). Third, night performance pavement markings such as yellow lane-lines and white edge-lines or fixed medium (if necessary) should be installed to avoid improper lane change, particularly at the exit part of the tunnel.

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Analysis on Curative Expenditure on Child Injury in Northwest China: Based on SHA 2011

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Abstract

To estimate child injury curative expenditure in Gansu Province based on the System of Health Accounts 2011(SHA2011), and to analyze the expenditure by financing schemes and health providers to provide the scientific basis for the control of child injury expenditure. Based on the SHA 2011 framework and the connection with the provided characteristics of children health services, it is estimated that the aggregate of curative care expenditure on child injury, as well as the health expenditure was accounted from the aspects of financing programs, flows of institutions, service function and beneficiary population. The sample institutions were gained through multi-stage stratification sampling. The total amount of curative care expenditure for child injury in 2014 was 253.48 million Yuan, accounting for 9.60% of curative care expenditure on total injury. The top five injuries with the highest treatment costs were head injury, shoulder and upper arm injury, ankle and foot injury and knee and calf injury. The patients aged between 2~7 years old, accounted for 50.33% of the whole age range, consumed the largest share of curative expenditure. Males consumed more than the females. The inpatient services medical expenditure on child injury accounted for 75.66%. The medical expenditure on child injury was main flow to the hospitals(83.84%) and primary health care institutions (9.28%), while the former taking the inpatient expenditure as a major part, and the latter taking the outpatient expenditure as a major part. The health resources consumed by child injury in male were higher than female and the 2~7 years old group was the focus of injury. The distribution of the expenditure by health provider was unreasonable. It is necessary to intensify health inventions for child injury, and we also need to optimize the health resource allocation of child injury in different levels of medical institutions.

Keywords: System of Health Accounts 2011; injury; child; curative expenditure

1 INTRODUCTION

Injuries pose a great health threat for children in many countries. The burden of child injuries worldwide is disproportionately concentrated in low and middle-income countries^[1-4]. The mortality due to disease has declined during the 20th century, but for a long time the child injury mortality rate has been continually rising and has only recently started to decline. In New Zealand, injury kills more children (ages 1–14 years) than other diseases^[5]. In recent years, the financial burdens of the injury have become some of the popular topics in the world. According to one analysis, unintentional injury received less US government expenditure, relative to its cost to society than a variety of other public health concerns, including cancer, AIDS and heart disease. Injury has been described as ‘the last major plague of the young’^[6]. In the 1998 fiscal year, the Health Funding Authority (HFA) of New Zealand spent \$3.7 million on injury prevention, less than 5% of its annual budget (HFA, pers. comm, 1999). The injuries in the children lead to higher health care expenditure than other population. It is the first time that we used a new system of health account, System of Health Account 2011 (SHA 2011), to account curative care expenditure(CCE) in child injury ,The CCE is different from health care expenditure , which refers to the expenditure of direct treatment that does not include the expenditure of prevention^[7].

A new manual of System of Health Accounts (SHA) 2011, was published jointly by the Organization for Economic Cooperation and Development (OECD), Eurostat, and World Health Organization in 2011^[8]. The System of Health Accounts (SHA) 2011 is the current international standard for health accounting^[9]. SHA 2011 could precisely count the expenditure burden of child injury, and can analysis

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population distribution on curative care expenditure in a more comprehensive and reasonable way, such as scale of curative care expenditure of child injury, fund raising, etc. In addition, SHA 2011 also could sufficiently analyze curative care expenditure in aspect of age-specific, sex-specific, and disease-specific on curative care expenditure^[10,11].

Gansu is located in northwest China with a low level of urbanization and agricultural population and it is also one of the poorest provinces in China due to the environmental conditions. In Gansu, total health expenditure has increased from 917.06 billion RMB in 2004 (1 USD \approx 6.22 RMB, 2014) to 5748.58 billion RMB in 2014 (1 USD \approx 8.27 RMB, 2014)^[12]. The excessive growth of health expenditure turns out to be a hotspot in our society at present. In Gansu, which has the lowest per capita GDP in China, the child injury spending is especially serious. Injury is also the leading cause of death, significant disability, and utilization of acute medical care in children and adolescents, it is also a heavy burden on both our government and individuals, How to solve the issue of “being unaffordable and difficult to see a doctor” has become the key point and difficulty in the course of our medical care reform^[13]. Therefore, hospitalization curative care expenditure occupied the most part in medical institution. Many studies focus on methodological discussions of National Health Accounts and SHA 2011 and the total health expenditure for all populations and disease categories, the study of the curative care expenditure in child injury is extremely rare. In the present study, we aim to describe the aggregate of curative care expenditure of child (0–14 years) injury, as well as the health expenditure that was accounted from the aspects of flows of institutions, service function and beneficiary population.

2 METHOD

2.1 Data

Data was obtained from the 2014 Gansu Health Statistical Yearbook, 2014 Gansu Health Financial Yearbook, China National Health Accounts Report 2014, Gansu Health Accounts Report 2014, etc. Study sample was obtained from 2014 Gansu statistical yearbook, medical institutions, and public health institutions. The data used in our study was investigated with multistage stratified cluster random sampling.

Step I: Choose sample cities from Gansu province based on the level of economic development. The perfection of health information management system should be taken into consideration. Thus we selected three cities, Dingxi, Tianshui and Wuwei.

Step II: Select two counties, one district, and then selected five township hospitals and community health service organizations in each country and district.

Step III: Six village clinics and private clinics were selected from rural town or community.

Finally, 11 provincial-level hospitals, 27 city-level hospitals, 48 county-level hospitals and 50 private clinics, 87 village clinics and health centers have been chosen. A total of about 3.6 million data was collected and collated. In addition, we also retrieved New Rural Cooperative Medical System (NCMS) data from local NCMS Management office in six counties and collated almost 2.4 million of them. The basic information included gender, age, season, disease, expense, region, etc. The diagnosis of the diseases was coded according to the International Classification of Disease Tenth Revision (ICD-10). There were nearly 6 million data samples after excluding the invalid or wrong message.

2.2 Method

In this study, we used a new system of health account, A System of Health Accounts 2011 (SHA 2011), to account curative care expenditure (CCE) in the child injury^[14]. The top-down approach was used to calculate the CCE, we focus on hospital care, then distribute the reliable administrative data to the sample data. By estimating disease specific expenditures in such a top-down approach, it is possible to aggregate (by age, sex) and disaggregate the various components to ensure that no double counting occurs.

2.2.1 Curative care expenditure accounted

The CCE contained curative income and basic expenditure allowance, which refer to outpatient and inpatient. The formula is shown as follows:

$$S_{CCE} = \sum_{k=1} (Sk\ inc + Sk\ sub) \tag{1}$$

In the above formula, *Sk inc* and *Sk sub* represent the curative income and basic expenditure allowance respectively in different medical institutions. The formula of curative income is as follows:

$$Sinc = Stinc \left(\frac{totalexp}{totalexpsum - totalexpprev} \right) \tag{2}$$

$$Sinc' = Stinc \left(Sinc \times \frac{totalexp}{totalexpsum - totalexpprev} \right) \tag{3}$$

Above all of the formulas, curative income in per patient from the sample is denoted as *totalexp*, total curative income is denoted as *totalexpsum*. Add all samples containing preventive service on the basis of ICD-10, denoted as *totalexpprev*, per patient sharing coefficient denoted by $\frac{totalexp}{totalexpsum - totalexpprev}$.

Moreover, *Sinc* represents the income of outpatient and inpatient from 2015 Gansu Health Statistical Yearbook and 2015 Gansu Health Financial Yearbook. The purpose of formula (2) is to remove prevention expenditure in patient, and the formula of *Sinc* is to account the curative income in patient with the same age, gender, region, etc. The formula (3) means that could calculate curative income in various dimensions, such as age, disease, etc. Those formulas about basic expenditure allowance were similar to curative income. Curative income and basic expenditure allowance for child injury shared by above ways. Mark off the different dimensions in age, gender, etc. According to the results, the total curative care expenditure in different age, sex, disease, etc. all could account from above formulas.

3 RESULTS

3.1 Fundamental results in curative care expenditure for child injury

The CCE in 2014 for child injury and above was 2.535 billion RMB, accounting for 7.48% of curative care expenditure for child injury in all disease classification in Gansu Province, and per capita was 183.226 RMB under the age of 14, the outpatient was about 6230.44 million RMB and accounted 24.80 % in all (Table 1).

Table 1. Comparison the fundamental results in curative expenditure between inpatient and outpatient in child injury in 2014 (ten thousand RMB)

Institution Types	outpatient		inpatient		total	
	cost	%	cost	%	cost	%
General Hospital	2919.98	46.87	15870.34	83.01	18790.32	74.13
Hospital of Chinese medicine	604.72	9.71	1857.13	9.71	2461.85	9.71
Specialist Hospital	62.96	1.01	126.43	0.66	189.39	0.75
Basic Medical Institutions	1999.23	32.09	353.80	1.85	2353.03	9.28
Maternal and Child Health Hospital	533.71	8.57	910.29	4.76	1444.00	5.70
Out-patient Department	109.84	1.76	0	0.00	109.84	0.43
Total	6230.44	100	19117.99	100	25348.43	100

3.2 Allocation of medical institutions for the child injury in curative care expenditure

Most of the curative care expenditure for the child injury was in the hospital (general hospital, traditional Chinese medicine hospital and Basic Medical Institutions), accounting for 93.12%. Maternal and Child Health Hospital was followed (5.70%). The expenditure occurring in the specialist hospital and Out-patient Department was 2.99 million rare in total expenditure. In general, the curative care expenditure in outpatient and inpatient accounted for 24.58% and 75.42% respectively. From the result, it is observed that child injury patients spent a lot of CCE in the hospital rather than in other medical institutions which has a small percentage of curative care expenditure. (Table 1).

3.3 Disease

The expenditure of different parts of injury (according to the ICD-10) expenditures on injury were collected according to the ICD-10 chapter(S00-T98), the top four of CCE in disease classification were the head injury, shoulder and upper arm injury, ankle and foot injury, knee and calf injury. More than 50% in CCE, about 150.37 million RMB. Besides, Chest Injury, Elbow and forearm Injury were 29.35 million RMB, also high in CCE (Table 2), In terms of ICD-10, the highest expenditure happened in head Injury.

Table 2. The CCE of diseases classified by ICD-10 in different service function (ten thousand RMB)

ICD-10	Outpatient		inpatient		total	
	cost	%	cost	%	cost	%
Head Injury	1762.92	28.30	6288.46	32.89	8051.38	31.76
Shoulder and upper arm Injury	257.29	4.13	2466.34	12.90	2723.63	10.74
Ankle and foot Injury	1930.11	30.98	595.31	3.11	2525.42	9.96
Knee and calf Injury	195.74	3.14	1540.94	8.06	1736.68	6.85
Abdomen, lumbar spine lower pelvic bone	112.19	1.80	1467.57	7.68	1579.76	6.23
Chest Injury	31.10	0.50	1528.74	8.00	1559.84	6.15
Elbow and forearm Injury	406.01	6.52	969.26	5.07	1375.27	5.43
Buttocks and thigh Injury	39.97	0.64	1224.71	6.41	1264.68	4.99
Undefined damage to the trunk, limbs or body parts	641.92	10.30	411.03	2.15	1052.95	4.15
Burn and corrosion	308.55	4.95	563.42	2.95	871.97	3.44
Neck damage	5.65	0.09	672.31	3.52	677.96	2.67
Hand and wrist	79.56	1.28	363.23	1.90	442.79	1.75
Surgical and medical care complications NEC	8.00	0.13	310.59	1.62	318.59	1.26
Influence of foreign matter entering through natural orifice	143.60	2.30	172.42	0.90	316.02	1.25
Involved in multiple parts of the body injury	139.13	2.23	161.14	0.84	300.27	1.18
The main source of non-toxic substances from toxic effects	59.98	0.96	224.22	1.17	284.20	1.12
Other and undefined exogenous inf	68.77	1.10	33.43	0.17	102.20	0.40
Poisoning caused by drugs, agents and biological substances	6.94	0.11	68.74	0.36	75.68	0.30
Damage, poisoning and other sequelae of exogenous consequences	19.54	0.31	43.89	0.23	63.43	0.25
Some of the early complications of trauma	13.45	0.22	12.25	0.06	25.70	0.10
Frostbite	0.01	0.00	0.00	0.00	0.01	0.00
Total	6230.44	100	19117.99	100	25348.43	100

3.4 Age and Gender

From Figure 1, we compared the expenditure of age groups between male and female. The boy's expenditure on injury was about 169.50 million RMB, and the girl is lower than boy which is 82.97 million RMB. For the boys, the spending focused on the age between 2~4, 6~7 and 12~15 years old, was responsible for the majority of expenditure(accounted 57.57%). For the girls, the expenditure of age groups was different from boys, was between 3~4 and 12~13 years (accounted 57.57%). Above all, the distribution of injury had different performance in different age and different gender.

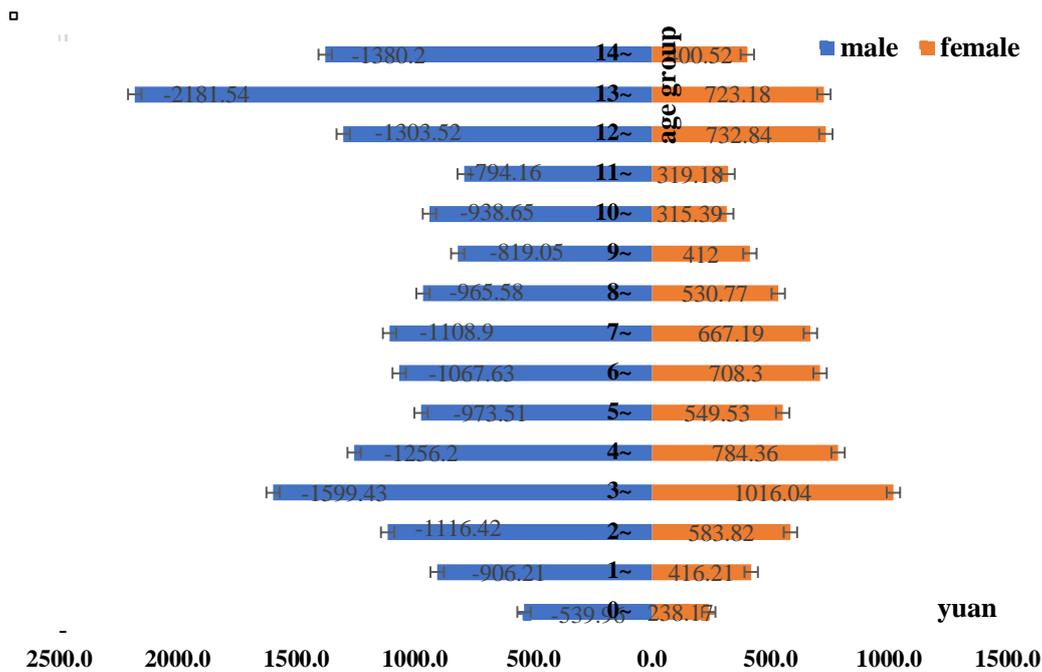


Figure 1. The CCE between males and females in child injury in 2014

4 DISCUSSION

We analyzed the curative care expenditure of child injury based on SHA 2011 comprehensively, including distribution in age, disease, medical institution and service function.

4.1 How is the curative expenditure on child injury flowing into medical institutions?

From the results of SHA 2011, it is observed that the CCE spending on child injury was much higher in the hospitals than other medical institutions. For example, Hospital of Chinese medicine as well as basic Medical Institutions (township hospital, community health service center), specialist hospitals and out-patient department all had a small percentage of curative care expenditure (Table1). Furthermore, the health resources allocation in Gansu was uneven, the distribution of health resources is unreasonable, and the health resources are deficient in the rural area^[15]. One reason is medical resources prefer to flow to the places or institutions where the medical institutions have huge purchasing power and high-level surgical treatment lies. Cause of lacking medical workers, financial and other resources in basic medical and health institutions, child patients and his guardian are more willing to go to a hospital. Peter’s analysis of Europe’s decades of medical reform thought to think more reasonable allocation of health resources can effectively alleviate the economic burden caused by decomposition damage in different institutions^[16].

The number of health institutions and health technicians in Gansu province are in medium level in China. However, in 2014, the government health investments in Gansu province (the government health expenditure made up 21.7% of the total health expenses was much higher than other financial sources, where the government health expenditure were 36.45% in the total health expenses in Gansu^[17]. Changing the distribution of medical resources and solving the problem of payment mechanism are necessary. If the new round of health care reform wanted to achieve universal coverage of basic medical services in 2020, it requires us to consider the accessibility and affordability of medical service, and research on priority resources allocation is contributing to the sustainable development of our country’s medical system^[18].

We also found that child injury’s hospitalization expenditure took the largest proportion in the CCE. Because the major part of child injury needs emergency or hospital treatment. The care and recovery of injury need time, which leads to high hospitalization expenditure.

4.2 The financial burden of child injury in different age group

For children between 2~7 and 12~14 years old, the CCE was found to constitute 71.62% of the CCE in all age groups, while for children in other age group it was 28.38%. Age is a known risk factor for child injury. Some studies found that children aged 10 years old have the greatest risk of being injured. This result is similar to those of the studies conducted in France, the U.S., and the Europe^[19-21].

From the perspective of curative care expenditure, the CCE for children between 3~4 years old is high. The reason is that they begin to have a sense of autonomous activity, but their ability to judge safety and danger is insufficient. Besides, the CCE for children between 13~14 years old is also the highest among all age groups. The probable reason is the confluence of developing mobility and underdeveloped cognition in children of this age. On the one hand, children of this age begin to show their mobility and independence without adult supervision. On the other hand, children of this age are not yet cognitively capable of simultaneously handling the several tasks required for safe pedestrian activity^[22], parents and their children themselves overestimate children's ability to cross streets and parking lots independently^[23].

There is also a gender difference CCE in injuries, the results of the study showed that the curative care expenditure of the injury in male was much higher than that of female, which means males take the heavy burden. Not merely in China, but also in other developing and even developed countries, there is also heavy burden on the boys^[24]. This difference may be attributed to two reasons, males are known to have a higher rate of injury hospitalizations than females may be the most significant reason, which is likely to be as a consequence of their higher risk taking. A number of studies have demonstrated that among children, boys are more frequently injured as pedestrians than girls^[25,26]. There are several explanations for the gender disparity in pedestrian injuries. First, boys tend to have more impulsive, uncontrolled behavioral styles that lead to higher risk for injury^[22]. Second, boys are more likely to overestimate their physical ability, which can lead to more repeated injury - risk behavior than girls^[27]. Third, societal expectations and gender role socialization influence risk^[28]. Boys are expected and permitted to take greater risks and to approach physical hazards more quickly and fearlessly^[29].

4.3 The burden of different injured parts

Head injuries (31.76%), shoulder and upper arm injuries (10.74%), ankle and foot injuries (9.96%) is the three most higher cost injury diagnoses in all injury parts. The proportion of head injuries remains high. These same injury types are also the most common in Chinese study of children. Besides, the large number of head injuries is particularly concerning. Children with multiple head injuries are at increased risk for long-term sequelae, which may lead long-term medical expenses^[30-32]. Patients spent more on upper limb injuries than lower limb injuries because children have more cases of upper limb injuries.

4.4 How to take measures to reduce the incidence of injuries, thereby reducing the cost of injury?

If policy making and resource allocation are made based on the scientific pieces of evidence, an enormous amount of capital can be saved through reducing death and injury rates. This method seems to be a precise method to traffic injury cost estimation than human capital method. We can effectively control the cost of the disease if triple prevention is applied for child injury. For children who have high risk of getting injured, the government can provide a suitable prognostic measure to prevent further deterioration and improve the overall outcome for the individual. Priority is given to shelter the high-risk children, which could shorten the length of stay and hospitalization expenditure.

Almost all of the children are unable to work and relying on their guardian, and they have to be raised by parents, which makes the family under a heavy economic pressure. So endowment insurance needs to be expanded. And designing specific type of insurance for children is increasing reimbursement when they get injured. In our research, the proportion of commercial insurance financing is very low. The commercial insurance market of our country develops relatively late and far less than developed countries. What's more, the reimbursement of commercial insurance is aimed at inpatient, rarely in outpatient. The government should introduce appropriate policies to encourage the development of commercial insurance particular for major medical expenditure, and not only in hospitalization, but in outpatient who needs medical insurance as well.

Given the cost of these injuries, and the projection that hospitalization rates will continue to increase^[33], targeted preventive strategies to increase playground safety are necessary. For example,

reducing risk-taking behavior, through hazard awareness, engagement in advocacy and communication about risk-taking on playgrounds, and the Stamp in Safety programme develops supervision skills in teachers and caregivers. There is a clear need for further targeted child injury prevention programmes, advocacy and educational campaigns to increase awareness of playground safety and reduce hospitalization rates of children.^[34-36] Injury prevention campaigns need to focus on the specific types of equipment that are associated with falls, the location of the playground equipment, the age groups of children who are getting injured and the most common types of injuries occurring.

There are several limitations of this study. First, although this study can report overall financial burden as they exclude carer's leave, transport costs, ongoing medication costs and private medical costs, as well as the long-term disability, and psychosocial impact of child injury and their family. Then, the ICD-10 in hospitalizations was coded as occurring on 'other' or 'unspecified' types of equipment. These gaps highlight the need for improved improving the report on reporting of injury circumstances in hospitals, to allow more comprehensive injury surveillance.

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Urban structures and traffic safety – a systemic interdisciplinary approach

Hermann Knoflacher^{1a}

“When you change the way you look at things, the things you look at change.” Max Planck

Abstract

Thousand years of urban development followed principles of human scale to provide a safe environment. Availability of fossil fuels and new technical transport modes were new phenomena for human civilisation. One attempt to overcome some unwanted effects of the new technologies was the Charter of Athens defining principles for a new urbanism based on technical transport modes. Plausible assumptions, not sound science, became the base of land use, urban and transport planning. When traffic accidents happened 95% of accidents were assigned to ‘human failure’. Therefore, no transdisciplinary scientific system analysis seemed necessary and neither was the real behaviour of the system studied. If we consider the intermodal effects and interrelations between transport and patterns of urban structures, a cause-related treatment of traffic safety is possible. This new approach enhances the understanding of importance of structural effects of traffic safety measures not only in the transport system, but also that of urban and land use structures. Parking organization and urban planning standards came so into the focus as key traffic safety measures, since they are the decisive factor for urban structures and human behaviour. Some of the contradictions between physical reality and expected effects of road transport principles can be resolved.

Keywords: Urban and transport planning principles, system structure, human and system behaviour, urban motorway and safety, paradigm shift.

1 INTRODUCTION

Cities are probably the most complex manmade artificial structures human societies have developed over the last 8,000 years. For most of this time walking was by far the dominant transport mode, other modes, such as animal pulled vehicles and boats, played only a limited role. In the 19th century this changed with the invention of railway and the industrial revolution which resulted in the migration of people from rural areas to cities. The quality of life in the new working-class districts was not particularly good with problems such as air pollution, poor sanitation, poor housing and high population densities. These “unexpected” problems fuelled social and political unrest and demands for solutions.

2 THE URBAN STRUCTURES OF THE CHARTER OF ATHENS 1933

As a reaction on these experiences, architects developed ideas and recommendations how urban structures should be built and organized in the future. Towns were divided into zones assigned to different areas for working, living, leisure time activities and traffic. This separation of functions corresponded to the key concepts of modern town building that were later propagated in the "Charter of Athens", which has influenced urban planners since the 1930s. The result (worldview) of their ‘analysis’ were the ‘Four Functions of the City’: Dwelling, Recreation, Work, Transportation.² The following were the recommendations of the Charter on transportation:

“51. The existing network of urban communications has arisen from an agglomeration of the aids roads of major traffic routes. In Europe these major routes date back well into the middle ages, sometimes even into antiquity.

52. Devised for the use of pedestrians and horse drawn vehicles, they are inadequate for today's mechanized transportation.

53. These inappropriate street dimensions prevent the effective use of mechanized vehicles at speeds corresponding to urban pressure.

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² Charter of Athens, <http://portal.uur.cz/pdf/charter-of-athens-1933.pdf>

54. Distances between crossroads are too infrequent.
55. Street widths are insufficient. Their widening is difficult and often ineffectual.
56. Faced by the needs of high-speed vehicles, present the apparently irrational street pattern lacks efficiency and flexibility, differentiation and order.
57. Relics of a former pompous magnificence designed for special monumental effects often complicate traffic circulation.
58. In many cases the railroad system presents a serious obstacle to well-planned urban development. It barricades off certain residential districts, depriving them from easy contact with the most vital elements of the city.”

The recommendations derived from that analysis were carefully worded in the subchapters 59 – 64:

“It Is Recommended That

59. Traffic analyses be made, based on accurate statistics, to show the general pattern of circulation in the city and its region, and reveal the location of heavily travelled routes and the types of their traffic.
60. Transportation routes should be classified according to their nature, and be designed to meet the requirements and speeds of specific types of vehicles.
61. Heavily used traffic junctions should be designed for continuous passage of vehicles, using different levels.
62. Pedestrian routes and automobile routes should follow separate paths.
63. Roads should be differentiated according to their functions: residential streets, promenades, through roads, major highways, etc.
64. In principle, heavy traffic routes should be insulated by green belts.”

These recommendations became the “paradigm” for urban and transport planning in the 20th century. This concept was based on ethics of opinion and not on ethics of responsibility (Max Weber 1864 - 1920).³ The points 51 – 64 of the Charter were never questioned by urban and transport planners. The contradiction between chapter D and the other chapters of the Charter was not recognised.

Keeping car traffic flowing at reasonably high speeds became a goal for urban structure design, as well as the separation of pedestrians and cars. Rail based public transport was seen as an obstacle for the future. Point 60 is an order to build and organize the city around the needs of motorized vehicles. The disciplines to tackle these new challenges in urban, land use and transport planning, and standards for design and construction of vehicles, infrastructure and operation were established. The human scale of historical cities was lost, which gave the planners – and politicians - unlimited freedom.

3 UNEXPECTED AND UNWANTED EFFECTS

Engineers, architects and later the newly established departments in universities for land use and urban and traffic planning began to execute such ideas. Technical guidelines to design and build the environment in order to serve car traffic were drafted based on elementary physics, assumptions about human behaviour and personal experiences. The engineers, as well as all other disciplines responsible for the transport system had no knowledge or evolutionary experience about the effects of this new fast personal vehicle. The motor car exceeded human power and speed multifold, but the brain of the driver was still that of the pedestrian and had not developed to cope with this new situation. Nor had the brains of engineers, urban planners and politicians. When the private cars gained momentum as the main mode of transport in the cities, the unexpected and unwanted symptoms of the existing theories and ideas, started becoming evident. Road traffic accidents were the first of the unwanted effects of these new urban planning principles, followed by noise and air pollution. Ironically, this was precisely what the authors of the Charter of Athens wanted to prevent with their new planning principles. Increase in accidents was not anticipated in the proposed planning process and it came as a surprise for the representatives of the planning disciplines dealing with these new tools for the ‘modern transport

³ Weber, M. <https://www.britannica.com/biography/Max-Weber-German-sociologist>

system'. The assumption was that the road user must be the cause of these events. As a result 95% of accidents were assigned to 'human failure'.

Building codes had to comply with "the existing and future needs of car traffic" (1) and formed the new city shape, scale and use of space and functions. New traffic regulations changed the face of urban space and the behaviour of its users.

3.1 Accidents are one of the symptoms

Traffic accident and injuries were unexpected and unwanted effects and not an issue to be tackled by town planners for decades. Engineering disciplines began to pick up this subject first. USA became the leader in road design and traffic engineering, developing the blueprint for the rest of the world. The fact that the US had no historical urban tradition did not count, because it was not considered to be relevant at that time. Accidents were an accepted byproduct of a fast development toward human wealth and finally a drive for growth or at least a leading indicator for it. The increase of motorization was so impressive that the professions working on urban transport had to cope with the pace and needs of making physical mobility convenient and fast. They instinctively believed that in a linear growth of motorization with per-capita incomes (Figure 1). An untenable position for any discipline of science. But they developed a paradigm based on extrapolation of individual experience, plausible explanations and attractive ideas: the (still) dominant paradigm in urban and transport planning.

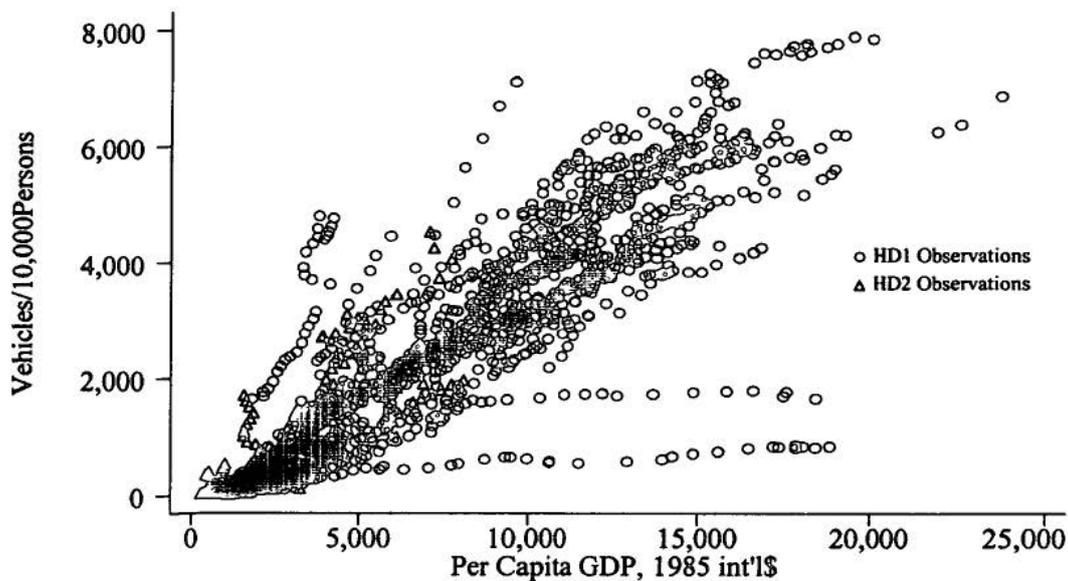


Figure 1. Motorization rate vs. income: All countries and years (2)

4 THE TRADITIONAL PARADIGM

The car became the unit of scale for land use, urban and transport planning. The Highway Capacity Manual (3) became the 'bible' for transport planning and traffic engineering. Transport economists proved the benefits by calculating 'time saving' or faster transport systems as justification to invest billions of dollars in fast transport modes and its infrastructure. Motorways in and around cities to solve transport problems in the crowded and continuously expanding cities were designed and built, based on these principles. Improving traffic safety was an argument for promoting such projects also.

4.1 Traffic safety questioning traditional paradigm

With increasing number of accidents and road traffic victims questioning the paradigm became necessary. Accidents are the visible outcomes associated with risk in a transport system. First, the obvious effect of speed became partly clear: once enhanced from 2 to 30 miles per hour (50 km/h) and even more,⁴ was lowered to 30

⁴ UK Speed limits 2018, <https://www.autoexpress.co.uk/car-news/98575/uk-speed-limits-everything-you-need-to-know>

km/h and even to a lower level to make urban roads safer.⁵ This happened in Europe in the late 1960s and 1970s.⁶

These measures reduce traffic accidents and were developed further with other concepts such as ‘Traffic Calming Measures’. The fundamental concept of time saving by fast transport systems, had not yet been questioned, although some doubts, whether it is valid, came up in the literature (4). Questioning the space provided and used by cars came later in the 1960s. However, science and empirical proof from traffic accident studies began to undermine existing urban road design standards. New recommendations for urban roads based on sound theory and empirical results were developed, taking into account not only the needs of car traffic, but also the non-motorized road users (5).

It was the beginning of basic research in transport science, which had not developed since Lill’s law at the end of the 19th century.⁷ One of the early findings was the relationship between speed and lane width. Human physiology, mathematics and traffic engineering contributed to understand the processes in our brain and body, which enable us to drive with a high speed on narrow lanes. Wider lanes encourage higher speed. Lane width and road width were dependent on the hierarchy of road types. National roads had 3.75 m wide lanes also in urban areas, without exception. Tables 1a and b shows the proper lane width in accord with the speed limits (6).

Table 1a. Lane width and average speed

width of lane	Speed			ART	Anwendung
	Truck	BUS	PKW		
3,75 m	krit.	110	140	one way road	Rural road
3,50 m	80	100	125		
3,25 m	70	80	110		
3,00 m	60	70	90		
3,00 m	60				Urban road
2,75 m	50				
2,50 m	50				
2,50 m	50				
3,75 m	krit.	105	120	Two way roads	Rural road
3,50 m	80	90	110		
3,25 m	70	80	100		
3,00 m	60		80		
3,00 m	50				Urban road
2,75 m	50				
2,50 m	50				
2,50 m	50				

Table 1b. Lane width and 85% speed.

$v_{50\%b_a}$ [km/h]	b_f [m] PKW		b_f [m] LKW	
	RV	GV	RV	GV
40	2,05	2,15	2,55	2,65
50	2,10	2,30	2,65	2,75
60	2,25	2,45	2,75	2,85
70	2,40	2,60	2,90	3,00
80	2,55	2,75	3,00	3,15
100	2,90	3,05	3,30	3,45
120	3,25	3,45		
130	3,40	3,60		

RV – one way traffic
GV – two way traffic
V50% - average speed

⁵ RP Online 2013, https://rp-online.de/leben/auto/news/30-jahre-tempo-30-zone_aid-14606007

⁶ Fakten aus Berlin 2017, <http://de.30kmh.eu/fakten-aus-europaeischen-staedten/berlin/>

⁷ Lill Eduard 1830 - 1900 https://en.wikipedia.org/wiki/Eduard_Lill

5 COLLAPSE OF THE ‘MOBILITY GROWTH PILLAR’

During the preparation of the new Transport Masterplan for Vienna (1975 -1979), the ‘Mobility Growth Paradigm’ came into conflict with the result of an analysis of cycling infrastructure and use of cycles (Knoflacher H 1979). There were now two diagrams, one for cycling and the traditional one for motorization. Both related to ‘mobility’, which mean, trips in public space. The question came up: What is the cause for making trips? The cause is in the origin and destination. What you need, but do not find at home, you have to satisfy by traveling to a destination. The number of daily needs is not dependent on cars, they are on the need for working, shopping, education, leisure, social contact etc. Household travel surveys show that the average number of trips remain constant. It is a system-constant, with a big variation among age groups, professions etc. It has not changed with the increasing car ownership.

If we define mobility as purposeful travel, which means every trip (in public space) has a purpose, ‘mobility growth’ can only happen if the number of people and/or purposes for travel in the society increase. However, the average number of daily trips per person is around 3 – 4 trips per day, independent of the method of counting or the lengths of trips. This has fundamental consequences for transport or urban-planning. We cannot follow a miraculous ‘growth of mobility’ by building more roads anymore; we have to decide about the share of the modes, which modes we want to have in the system. We have to decide if we support the safe modes with low risk or the fast modes with high risk.

5.1 No travel-time-saving benefits by enhancing speed

Investments in transport infrastructure have been based on the benefits from travel time saving. Based on empirical data Zahavi (4) hypothesized the constant travel time budget for car traffic by analysing travel time distributions and budgets in European cities, and found that travel time budgets distributions for various modes were not different if system speeds changed. The visible effects of increases in speed are urban sprawl and the appearance of big shopping centres outside of cities. As a result, more and more travel kilometres become necessary to satisfy daily needs. At the same time the closing of local shops and workshops happens which has negative effects on the society and local economy. When the distance between home and daily life activities/duties increases, some modes become more necessary. More car kilometres come into the system with more risk, and as a result more accidents occur. Traffic accidents, noise and air pollution are symptoms of these changes in mobility. This has far reaching consequences for transport planning and traffic management. When people prefer to use the car or are forced to do so has multiple effects:

- the dimension of public space has to accommodate the needs of car traffic everywhere,
- causes conflicts with all other road users,
- enhances risk in public space,
- high speed is brought into public space,
- due to time constancy the individual car user has a greater freedom in space
- public transit loses customers,
- increase in noise and air pollution etc.

Vulnerable road users are suppressed, due to the presence of cars in public space. Public space in cities get converted by this practice into a life endangering hostile environment and barriers for all other kinds of mobility. The life supporting and life enjoying public spaces, keeping societies in villages and cities together, are now divided by car lanes and high speed (faster than walking and cycling). The widespread provision of parking spaces is the real cause of many later problems, from congestion to accidents (7). These are the ingredients that endanger human life, destroy the human scale of cities and villages, undermine public transport, contribute to climate change and the dominance of corporations over democracies. It has established enormous concentration of power in all kinds of industries developed to exploit the global resources in an unimaginable pace.

6 THE NEW PARADIGM

The new paradigm based on science and empirical evidence can prevent these negative effects, but success will depend on system understanding above the level of narrow thinking professional disciplines. Developed more than four decades ago, published in textbooks and successfully implemented in many cities, these principles are based on the following understanding:

- The number of trips in the system is constant.
- The travel time budget in the system is constant,
- Structures determine the behaviour of the system users.

Modal split is the new indicator, replacing ‘Mobility Growth’. Speed has lost its core position and replaced by sustainable compact urban structures that supporting walking, cycling and public transport use. Congestion should no longer be considered a problem, but as a tool to help people to choose the sustainable modes and parking private cars should be banned/discouraged from city centres.

The consequence is the need to change the urban structures if we want to live in a safe urban environment. Therefore, the basic relationship between structure and behaviour (of people and the system) and effects (Figure 2), in our case accidents, must be considered carefully. The feedback loops are not linear indicating the responsibility of planners for the effects of their structures (8).

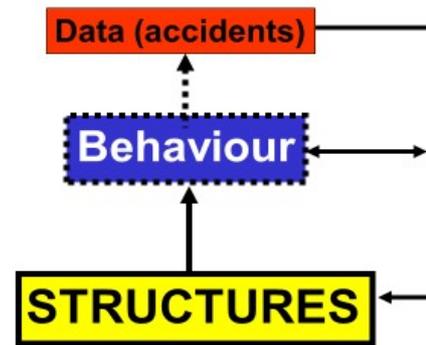


Figure 2. Basic relationship between data, behaviour and structures.

Structures are people, the society, the social, cultural, political structures as well as the administrative, scientific, physical, legal, financial and organizational structures. There are feedbacks between the entities in the diagram. Most of the relationships are not linear. Structures are always hierarchical, some of them are dominant, some of minor importance or more symptomatic. In the man-made transport system of today, these structures produce accidents, injuries, damage, air pollution etc. in- and outside of cities. Cities are the main origins and destinations of human mobility. Their structures determine the system behaviour.

Since the structures of modern cities developed on a wrong paradigm, they became the core of the transport problems of today. A structural change will be necessary to make the ‘Vision Zero’ a reality. By implementing the principles of the new paradigm, the ‘Vision Zero’ is not a vision any more, it is the logical outcome of land use, urban and transport planning based on the new paradigm. Between scientific findings, knowledge gained and practical implementation is a big gap exist with many barriers to overcome.

Table 2. Modal choice, energy consumption, pollution, accidents.

Cities	Modal split (walking+cycling+PT)	Energy consumption (Mj/inhab./year)	Pollutant gas emissions (kg/inhab./year)	Annual number of people killed in road accidents (per million inhabitants)
Houston	4.5 %	86,000	330	130
New York	25 %	43,000	170	95
Paris	56 %	15,500	120	85
Munich	60 %	17,500	110	55
Singapore	47 %	12,000	75	80
Hong Kong	82 %	6,500	25	40

(Source : Millennium Cities Database ; UITP - Murdoch University)

7 URBAN STRUCTURE A CAUSE OF TRAFFIC ACCIDENTS?

The old paradigm, based on assumptions about behaviour in a transport environment, which was far removed from actual human experience evolved from plausible assumptions and naïve extrapolations of individual experience. This is the background of urban structures of today. For more than four decades a new science based paradigm has been available, however, the process of its implementation is very difficult and slow moving. There are indicators, which show that urban structures determine traffic safety in the cities, at least on a global scale if we compare typical urban structures from different continents. Table 2 shows the effects of motorization and car use on energy consumption, pollution and road victims in cities and Figure 3 shows the relationship between car-use and traffic deaths in cities (9). This selection of six cities gives an idea of a simple and clear relationship between share of car trips and road victims.

If we look to a wider group of cities in Figure 3 (right), the picture is not so clear any more. There is a much broader spread of accident rates of global urban structures, which gives an impression of the complexity of cities and their transport system. If we select a rather homogenous group, like cities in Europe, we get results shown in

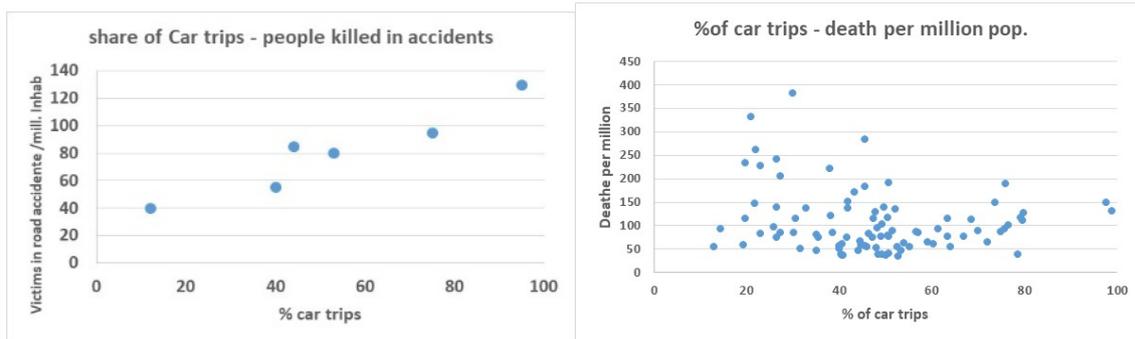


Figure 3. The relationship between car use and traffic safety in 6 cities in Table 3 (left) and for a larger group of cities in the UITP database (right)

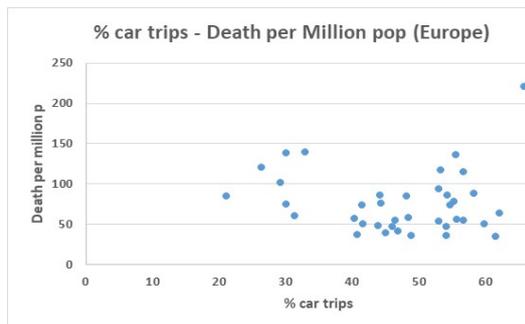


Figure 4. Percent car trips vs death rate (European cities)

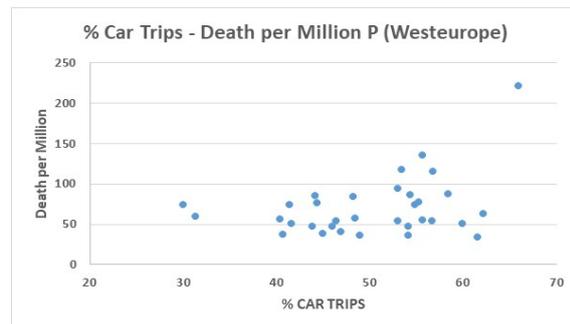


Figure 5. Percent car trips vs death rate (West European cities only)

Figures 4 and 5. European cities have a similar urban history. Between 1945 and 1989 cities motorized faster in the west than cities in the satellite-states of the Soviet Union, the urban development was also different. The analysis show that this general comparison of statistical data does not give a clear picture about the accident-producing mechanism in the cities. There is a general tendency, that increasing car use, increases the death rate, but some cities were able to keep the death rate on a low level. Not only built structures can explain the difference, but also legal, financial and organization structures influence the traffic safety in cities.

7.1 Urban road pattern and traffic safety

There are very few studies about urban road pattern and traffic safety. According to Marshall and Garrick (10) “Denser street networks with higher intersection counts per area are associated with fewer crashes across all severity levels. Conversely, increased street connectivity as well as additional travel lanes along the major streets is correlated with more crashes. Our results suggest that in assessing safety, it is important to move beyond the traditional approach of just looking at the characteristics of the street itself and examine how the interrelated factors of street network characteristics, patterns, and individual street designs interact to affect crash frequency and severity.”

An analysis of road network and road traffic crash fatality rates in these randomly selected U.S. cities by Mohan, Bangdiwala (11) shows that: (a) higher number of junctions per road length was significantly associated with a lower motor-vehicle crash and pedestrian mortality rates and, (b) increased number of kilometres of roads of any kind was associated with higher fatality rates, but an additional kilometre of main arterial road was associated with a significantly higher increase in total fatalities. When compared to non-arterial roads, the higher the ratio of highways and main arterial roads, there was an association with higher fatality rates.

These results have important implications for road safety professionals. They suggest that once the road and street structure is put in place, it will influence whether a city has low or high traffic fatality rates. A city with higher proportion of wider roads and large city blocks will tend to have higher traffic fatality rates, and therefore in turn require much more efforts in police enforcement and other road safety measures. Urban planners need to know that smaller block size with relatively less wide roads will result in lower traffic fatality rates and this needs to be incorporated at the planning stage.

In 2018 the EU-SafetyCube project was published which supports these conclusions also in its data base.⁸ The effects of an urban motorway on the traffic safety of a city analysed in Vienna over a longer period show the effect of the motorway on traffic safety of the city. It is clearly visible on the increase of accidents over a period of 15 years, till the system reached an equilibrium again (12).

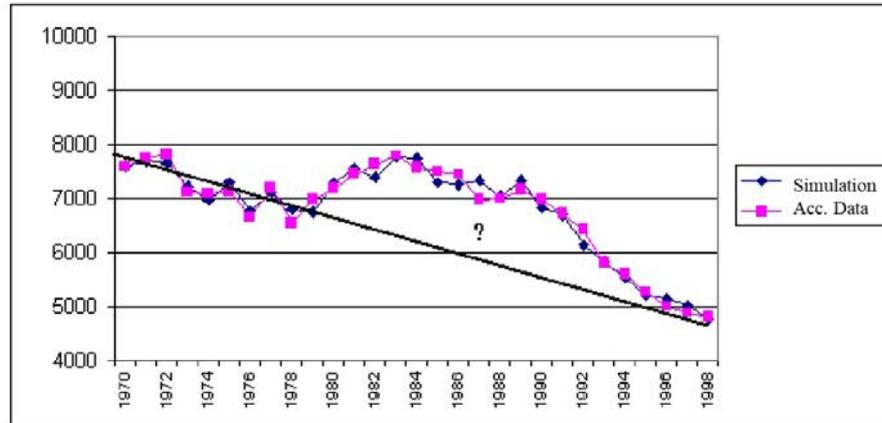


Figure 6. The downward trend of accidents in the city of Vienna interrupted with the opening of the motorway in 1978.

8 A SYSTEMIC APPROACH

Other than motorways with simple structure and rather homogenous traffic system users (in most countries), urban structures are much more complex in its grid, its environment, its functions and management. There are much more potential conflicts with a greater variety of conflict partners, especially vulnerable users in the public space. Nevertheless, the basic relationship between flow, density and speed is valid for all traffic system users, whether they are pedestrian, cyclist, motorcyclist or car-user.

$$M_i = D_i * V_i$$

M is the number of kilometers, dependent on the system speed V of a certain group of users i.

D_i is the number of the system users i.

Travel time in the system is a constant.

Each of the system users have a risk; a passive, endangered from others, as well as an active risk, endangering others (13).

Accident risk = probability of an incident and its consequences. In other words: probability of conflicts times mass, square of the speed.

$$A = \sum r_i * D_i * V_i$$

Where i is the indicator of the modes. If we want to change the number of accident in the system over a certain time T we have three opportunities

$$\delta A = \frac{\delta r_i}{\delta T} * D_i * V_i + r_i * \frac{\delta D_i}{\delta T} * V_i + r_i * D_i * \frac{\delta V_i}{\delta T}$$

We have three basic terms, if we take the simple version without all the existing interdependencies between r, D and V.

The first term $\frac{\delta r_i}{\delta T} * D_i * V_i$ represent measures, which reduce the risk of any road user by technical measures for active and/or passive safety, education, enforcement. Helmets, Safety belts, camera surveillance, bright and/or reflectorizing cloths are in this category.

The second term $r_i * \frac{\delta D_i}{\delta T} * V_i$ represent measures, which change the modal split in the system. Reduce the number of risk prone system users or remove them.

⁸ European Road Safety Decision Support System. <https://www.roadsafety-dss.eu/#/>

The third term $r_i * D_i * \frac{\delta v_i}{\delta T}$ comprise all measures, which change the speed, narrow lanes, humps, roundabout, speed cameras, speed limits and the effect of speed in the risk factor.

The consequences of a traffic accident are dependent on the collision partners, the mass and the speed. Among the four urban modes, only motorized vehicles have a risk, which exceed the risk of all other system users by several decimal powers, if it is faster than pedestrian. It is the main cause of road traffic accidents in cities and the cause of the existing unsafe urban road structures also. Public transport on the surface has the same speed like cars, but the probability of an incident is two decimal powers less

All motor vehicles bring risk into the urban system, and pedestrians and cyclists are the endangered species in the urban structures of today. If we take into account that the number of kilometres for motorized transport users is much higher than that of pedestrians and cyclists the situation among the road users in the urban environment becomes clear. Motorized vehicle users are the core of the traffic safety problem in cities. The planning issue is becoming now more evident.

Taking into account these facts, term 1 and 3 are important as mitigating measures (symptom level) for the existing urban transport system. They will have also more or less slight effects on modal split, but they are not going to the roots of the traffic safety problem of the cities of today. The omnipresence of private cars in the cities, convert the public space for safe human mobility into a life- and health-endangering environment.

Traffic flow is not the cause of the problems of today, it is only the symptom of the organization of parking private cars. If parking places for private cars are planned and built adjacent to all human activities, risk and accidents in the public urban space is the unavoidable consequence. This fundamental mistake in urban planning is also the cause of the unlimited growth of congestion if more road space is provided for cars. The “Vision Zero” is an illusion under these circumstances. This is the urban structure, which cause all the unwanted effects, which the professional society tries to solve on the symptom level of traffic flow. Term 2 of the equation above is the key how to prevent accident-prone urban structures in the future.

9 CONCLUSION

Traffic safety is dealing with symptoms of a man made urban and transport system and not with the paradigms of the disciplines responsible for the urban pattern, the management of location of origins and destinations of transport modes. So far, its focus has been the traffic flow and the effects of interactions within the traffic system and with the environment. Therefore, the source of the risk coming was not recognized. It is the location of private car parking, which is organized in such a manner, that people are forced to use the car and at the same time all other kinds of mobility are suppressed and endangered. Speed limits can mitigate the risk, but can nor prevent all the other adverse effects of this mode, use and misuse of precious public space, noise, air pollution and severe constraints for non-motorized urban transport system users.

If planners are not aware of the effects and don't know the real system behaviour, they plan and build urban structures, which continuously enhance the problems, by providing more and more space for cars instead of curtailing the mode, which is not agreeable with the future of the sustainable city. Only ignorant planners fight with the problems of traffic flow, planners solve the problem at the source and reorganize parking of private cars (of course also business cars). Private car parking has to be limited strictly and be removed from all public space in the cities step by step. Alone the implementation of principles of market economy for the use of space will remove parking from the urban structures. If somebody believe to need a car, he has to rent a parking place, provided by skilled and responsible urban and transport planners outside of cities, where they can't harm the society, the city, the local economy and the sensitive urban environment. I know the challenge is tremendous, but the way to go is solid.

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China's Progress in Reducing Road Traffic Mortality: An Analysis of National Surveillance Data from 2006 to 2016

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1 INTRODUCTION

In 2010, The United Nations (UN) General Assembly approved the target of “halving the number of global deaths and injuries from road traffic accidents by 2020” as part of the Decade of Action for Road Safety 2011-2020 (1). This target was reaffirmed in 2015 as one of the UN's Sustainable Development Goals (SDGs) (2). Naturally, evaluating progress in this goal at global, regional and national levels is a health research priority. Currently, a few global health initiatives and international organizations regularly release progress reports on the SDGs, offering data to influence and support evidence-informed decision-making at global and national levels. These reports include those from the Global Burden of Diseases (GBD) research group, the United Nations (UN), the World Health Organization (WHO), the Sustainable Development Solutions Network (SDSN) and the World Bank (3-7). None of these reports, however, explore fine-grained details of progress for road traffic SDG safety goals in China.

As the most populous country in the world, China suffered over 272,000 road traffic deaths in 2016, accounting for about 22% of global road traffic deaths (8). China's progress therefore has substantial impact on the achievement of global road traffic safety goals and fine-grained analysis of recent patterns, mechanisms, and trends in Chinese road traffic mortality would be valuable to policy-making and implementation of road traffic safety interventions. A few previous studies offer some data on recent Chinese road traffic safety trends. Hu et al (9) and Zhang et al (10) used police-reported data from 1985-2005 and 1951-2008 respectively to report trends in road traffic mortality disparities based on socio-demographic factors, geographic regions, and types of road users. However, these studies are based on police-reported data in China, data which scholars suspect are seriously biased by underreporting (11). Similarly, the GBD study group used sophisticated quantitative modeling to estimate the attainment of road traffic mortality goals as well as 36 other health-related SDG indicators in 188 countries. Their modeling study concluded that like all other countries, China would not reach the SDG target for road injury mortality by 2020 without dramatic acceleration of progress to improve outcomes, reduce risk exposure, and expand essential health services (3). Other published studies report road traffic mortality change in a single Chinese city (Macheng) (12) or a specific age group (0-14 years) (13). Taken together, existing evidence is incomplete and/or not nationally representative. No current reports consider national-level epidemiological details on the influence of place (urban/rural), geographic location (province), and type of motor vehicle (for occupant deaths) for Chinese road traffic mortality rates over time.

In this report, we use data from the National Diseases Surveillance Points System (DSPs), a sample-based system that collects nationally representative data in China on births, cause of death, and incidence of infectious diseases (14). The DSPs offers a routinely updated national dataset on mortality rates of China that is ideal to address the research gaps mentioned above: we examined progress in road traffic injury mortality and mortality differences by sex, age group, place (urban/rural), geographic location (province), and road user from 2006 to 2016 in China.

2 METHOD

2.1 Study Design

Based on the DSPs data, we designed a population-based longitudinal analysis. This present manuscript is prepared in compliance with the Guidelines for Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement (15).

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2.2 Data source

Mortality data were derived from the DSPs, which was initiated in 1978 by the Chinese central government and has been used to estimate national fatal health outcomes by policymakers and researchers for decades (14, 16). The DSPs underwent three major adjustments, in 2004, 2008, and 2013. In 2004, the number of DSPs surveillance points was expanded from 145 to 161, creating a demographically representative sample of the whole country (16). In 2008, an internet-based reporting system was adopted, significantly improving the timeliness of data reporting. Finally, in 2013 the central Chinese government combined the surveillance points of the Vital Registration System with the DSPs to generate both nationally and provincially representative death estimates. At that time, the number of surveillance points was also further expanded to 605, representing 323.8 million Chinese citizens (24.3% of the national population) (16). To avoid bias from the 2013 expansion of the DSPs, in national-level analyses for our report we analyzed data only from the 161 surveillance points that were consistent from 2006 to 2016. Province-based analyses were based on data from all 605 surveillance points from 2014 to 2016, as provincially-representative data were unavailable before 2014.

The DSPs collect death data using a standard protocol that is implemented by trained workers. Death certificates at each surveillance point are completed by county-level CDCs and then reported to superior CDCs for verification before being entered into the online DSPs reporting system (14). Two methods are adopted to evaluate, validate and correct the DSPs data (14). First, an internal procedural check system evaluates reporting timelines and completeness and accuracy of data entry. Any detected errors are corrected. Second, an independent sample survey is conducted every three years in each province to adjust for data underreporting.

2.3 Classification of road traffic injury

Using the external cause of injury mortality matrix for the 10th Revision International Classification of Disease (ICD-10) (17), motor vehicle traffic injury is divided into five kinds of road users: occupant (V30-V79 [.4-.9], V83-V86 [.0-.3]), motorcyclist (V20-V28 [.3-.9], V29 [.4-.9]), pedal cyclist (V12-V14 [.3-.9], V19 [.4-.6]), pedestrian (V02-V04 [.1,.9], V09.2), and other/unspecified (V80 [.3-.5], V81.1, V82.1, V87 [.0-.8], V89.2). Occupant-related injury is further classified into four subgroups based on type of motor vehicle: occupant of three-wheeled motor vehicle (V30-V39 [.4-.9]), car occupant (V40-V49 [.4-.9]), occupant of pick-up truck or van (V50-V59 [.4-.9]), occupant of heavy transport vehicle (V60-V69 [.4-.9]), and bus occupant (V70-V79 [.4-.9]) or other land transport vehicle (V83-V86 [.0-.3]).

2.4 Socio-demographic variables

Five relevant demographic factors were considered in the present study: place (urban/rural), sex (male/female), age group, geographic location (province), and year. Age was divided into seven groups: 0-4 years, 5-14 years, 15-29 years, 30-44 years, 45-59 years, 60-69 years, ≥ 70 years. Our data analyses excluded Taiwan, Hong Kong, and Macau because their data are not covered by the DSPs.

2.5 Statistical analysis

Age-adjusted mortality rates and standard errors were calculated using the census population in 2010 as a reference. We performed joinpoint regression analysis to examine overall and subgroup mortality trends from 2006 to 2016 and to identify significant changes in distinct time periods with different slopes. Annual percent changes (APCs) and 95% confidence intervals (CI) for the whole and each distinct period were used to quantify the changes. According to the guide for determining number of joinpoints (18), we allowed for a maximum of two joinpoints to fully demonstrate mortality fluctuations over time. Maps were drawn to demonstrate geographic variations in road traffic mortality and mortality change from 2014 to 2016 across the 31 Chinese provinces. Percent change in road traffic mortality between 2014 and 2016 was used to quantify the change for each province, which was calculated as “(mortality in 2016 – mortality in 2014)/mortality in 2014 \times 100%”. Chi-square tests examined the significance of change in mortality between 2014 and 2016 for each province. Multi-strata subgroup analysis yielded unstable subgroup mortality rates due to small numerators (deaths < 20) (19), so we computed sub-group analyses for occupant-related mortality by place and sex only.

Join point regression analyses were conducted through Joinpoint Regression Program version 4.5.0.1. Statistical maps were completed by MapInfo 12.0. Other statistical analyses were performed using SAS software version 9.2. Differences were considered statistically significant based on 2-side tests if p-values were less than 0.05.

3 RESULTS

3.1 Overall road traffic mortality and trends

In total, 109 568 road traffic deaths were reported by the DSPs between 2006 and 2016. Crude and age-adjusted mortality rates showed highly similar change patterns across the study time period, except age-adjusted rates

were somewhat higher than crude rates before 2011 but lower than crude rates after 2011 due the aging population (Figure 1a). The crude road traffic mortality was 9.6 per 100 000 population in 2016 (Supplementary table 1). Age-adjusted road traffic mortality increased from 9.8 per 100 000 population in 2006 to 15.7 per 100 000 population in 2011 (APC: 9%, 95% CI: 7% to 12%) and then gradually decreased to 9.1 per 100 000 population in 2016 (APC: -11%, -14% to -9%) (Supplementary figure 1 and table 2).

3.2 Road traffic mortality differences based on place, sex, age group and geographic location

Across the study time period, age-adjusted mortality rates in rural areas were 1.6-2.2 times those in urban areas (Figure 1b). Urban and rural mortality rates displayed similar trends between 2006 and 2016 - they first increased to reach a peak around 2010/2011, and then decreased continuously (APC: 11% in 2006-2010 and -11% in 2010-2016 for urban areas; 12% in 2006-2011 and -10% in 2011-2016 for rural areas) (Supplementary figures 2a and 2b).

Males were at consistently higher risk of age-adjusted road traffic mortality compared to females between 2006 and 2016 (male/female ratio: 2.9-3.4 times) (Figure 1c). Male mortality increased from 2006 to 2008 (APC: 15%, 5% to 26%), remained relatively stable from 2008 to 2011 (APC: 8%, -1% to 17%), and then started to drop substantially from 2011 through 2016 (APC: -12%, -13% to -10%). In contrast, female mortality increased from 2006 to 2011 (APC: 9%, 5% to 12%), and then began to decrease afterwards from 2011 to 2016 (APC: -10%, -13% to -7%) (Supplementary figures 2c and 2d).

Road traffic mortality increased dramatically as age increased across the full study period (Figure 1d). Subgroup analyses displayed similar change patterns as the overall age-adjusted mortality, but the observed reduction since the peak year (2011/2012) varied across age groups, with the largest decreases among youth ages 5-14 years (APC=-15%, -23% to -6%), followed by an APC of -14% in the 30-44 years age group and -11% in the 45-59 years age group (Supplementary figure 3).

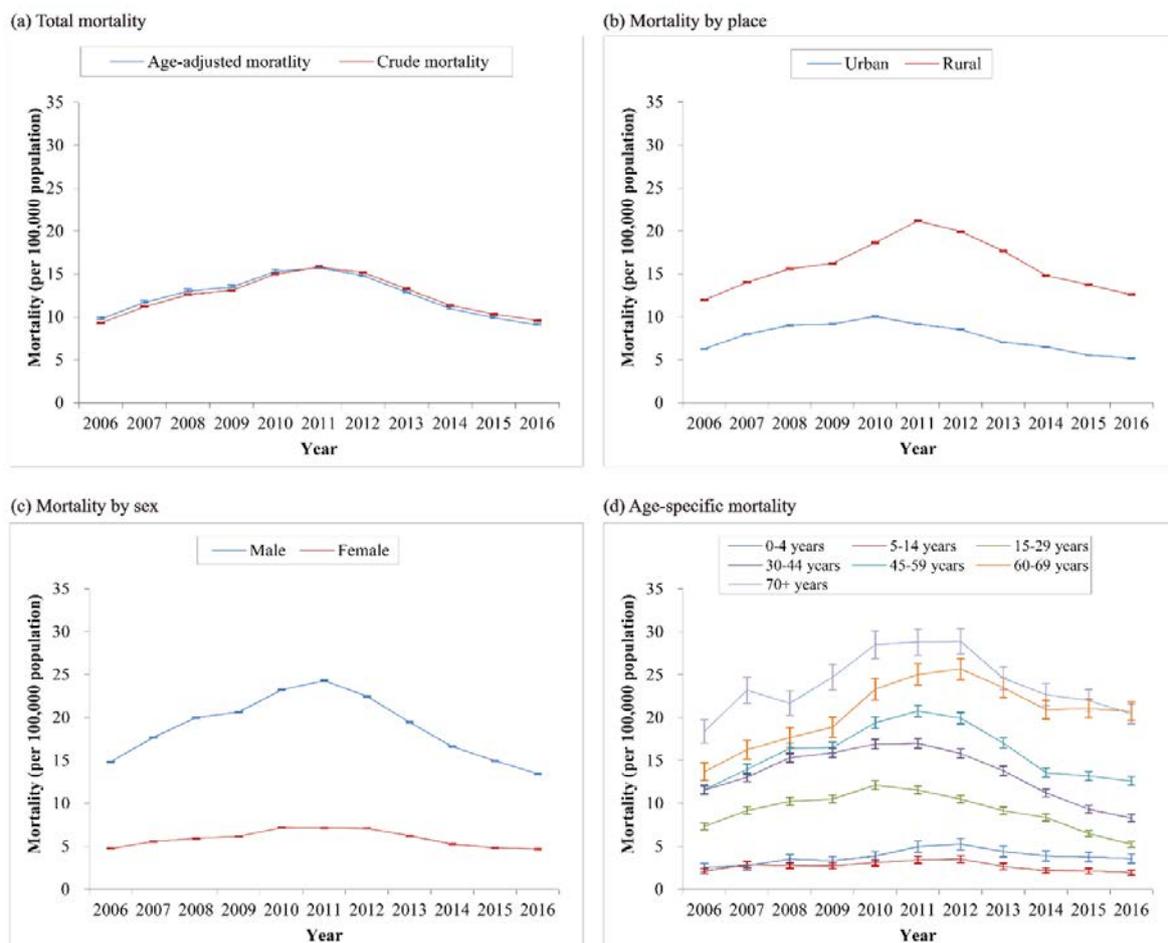


Figure 1. Road traffic mortality in China, 2006-2016. Mortality rates were age-adjusted in Figures 1a, 1b, and 1c using the population data from the 2010 national census.

Provincial data were available from 2014 to 2016 and suggest that age-adjusted road traffic mortality varied greatly across the 31 provinces in mainland China, ranging from 2.6 per 100 000 population in Tibet to 16.2 per 100 000 population in Ningxia (Figures 2a, 2b, and 2c). Between 2014 and 2016, 23 of 31 provinces experienced significant mortality reductions; the largest mortality decreases occurred in Beijing (-35%), Chongqing (-33%), and Gansu (-30%) (Figure 2d). In contrast, eight provinces experienced increases, with the largest increases occurring in Shaanxi (29%), Tianjin (18%), and Jiangsu (16%).

3.3 Subgroup analysis by road user

Between 2006 and 2016, pedestrians, motorcyclists and occupants were the most common road users experiencing road traffic mortality in China, accounting respectively for 43%, 24%, and 16% of total age-adjusted road traffic mortality (Figure 3a). In general, mortality rates for pedestrians, motorcyclists, pedal cyclists, and other/unspecified road users followed a change pattern that was similar to the overall mortality rate (Supplementary figure 4). Notably, mortality of vehicle occupants remained relatively stable in the observed ten-year time period, ranging from 1.6 to 2.4 per 100 000 population.

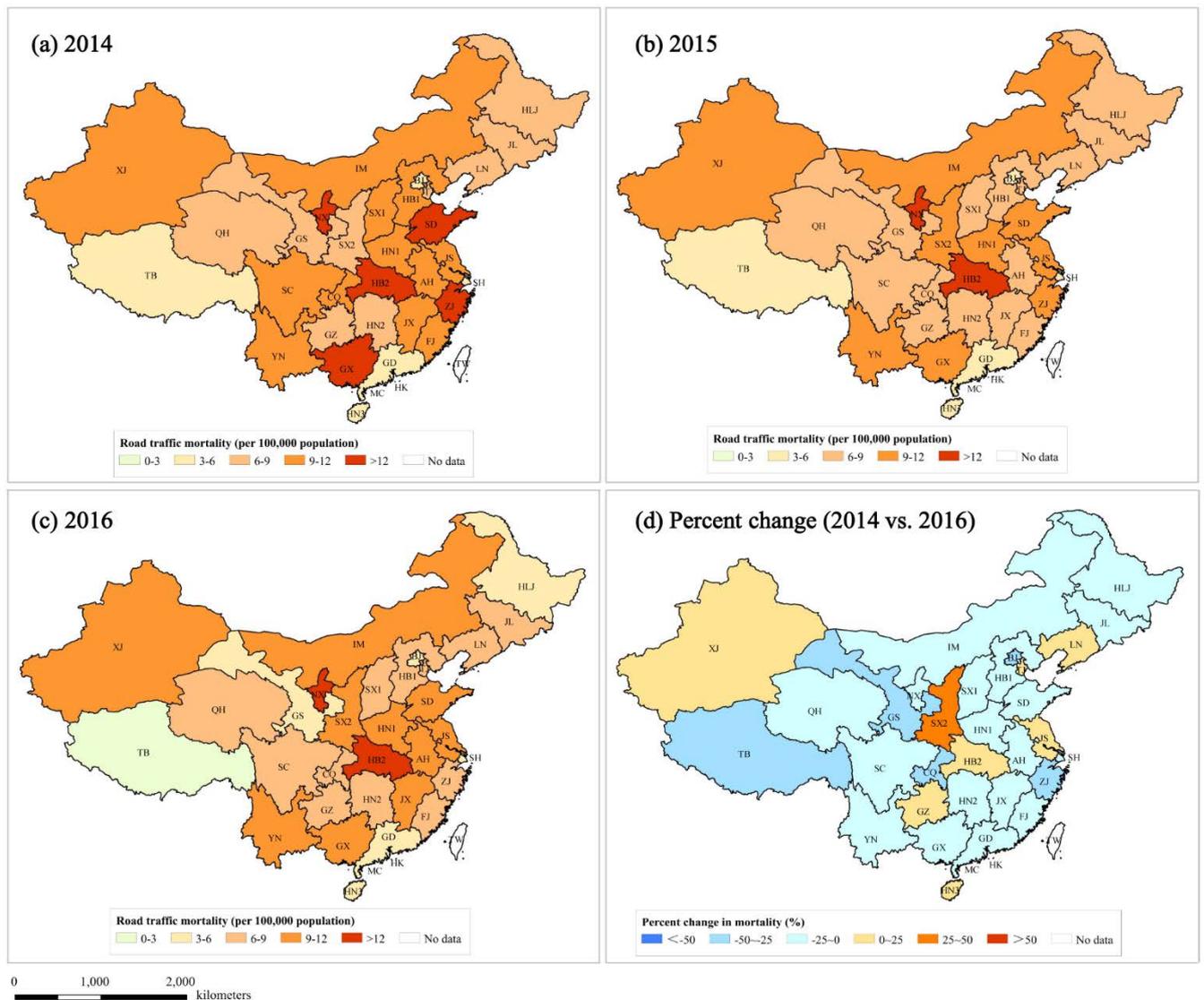


Figure 2. Age-adjusted road traffic mortality and percent change in mortality by province in China, 2014-2016. Mortality rates were age-adjusted using the population data from the 2010 national census. Percent change in mortality between 2014 and 2016 was calculated as “(mortality in 2016- mortality in 2014)/ mortality in 2014*100%”. Abbreviations: BJ - Beijing, TJ - Tianjin, LN - Liaoning, JL - Jilin, HLJ - Heilongjiang, HB1 - Hebei, SD - Shandong, JS - Jiangsu, SH - Shanghai, ZJ - Zhejiang, AH - Anhui, HN1 - Henan, SX1 - Shanxi, IM - Inner Mongolia, NX - Ningxia, SX2 - Shaanxi; HB2 - Hubei, JX - Jiangxi, FJ - Fujian, TW - Taiwan, GD - Guangdong, HN2 - Hunan, CQ - Chongqing, GS - Gansu, XJ - Xinjiang, QH - Qinghai, SC - Sichuan, GZ - Guizhou, GX - Guangxi, HN3 - Hainan, YN - Yunnan, TB - Tibet, MC - Macau, HK - Hong Kong.

Figure 3. Age-specific road traffic mortality by road user in China, 2006-2016. Mortality rates were age-adjusted in Figures 3a using the population data from the 2010 national census.

Urban and rural areas roughly followed similar patterns road user mortalities from 2006 to 2016, with the exceptions of a comparatively high proportion of motorcyclist mortality in rural areas (27% vs. 16% in rural vs. urban areas) and a relatively low proportion of pedestrian mortality in rural areas (40% vs. 50%) (Figures 4a and 4b). Urban areas and rural areas also demonstrated similar trends in mortality rates by specific road users across the study time period, except for reaching peak mortality rates at different years for occupant mortality (2008 vs.

Figure 4. Trends in road traffic mortality by place, sex and road user in China, 2006-2016. Mortality rates were age-adjusted using the population data from the 2010 national census

2012 in urban vs rural areas) and motorcyclist mortality (2009 vs. 2011) (Supplementary figures 5a-8a and 5b-8b)..

Males had much higher age-adjusted mortality in all road user categories than females across the study period, especially as motorcyclists (4.7-6.5 times) and vehicle occupants (3.4-4.5 times) (Figures 4c and 4d). The percentage of deaths by road user also differed between males and females. In particular, there were significant differences for motorcyclists (27% of male deaths and 15% of female deaths) and pedestrians (40% vs. 52%). Males and females displayed similar trends in road user specific age-adjusted mortality over time, except that mortality remained nearly stable among female occupants in the study time period, ranging from 0.7 to 0.9 per 100 000 population (Supplementary figures 5c-8c, and 5d-8d).

Pedestrians experienced road traffic mortality most often across all age groups, except motorcyclists for individuals aged 15-29 years (consistently) and aged 30-44 years (in a few years) experienced higher mortality rates than pedestrians (Figures 3b-3h). From 2006 to 2016, road traffic mortality showed similar patterns of change over time for almost all road users in all age groups, generally increasing from 2010 to 2012 and then falling continuously from 2012 to 2016. The magnitude of mortality change varied across road users and age groups (Supplementary figures 9-12).

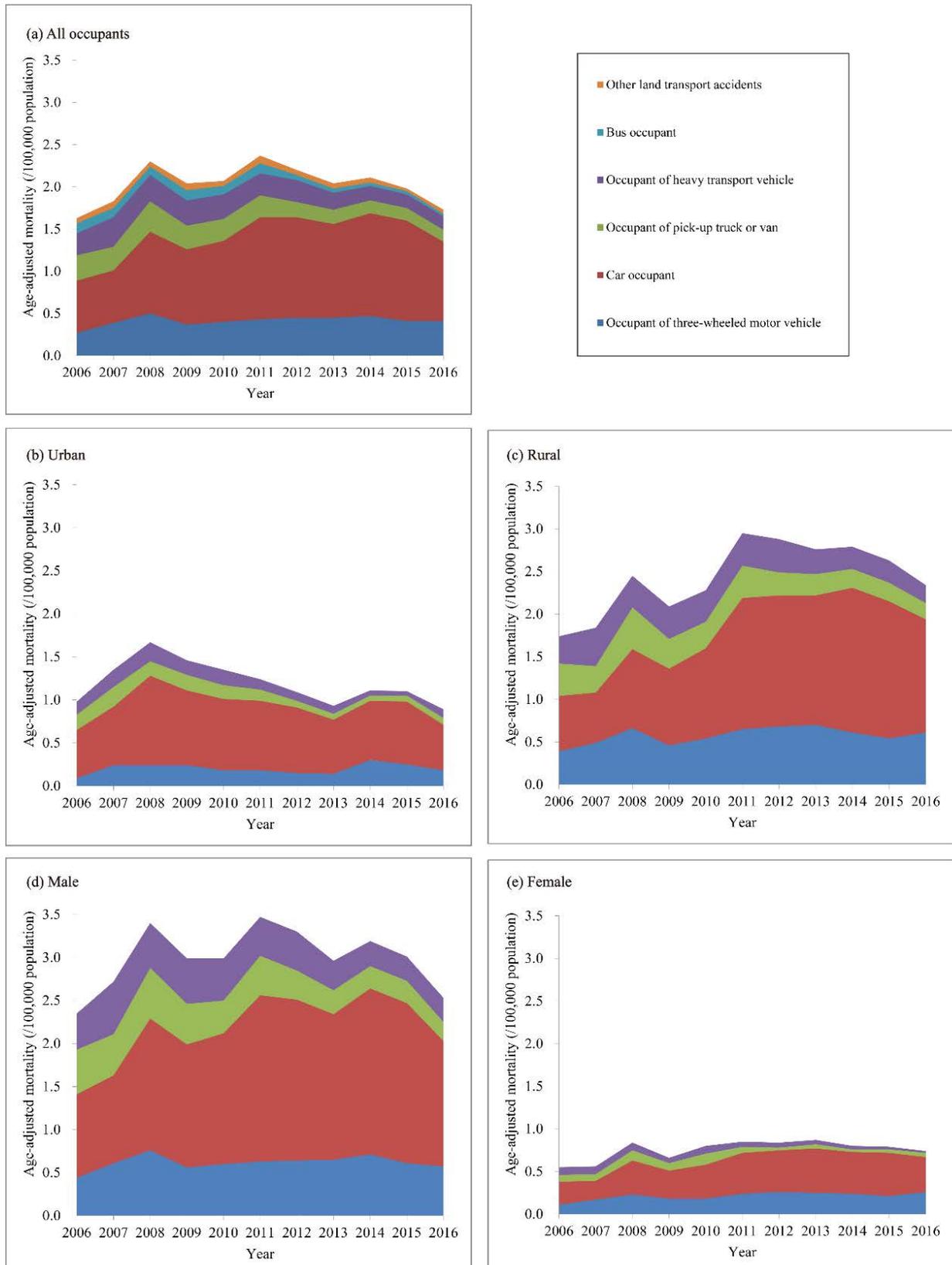


Figure 5. Road traffic mortality among occupants by place, sex, and type of motor vehicle in China, 2006–2016. Mortality rates were age-adjusted using the population data from the 2010 national census. Because sex- and place-specific mortality rates were unstable due to less than 20 deaths (19) for bus occupant and other land transport accidents, we excluded them from Figures 5b, 5c, 5d, and 5e.

Further analysis of mortality by type of occupant revealed that occupants of cars and three-wheeled motor vehicles were most common, respectively accounting for 53% and 20% of total occupant deaths from road

traffic crashes in China between 2006 and 2016 (Figure 5a). Age-adjusted mortality rate for car occupants continually increased during the study time period (APC: 4%, 0% to 8%), while mortality for occupants of three-wheeled motor vehicles increased from 2006 to 2008 (APC: 30%, 6% to 59%) and then remained relatively stable from 2008 to 2016. Male occupants and occupants from rural areas were at greater risk of road traffic mortality compared to female occupants and those from urban areas (Figures 5b-5e, Supplementary figure 13).

There were notable geographic variations for all specific road users across the 31 Chinese provinces for both age-adjusted mortality and mortality changes between 2014 and 2016 (DSPs data are representative for individual provinces only from 2014 to 2016). As shown in [Supplementary figures 14-17](#), there were 13, 19, 19, and 26 provinces respectively that witnessed significant decreases in age-adjusted road traffic mortality for occupants, motorcyclists, pedal cyclists, and pedestrians between 2014 and 2016. In contrast, 17, 12, 10, and 5 provinces experienced significant mortality increases for the four respective types of road users.

4 DISCUSSION

4.1 Key findings

Our systematic analysis using the DSPs data to report road traffic mortality characteristics from 2006 to 2016 in China yielded three key findings. First, overall age-standardized road traffic mortality increased from 2006 to 2011 and then began to decrease gradually through 2016. Second, we observed large mortality gaps and inconsistent mortality changes across place (urban/rural), sex, age group, and provincial locations. Last, vulnerable road users - pedestrians, pedal cyclists, and motorcyclists - together constituted 74% of road traffic mortality from 2006 to 2016 in China, and the most common occupants suffering road traffic mortality were those riding in cars and three-wheeled motor vehicles. We discuss these findings below.

4.2 Interpretation of findings

Contrary to previous reports using police-reported data with validity that has been questioned (13, 20), our results suggest road traffic mortality in China increased from 2006 through 2011, and then began to decrease. Further, our estimates suggest mortality rates may be over two times the rate documented in police reports (10).

Our estimates are significantly lower than those by another leading group, the GBD study group (e.g. 9.6 vs. 22.8 per 100 000 population in 2016 for crude mortality) (8). Similar gaps have been reported for injury deaths between United States government data and GBD estimates (21). The gaps may be a result of GBD modeling strategies, which are designed to correct data with “garbage codes” and therefore increase the comparability of results across countries (21).

Based on our estimates, China has comparatively high road traffic mortality rates (10.3 per 100 000 population) compared to many high-income countries in 2015 (e.g. the United Kingdom, 2.7 per 100 000 population; Japan, 4.2 per 100 000 population; and Australia, 5.4 per 100 000 population) (22). The disparities may reflect a range of factors, including the following aspects of Chinese culture and infrastructure: different patterns of population mobility that include more pedestrian, bicycle, and motorcycle travel; poorer road infrastructure, laxer traffic control, inferior emergency and long-term trauma care in some regions; and different patterns of population aging (23).

The observed decline in road traffic mortality in China since 2011 is encouraging and likely reflects substantial improvements in transportation infrastructure investment (24), transitions to use express trains, airplanes, and ships instead of coaches or cars for long-distance travel (25), and legislative and public education programs to improve motor vehicle safety. Between 2011 and 2015, 12.5 trillion Chinese Yuan were invested to improve transportation infrastructure across the country (1). The percentage of passenger volume on trains increased from 5.3% in 2011 to 14.8% in 2016, contrasting with a decrease of the volume of passengers riding long-distance buses (from 93.2% to 81.2% in the same time period) (25). In terms of policy, China revised national drunk driving laws in 2011, greatly increasing penalties (26). Continued efforts have been made by the central government to improve road safety awareness among the public (27).

In addition to replicating previous findings that males, rural residents, and older adults are at higher risks of road traffic mortality compared to females, urban residents, and younger persons (28, 29), this study identified urban-rural and province disparities in mortality and mortality changes in China. These findings, which match reports from United States, India, and Peru (30-32), may reflect a combination of factors in rural areas and underdeveloped provinces, including poor road infrastructure and road traffic control, underdevelopment of pre-hospital trauma aid and hospital treatment, adopting different policies for road traffic management (e.g. the

government prohibits riding motorcycles in most large and medium-sized cities but encourages automobiles and motorcycles in rural areas from 2009 to 2013) (33, 34), less stringent road traffic policies and enforcement, and comparatively frequent law violations and risky driving/riding/walking behaviors (28, 35, 36).

Another notable finding is that vulnerable road users accounted for over 70% of road traffic deaths in China. This figure generally agrees with data from other low- and middle-income countries, but is much lower than data from high-income countries where car occupants experience more road traffic deaths (23). In particular, vulnerable road users in rural areas and some provinces of China had very high mortality rates and significant mortality increases between 2014 and 2016. The data patterns reinforce the urgency of efforts to protect vulnerable road users in China.

Finally, we found that occupants of cars and three-wheeled motor vehicles were the predominant road traffic mortality victims among vehicle occupants. This result is not surprising, as cars constitute the majority of registered motor vehicles in China (84% of registrations in 2016) (34) and three-wheeled motor vehicles suffer from risky engineering, easily flipping and jeopardizing the safety of their drivers and passengers (37). Strikingly, the percentage of Chinese road traffic deaths for occupants of three-wheeled motor vehicle compared to all occupant deaths (24%) is greatly disproportionate to the percentage of three-wheeled motor vehicles to all motor vehicles (3%) (34) in 2016. This may be due to that lack of safety devices such as air bags, antilock brake systems and seatbelts in most three-wheeled motor vehicles, frequent law violations (e.g. overloading) among three-wheeled motor vehicle operators, and lack of regular maintenance for three-wheeled motor vehicles (37).

4.3 Policy Implications

Our findings suggest road traffic mortality in China has been decreasing since 2011, but the progress is inadequate to achieve SDG targets of halving deaths by 2020 without new and substantial efforts to accelerate progress. Large urban-rural disparities remain, and there are variations in mortality rates and mortality changes across provinces. Very high mortality rates exist among vulnerable road users, especially pedestrians, as well as occupants of cars and three-wheeled motor vehicles. Systematic and sustainable efforts are needed to reduce disparities and protect vulnerable road users in China.

The steps that can be taken to reduce road traffic mortality in China are largely known. Proven solutions include city and transport planning (38), protective policies for vulnerable road users (23), improved post-crash responses (1, 23), efforts to implement infrastructure that prevents pedestrians from violating traffic rules (e.g., construction of sidewalks, raised crossings, traffic signals, and refuge islands) (35), and legislation to prohibit risky traffic behaviors (driving while intoxicated, failing to use bicycle and motorcycle helmets, failing to wear seatbelts or use child restraints, speeding, and distracted driving). If fully implemented, proven solutions recommended by the WHO (1, 23) can be implemented to reduce road traffic injuries.

4.4 Limitations

This study was primarily restricted by the limitations of the DSPs data. Specifically, the DSPs data do not collect information on non-fatal road traffic injury or on relevant factors such as road environments, circumstances of crashes (e.g., violation of laws when the crash occurred; use of helmets, seatbelts, or child restraints). Such information is collected by police reports and other sources in some cases and would be valuable to be integrated into findings from the DSPs in future research. Further, our results are likely affected by the incompleteness and misclassification of the DSPs data. For instance, the data for underreporting adjustment are based on the survey at each surveillance points every three years, which may conceal underreporting variations across years. Although the data are routinely checked and corrected through internal procedural checks and independent sample surveys, no dataset is perfectly valid (14). Efforts should be made to continue to improve the validity and timeliness of road traffic injury data in China, and to translate epidemiological results into prevention practice to reduce injuries.

5. CONCLUSION

In conclusion, road traffic mortality in China decreased gradually from 2011 through 2016, likely as a result of the combination of several factors. However, the recent decreases are not on track to achieve the SDGs target of halving road traffic mortality by 2020 without significant effort. A series of proven multi-faceted interventions, such as those recommended by the WHO, should be systematically and efficiently implemented across China to accelerate progress in reducing the burden of road traffic injuries on public health.

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The Effect of Zonal Factors in Estimating Crash Risks by Transportation Modes: Motor Vehicle, Bicycle and Pedestrian

Jie Wang¹, Helai Huang^a

Abstract

Objectives: This paper aimed to (i) differentiate the effects of contributory factors on crash risks related to different transportation modes, i.e., motor vehicle, bicycle and pedestrian; (ii) explore the potential contribution of zone-level factors which are traditionally excluded or omitted, so as to track the source of heterogeneous effects of certain risk factors in crash-frequency models by different modes. *Methods:* Two analytical methods, i.e. negative binomial models (NB) and random parameters negative binomial models (RPNB), were employed to relate crash frequencies of different transportation modes to a variety of risk factors at intersections. Five years of crash data, traffic volume, geometric design as well as macroscopic variables at traffic analysis zone (TAZ) level for 279 intersections were used for analysis as a case study. *Results:* Among the findings are: (1) the sets of significant variables in crash-frequency analysis differed for different transportation modes; (2) omission of macroscopic variables would result in biased parameters estimation and incorrect inferences; (3) the zonal factors (macroscopic factors) considered played a more important role in elevating the model performance for non-motorized than motor-vehicle crashes; (4) a relatively smaller buffer width to extract macroscopic factors surrounding the intersection yielded better estimations.

Keywords: transportation modes; macroscopic variables; unobserved heterogeneity; buffer width; intersection safety

1 INTRODUCTION

Many communities have increased their interest in the implementation of multimodal transportation and advocated for the shift from motor vehicles to non-motorized modes of transportation, i.e., walking and cycling. In spite of the health and environmental benefits, an increasing number of crashes involving pedestrians and bicyclists has become a major concern in improving traffic safety. For example in 2013, the United States had 4735 pedestrian and 743 bicyclist deaths, accounting for 18% of all U.S. highway fatalities (1). The Federal Highway Administration's office of safety has established pedestrian and bicyclist safety as one of its top priorities. Thus, it is essential for traffic safety engineers to provide appropriate countermeasures or policies to achieve friendly and safe multimodal transportation.

A comprehensive understanding of contributing factors associated with crash occurrences by different modes is a prerequisite for developing safety improvement programs to effectively reduce traffic crashes. For a given road entity (e.g. road segments or intersections), the potential factors associated with multimodal crashes could be summarized as in Figure 1, according with Miranda-Moreno et al. (2), Mitra and Washington (3) and Ukkusuri et al. (4). The factors influencing road-entity-level crash frequency by modes include macroscopic factors related to built environment of the road entities - such as population and economic characteristics, land use characteristics and travel behaviors - as well as road features and traffic characteristics of the road entities. In addition, crash occurrence is also associated with individual characteristics such as gender, age, education, alcohol consumption, and other driver and pedestrian behaviors (5). Although discrete individual-level factors are not available to be integrated into the crash- frequency model, individual characteristics are always influenced by macroscopic factors (6).

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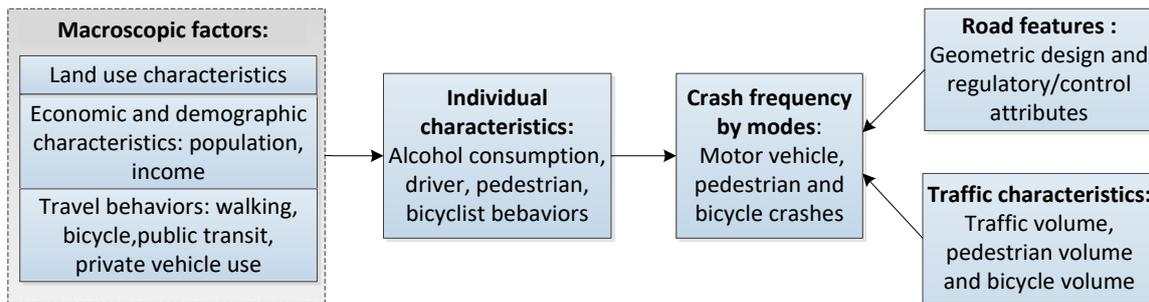


Figure 1. Factors associated with multimodal crashes

The choice of appropriate analytical method and the selection of representative explanatory variables are two important considerations for obtaining accurate model predictions. Over the past three decades, considerable research efforts have been devoted to developing and applying sophisticated methodological approaches associated with the analysis of crash frequency. Detailed descriptions and assessments of crash-frequency models can be found in the review papers by Mannering and Bhat (7). However, relatively few studies have focused on the identification and inclusion of traditionally excluded or omitted variables in crash-frequency analysis. In particular, variables related to macroscopic factors previously described (in Figure 1) are normally unavailable in crash databases and as a result have rarely been examined in great detail.

The objective of this paper is to examine the effects of a host of contributing factors including both macroscopic and microscopic factors on crash occurrence with respect to different transportation modes; and to shed further light on the contribution of the macroscopic factors which are traditionally excluded or omitted variables, to tracking the source of heterogeneity effects in coefficient estimators of regularly used variables and improving the model performance in crash-frequency analysis related to different modes.

2 DATA PREPARATION

In this study, data collected for 279 intersections located in Hillsborough County, Florida, USA were used to develop the intersection crash-frequency models for different transportation modes. The data for the analysis was mainly divided into four types: traffic crash data, traffic characteristics, road characteristics related to geometric design, traffic control/regulatory of the intersection, macroscopic factors including trip production/attraction, demographic and socio-economic characteristics surrounding the intersection. Table 1 provides descriptive statistics of crash data, traffic variables, road variables and macroscopic variables located in 0.5 mile buffer. The values of macroscopic variables located at 0.25 and 1 mile buffer are not listed for compactness of the Table1.

3 METHOD

In previous crash-frequency analyses, Poisson and Negative binomial model (NB), along with their variants (such as Poisson-lognormal model), are commonly used and proven to be successful as they effectively model the rare, random, sporadic, and non-negative crash data. As crash data exhibit over-dispersion (i.e., variance greater than mean), NB is superior to the Poisson model. The NB model could control for unobserved heterogeneity by omitted variables. However, this model assumes that the unobserved variables are uncorrelated with the observed explanatory variables. If this correlation exists, unobserved factors can introduce variation in the effect of observed variables on crash likelihood. Random parameters approaches are able to address this issue by allowing non-constant estimable parameters to vary across observations(8).

Three types of crash-frequency models for motor vehicles, bicycles and pedestrians were developed. Each type of model involved eight separate models based on four model specifications (one with only traffic volume and road features, the other three with macroscopic factors overlaid on 0.25, 0.5, 1 mile buffer respectively in addition to commonly included traffic volume and road features) and two analytical methods (NB and RPNB). LIMDEP econometric software was used to develop the statistical models described above. To enable focus on the most significant variables, variables that were not found to significantly different from zero at the 0.1 level of significant using a *t*-test were removed. Meanwhile, the likelihood ratio test was used to guarantee that each added variable significantly improved the overall model performance.

Table 1. Summary of variable and descriptive statistics

Variable	Definition	Mean ^a	SD ^a	Min ^a	Max ^a
Crash data					
Motor vehicle crash	Motor vehicle crash per intersection in 2005-2009	65.219	56.545	2.000	293.00
Bicycle crash	Bicycle crash per intersection in 2005-2009	1.018	1.340	0.000	8.000
Pedestrian crash	Pedestrian crash per intersection in 2005-2009	1.276	1.889	0.000	11.000
Traffic and road variables					
AADT-major	AADT on major approach (10 ³ pcu)	28.364	17.684	2.600	71.300
AADT-minor	AADT on minor approach (10 ³ pcu)	9.150	8.879	1.000	43.000
Leg-number	Number of legs (4 legs=1, 3 legs=0)	0.670	0.471	0.000	1.000
traffic signal	Presence of traffic signal (yes=1,no=0)	0.498	0.542	0.000	4.000
Speed-Major	Speed limit on major approach (mph)	40.502	6.154	6.154	60.000
Speed-Minor	Speed limit on minor approach (mph)	35.323	6.479	6.479	55.000
Macroscopic variables					
PA_density	Density of productions and attractions (per acre)	49.272	27.369	2.514	184.06
HB_prop	Proportion of home-based productions and attractions	0.680	0.084	0.317	0.840
Col_prop	Proportion of college productions and attractions	0.025	0.059	0.000	0.415
Pop_density	Density of total population (per acre)	5.631	2.554	0.342	11.798
Age 0 to 15_prop	Proportion of population between age 0 and 15	0.225	0.050	0.069	0.348
Age 16 to 64_prop	Proportion of population between age 16 and 64	0.652	0.054	0.561	0.917
Pub_prop	Proportion of workers commuting by public transportation	0.030	0.031	0.000	0.149
Wal_prop	Proportion of workers commuting by walking	0.025	0.017	0.000	0.080
MHINC	Median household income (in thousands)	36.728	15.199	4.300	89.035

^a These values relating to macroscopic variables are only for 0.5 mile buffer.

In the RPNB, if the variance of a random parameter was not statistically different from zero, the random parameter was simplified to be fixed across intersections. Thus, the results in NB were in accordance with that in RPBN when no estimate parameters of explanatory variable were statistically random.

Two goodness-of-fit statistics are used for model comparisons: Akaike Information Criterion (AIC) and log-likelihood ratio (LR). In addition, the proportion of reduction in variance (PRV), also called explained variance, proposed by Raudenbush and Bryk (9) can be used to assess the overall explanatory power of macroscopic factors for modeling the crashes by different modes. In this case, the PRV of macroscopic variables is defined as:

$$PRV = \frac{\tau_0^2 - \tau_1^2}{\tau_0^2} \tag{1}$$

where τ_0^2 is the variance of the error term in the base model without macroscopic variables. τ_1^2 is the variance of error term in the full model with macroscopic variables. The value of PRV is bounded by 0 and 1, and a higher value indicates a stronger explanatory power of macroscopic factors on the crash occurrence.

4 RESULTS AND DISCUSSION

This analysis below will emphasize testing effects of macroscopic factors on model performance in crash-frequency analysis for three transportation modes, and then comparison results of the parameter estimates and marginal effects between the base model and the full model with macroscopic variables will be discussed.

4.1 Effects of macroscopic factors on model performance

Tables 2-4 show goodness-of-fit measures for motor vehicle, bicycle and pedestrian crash-frequency models, respectively. As shown in Table 2, only five of eight motor vehicle crash-frequency models, including two base models (NB model and RANB model) and three fully specified NB models, were presented since there was no

Table 2. Goodness-of-fit measures for motor vehicle crash-frequency models

Model statistics	Base model		0.25 mile	0.50 mile	1 mile
	NB	RPNB	NB	NB	NB
Number of observers	279	279	279	279	279
Number of parameters	6	7	10	10	10
Log likelihood at convergence	-1280.07	-1279.42	-1269.25	-1270.86	-1276.28
AIC	2572.14	2572.84	2558.50	2561.73	2572.56
Log-likelihood ratio test					
$\chi^2 = -2(LL_N - LL_A)$		1.300	21.645	18.416	7.588
Degrees of freedom		1	4	4	4
P-value		0.26	<0.01	<0.01	0.11
Explanatory power of macroscopic factors					
Variance of the error term,	0.250	0.246	0.230	0.232	0.243
Proportion of reduction in variance, PRV		1.23%	7.98%	6.85%	2.67%

Note: LL_N denotes the log likelihood at convergence for Base + NB model.

Table 3. Goodness-of-fit measures for bicycle crash-frequency models

Model statistics	Base model		0.25 mile	0.50 mile	1 mile
	NB	RPNB	NB	NB	NB
Number of observers	279	279	279	279	279
Number of parameters	6	7	8	8	8
Log likelihood at convergence	-362.53	-361.61	-350.42	-351.14	-351.62
AIC	737.06	737.22	716.85	718.28	719.24
Log-likelihood ratio test					
$\chi^2 = -2(LL_N - LL_A)$		1.837	24.209	22.777	21.821
Degrees of freedom		1	2	2	2
P-value		0.17	<0.01	<0.01	<0.01
Explanatory power of macroscopic factors					
Variance of the error term	0.402	0.335	0.269	0.274	0.280
Proportion of reduction in variance, PRV		16.48%	33.02%	31.66%	30.27%

Note: LL_N denotes the log likelihood at convergence for Base + NB model

significant random parameter as measured by the t-statistics in all three models with macroscopic variables. Although there was no substantial difference in goodness-of-fit as reflected by likelihood ratio test between the base NB and RPNB model, the present of significant random parameters (e.g. the variable of ‘presence of traffic signal’ in this case study) demonstrated the existent of heterogeneity of risk factors in base model without considering macroscopic factors. More interestingly, no significant random parameters were found in all three full models with macroscopic variables. This implied that the heterogeneous effects of risk factors on motor vehicle crash frequency could be mostly captured by these macroscopic variables, at least for the Hillsborough dataset examined here. Frequency analysis models for bicycle crashes presented a similar result to motor vehicles crashes, as shown in Table 3. However, this was not the case for the pedestrian crash-frequency models (Table 4). Significant random parameters, such as ‘presence of traffic signal’, existed both in pedestrian crash models with and without macroscopic variables, suggesting that the heterogeneity effect in parameters estimation cannot be completely picked up by these macroscopic variables.

Apart from the potential effect in tracking the heterogeneity, results also revealed that incorporating the macroscopic variables in crash-frequency analysis led to an increasing model complexity but a considerable improvement in overall fit as measured by log likelihood at convergence. As shown in Table 2, the likelihood

Table 4. Goodness-of-fit measures for pedestrian crash-frequency models

Model statistics	Base model		0.25 mile		0.50 mile		1 mile	
	NB	RPNB	NB	RPNB	NB	RPNB	NB	RPNB
Number of observers	279	279	279	279	279	279	279	279
Number of parameters	4	5	7	8	7	8	7	8
Log likelihood at convergence	-399.51	-397.89	-	-	-	-	-	-
AIC	807.03	805.77	386.34	386.26	387.27	387.16	388.52	388.13
Log-likelihood ratio test								
$\chi^2 = -2(LL_N - LL_A)$		3.256	26.352	26.515	24.487	24.712	21.983	22.761
Degrees of freedom		1	3	4	3	4	3	4
P-value		0.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Explanatory power of macroscopic factors								
Variance of the error term	0.785	0.613	0.585	0.578	0.595	0.587	0.601	0.595
Proportion of reduction in variance, PRV		21.96%	25.57%	26.37%	24.26%	25.21%	23.48%	24.18%

Note: LL_N denotes the log likelihood at convergence for Base + NB model.

ratio test comparing the full NB models and the base NB models indicated that we were more than 99.99 % confident that the full models with macroscopic variables (except the full model with 1.0 mile buffer-width macroscopic variables) were statistically superior. This comparison suggested that the macroscopic variables explained a portion of variability in crash occurrences and should not be omitted in motor vehicle crash-frequency model. In regard to bicycle and pedestrian models, omission of macroscopic variables will also lead to a significant decrease in goodness-of-fit, as shown in Tables 3-4.

Comparing model outputs developed based on 0.25 mile, 0.5 mile and 1 mile buffer width data, these models with macroscopic variables of 0.25 mile buffer width had the lowest AIC, conversely, the models with macroscopic variables of 1 mile buffer width had the highest AIC in all three types of crash-frequency models by modes. Thus, a relatively smaller buffer width in extracting macroscopic factors surrounding the intersection would yield a better estimate.

To further assess and compare the overall explanatory power of macroscopic variables, the values of PRVs were calculated. As shown in Table 2, the motor vehicle crash-frequency model with macroscopic variables of 0.25 mile buffer width had the highest PRV of 7.98%. This meant that 7.98% of unexplained variation resulted from those omitted macroscopic variables, which also suggested the usefulness of the motor vehicle crash-frequency analysis by integrating macroscopic factors. Accordingly, the highest values of PRV were 33.02% and 26.37% in bicycle and pedestrian crash-frequency models respectively, as shown in Tables 3-4.

By comparing PRVs in models by different transportation modes, the PRVs in bicycle and pedestrian crash-frequency model were much higher than that in motor vehicle models. In other words, integrating macroscopic factors in non-motorized crash-frequency model was more vital than that in developing motor vehicle model. This result was in line with the expectation. One possible reason for this distinct effect is that pedestrian/bicycle volume (or pedestrian/bicycle activity) which is commonly identified as the main determinants of pedestrian/bicycle crash frequency has been omitted in the base pedestrian/bicycle crash-frequency models. Integrating macroscopic factors for pedestrian/bicycle crash-frequency analysis made up the absence of pedestrian/bicycle volume in predicting pedestrian/bicycle crash frequencies to some extent as demonstrated by previous study (3) that macroscopic data can serve as a surrogate for pedestrian and bicycle volume. Another reason, maybe even more importantly, originates from the differences in the travel distance between non-motorized and motor vehicle modes. As walking and bicycle are short-distance transportation modes, crash victims of pedestrians and

bicyclists generally reside near the crash intersection, and thus, the macroscopic factors extracted surrounding the intersection can probably better reflect pedestrian and/or bicyclist behaviors than that for motor drivers.

4.2 Safety effects of risk factors

Macroscopic factors of the surrounding zone of an intersection, such as ‘proportion of home-based productions and attractions’, ‘proportion of college productions and attractions’, ‘density of total population’, ‘proportion of population between age 16 and 64’, proportion of workers commuting by public transportation and ‘proportion of workers commuting by walking’, were demonstrated to have significant effects on intersection crashes; while these variables are always ignored in traditionally micro-level (e.g., intersections and segments) crash frequency model. This indicated that not only traffic volumes and road features but also macroscopic factors should be considered in estimating crash risk and identifying crash-prone locations.

By comparing results of the parameter estimates between the base model and the full model with macroscopic variables, we found that omission of macroscopic variables would result in biased estimation of retained microscopic variables. For example, the safety effect of minor approach AADT on motor vehicle and bicycle crashes are biased downwards by 16.8% and 17.6% in the absence of macroscopic variables.

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Application of Accident Data in The Development of Autonomous Vehicles

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Abstract

Traditional on-road tests of intelligent driving systems of autonomous vehicles are usually inefficient and cannot fully reflect the system's ability to avoid collisions in dangerous accident scenarios. The aim of present paper was to develop a new method to test the intelligent driving systems in order to avoid dangerous accidents and to protect vulnerable road users. A SIMULINK based software-in-loop platform was developed by coupling simulation with Apollo system and Prescan software. In-depth real-world accident data was used to reconstruct the simulation scenario using Prescan software and the dynamic durations of the vehicles involved in the accident were retrieved from reconstruction using PC-Crash software while Trucksim or Carsim was used to create a dynamics model of the tested vehicle which would be placed in the accident scenarios as the autonomous vehicle. Apollo system shared by BAIDU was applied as the intelligent driving system for the autonomous vehicle based on ROS system. AEB control model and fully autonomous driving model were tested in this software-in-loop platform in various accident scenarios. The results show that these autonomous vehicles can perform better in simple test scenarios, but still failed in some unavoidable traffic accidents. The simulation method using real-world accident data is efficient for autonomous vehicle testing in software-in-loop platform.

Keywords: accident scenarios, autonomous vehicle, apollo system

1. INTRODUCTION

With the rapid development of the autonomous vehicles, many vehicles have been equipped with advanced driving assistant system (ADAS). However, these "intelligent" cars are still reported to be involved in some traffic accidents. Although the cars with intelligence driving system have past the tests before mass-produced process, most of the products are imperfect. Consequently, a systematic test of the vehicle's intelligent driving system must be carried out to ensure that the system can maintain good stability and robustness in various complicated traffic scenarios.

According to the classification results by the NHTSA (National Highway Traffic Safety Administration)[1], most of vehicles equipped with intelligent driving systems on the market are generally in L2 or between L2 and L3, which means that most of these vehicle only have simple AEB and ACC driving assistance functions. In order to verify the effectiveness of these system, research institutions often need to develop a test vehicle with complete sensor system and other hardware such as the control system and the computing system, then test them in some basic scenarios[2]-[3]. For some vehicle equipped with L3 or L4 intelligent driving system such as the autonomous vehicle developed by Google[4], test vehicles often require long-distance driving tests on real roads or in a special test sites[5]-[8]. However, there are many limitations using the above test methods, such as the unrepresentative scenario and time-costed road tests. It is obvious that the traditional methods of the driving system is expensive and of low efficiency.

Simulations before road test are the widely used method to test the intelligent vehicle system which are of low cost and time efficiency. Commercial softwares, such as Prescan and Carsim, are applied in the simulation phase of autonomous vehicle development. Prescan is a physics-based simulation platform developed by TASS international, which is used in the automotive industry for development of Advanced Driver Assistance System(ADAS) that are based on sensor technologies such as radar, laser/lidar, camera and GPS. Prescan is also used for designing and evaluating vehicle-to-vehicle(V2V) and vehicle-to-infrastructure(V2I) communication application as well as autonomous driving applications. Prescan can be used from model-based controller design(MIL) to real-time tests with software-in-the-loop(SIL) and hardware-in-the-loop(HIL) systems. In this paper Prescan is used to rebuild the accident scene and build the sensor system of the test car. Carsim is a software developed by Mechanical Simulation Corporation, which delivers the most accurate, detailed, and

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efficient methods of multi-axle commercial and military vehicles. Carsim is universally the preferred tool for analyzing vehicle dynamics, developing active controllers, calculating a car's performance characteristics, and engineering next-generation active safety systems. In this paper Carsim is used to build the dynamic model of the test car.

The Apollo platform consists of three parts: localization, open-software platform[9]-[10], and cloud-service platform. Baidu explains on its Apollo website that the Apollo platform provides partners with high-precision map services with advanced technology, extensive coverage, and high automation. Apollo also offers a simulation engine, which the company claims as “the only one in the world that is open and is equipped with massive data.” Moreover, Apollo's end-to-end autonomous driving algorithm has “the world's largest volume of deep-learning data sets” that are open. In this paper we use Apollo as the intelligent driving system of test vehicle.

The accidents data used in the experiment comes from IVAC (Investigation of Vehicle Accident in Changsha) and CIDAS (China In-Depth Accident Study) project, IVAC is a project organized by Hunan University and GM, which has been in operation since 2006, focus on conducting in-depth traffic accident investigation, analysis and research for vulnerable road users (including pedestrians and bicycle riders).CIDAS begins in 2011, organized by Hunan University and China Automotive Technology and Research Center (CATARC), focus on conducting in-depth traffic accident investigation, analysis and research in various road traffic accidents involving motor vehicles in Changsha.

In this paper, test procedures have been developed through the construction of the software-in-the-loop co-simulation system based on the software mentioned above and the accident scenes based on the CIDAS and IVAC database. Hope that the test can reflect the real performance of the test vehicle with the Apollo control system. Which is of great value for the development and testing of autonomous vehicles.

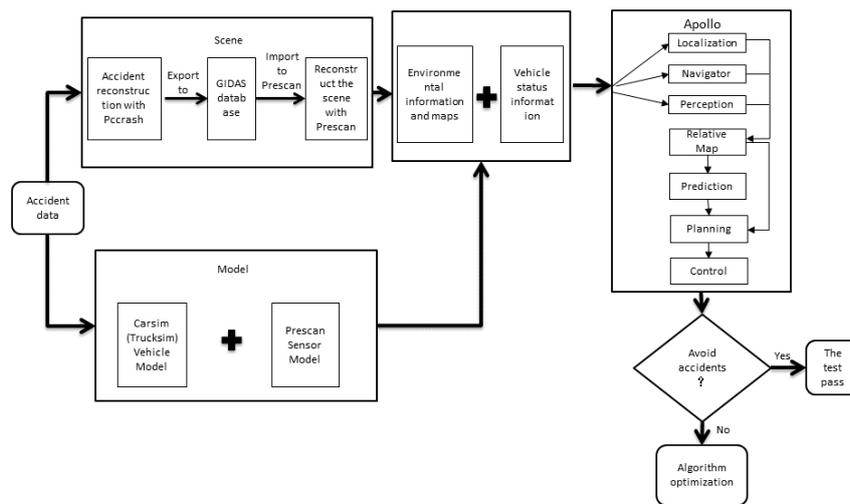


Fig. 1. Architecture of the co-simulation system

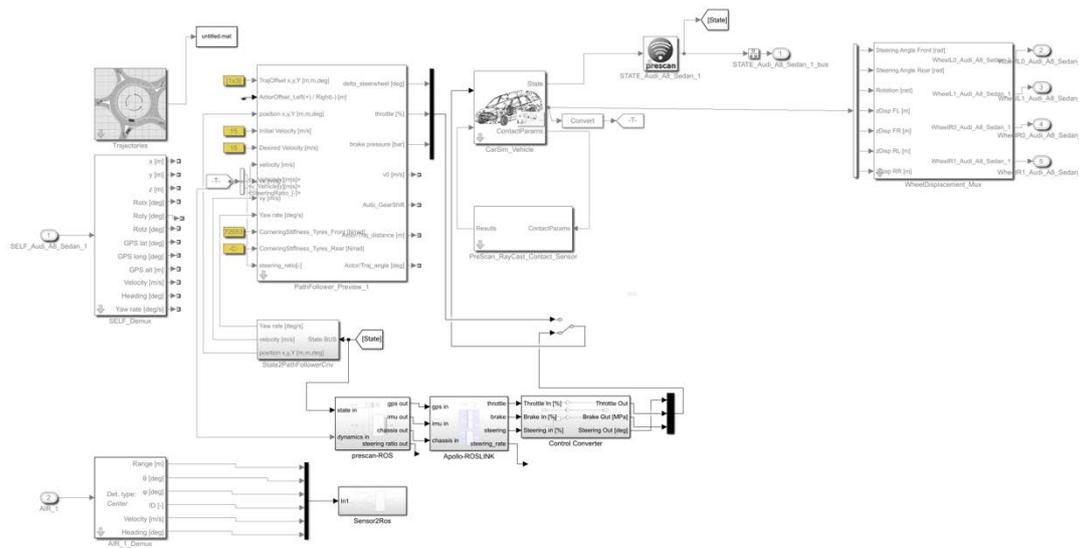


Fig. 2. Simulink model of the co-simulation system

Co-Simulation System

The Fig. 1 above shows the architecture of the co-simulation system. Whole process in the experiment can be divided in three parts: The accident scene reconstruction, Vehicle dynamics model creation, Construction of sensor data transmission interface and vehicle control signal transmission interface. To build whole co-simulation system, there need two computers, one computer with windows system was responsible for running the co-simulated Simulink model built by Carsim and Precan. The other computer was installed with Ubuntu system, and installed the Apollo open source software platform and connect with another computer via Wi-Fi and receive signals from another computer and generate corresponding vehicle control signals and control the vehicles in the Simulink model.

Accident Scene Reconstruction

Based on the in-depth investigation and research on local accident data in Changsha, a lot of accident cases have been rebuilt in the Pc-crash, Pc-crash can generate data in GIDAS format, which can be imported directly through Precan’s GIDAS interface, make trajectory of the accident vehicle as close as possible to the real situation. Through the further adjustment of the road environment and accident scene in Precan, the whole accident scene is more realistic.

1.1 Vehicle dynamics model creation

The vehicle models in precan can use vehicle dynamics models generated by Carsim or Trucksim. In carsim, the vehicle model can be adjusted in more detail according to the structural parameters and dynamic parameters of the real vehicle, so that the vehicle dynamic feedback in the virtual environment is closer to the real car.

1.2 Signal transmission system

Apollo is a platform with the combination of the hardware and the software, under normal circumstances, the signal received by the Apollo system comes from the hardware platform carried on the car, such as the GPS, IMU, Sensor signal and the vehicle status, these signal all transmitted to the Apollo software via the ROS communication system. Since Simulink has its own ROS communication module, we can use these modules to directly transmit the signals between two computers mentioned above.

The co-simulation of the Precan and the Carsim is performed in a Simulink model, the specific structure of the model is shown in the Fig. 2 above.

2. TWO SPECIFIC ACCIDENT CASES

Here we picked two accident cases to build virtual scenes in Precan, and let the AEB system and Apollo control the vehicle.

1.3 Pedestrian collide with vehicle

In order to verify the effectiveness of the two system(AEB and Apollo) in a simple scenario, the researchers built a scene of pedestrians running across the road directly in Precan.

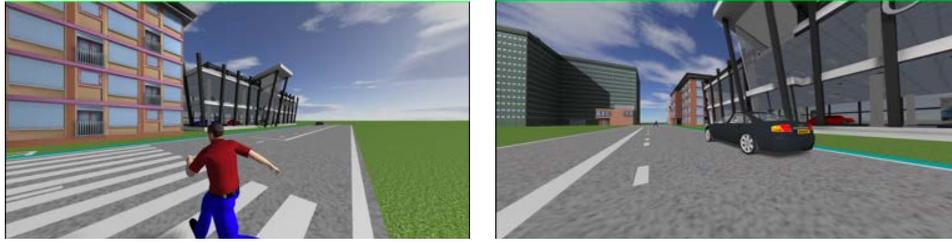


Fig. 3. pedestrain-vehicle accident scene

The scene in Prescan shown in the Fig. 3, in experiment researchers will let the test vehicle have initial speed of 60km/h.

1.4 Multi-vehicle accident

A total of three cars were involved in this accident, as the Fig. 4:

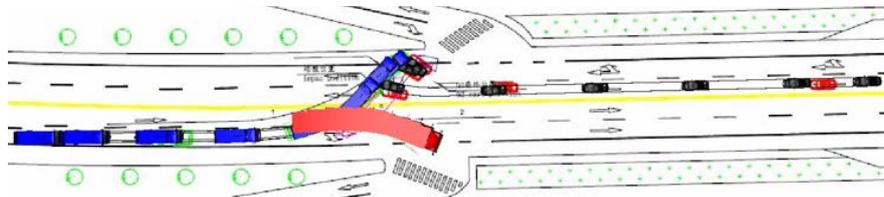


Fig. 4. Multi-vehicle accident plan

In this case, the car that came from the right side traveled at a speed of 64km/h, and the small truck from the left side was disturbed by the towed trailer, and entered the opposite lane. Because the small truck was in the blind spot of the car driver because it was blocked by the trailer before entering the opposite lane, there was not enough time for the car driver to react when the small truck entered the opposite lane, which eventually led to the occurrence of the accident.



Fig. 5. Pc-crash scene, Prescan scene vs. actual scene

Fig. 5 shows the effect diagram in the Pc-crash.Prescan can directly use the GIDAS database exported from Pc-crash for scene reconstruction, Fig. 6 shows the comparison of the accident scene reconstructed in prescan with the screenshot of the accident scene monitoring video.

3. RESULTS

After the simulation of the above cases, found that in the traffic scene of pedestrian-vehicle, the two control systems can recognize pedestrian and can avoid the collision with the initial speed of 60km/h. The simulation running process is shown in the Fig. 7.



Fig. 6. Experiment running with Apollo

In the case of multi vehicles, found that both system fail to avoid the collision. The simulation running process is shown in the Fig. 8 and Fig. 9.



Fig. 7. Experiment running with AEB

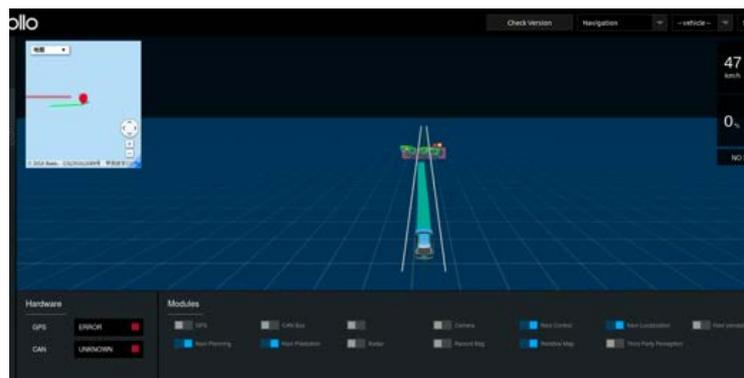


Fig. 8. Experiment running with AEB

4. CONCLUSION

Based on the above experiment results, we find that the existing vehicle control algorithms can indeed play a certain role in accident avoidance in some simple single scenes, but in complex road environments and complex accident scenarios, these control systems are often unable to effectively avoid collision.

With the continuous improvement of autonomous vehicle control algorithms and the continuous improvement of hardware manufacturing level, we may see many autonomous vehicles driving around us in different roads in the near future, but it is also worth studying more effective and comprehensive testing and evaluation of these

intelligent control algorithms, this article uses software-in-the-loop of ideas to build a complete intelligent driving algorithm co-simulation platform, it enables some research institutions to test and simulate the intelligent driving algorithm more quickly and effectively without using a lot of money and building a hardware platform, which can effectively shorten the early development cycle of the intelligent driving algorithm and enable the algorithm to enter the hardware faster. It also enables hardware-in-the-loop testing to become more stable and secure.

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Analysis of the Injury Risk for Elderly Drivers' Accident Based on Improved Decision Tree Algorithm

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Abstract

There are many factors affecting the safety of elderly drivers in the road traffic environment, the injury risk prediction analysis conducted in paper is based on 502 elderly driver accident data samples. In order to improve the accuracy of classification algorithm for the risk of accidental injury with elderly driver and reduce the impact of over-fitting and other problems on the prediction results, an improved decision tree algorithm was proposed based on ROC evaluation. The AUC is used as an evaluation index to provide an interpretable basis for the final classification prediction model. The results show that the traffic model of the other party has the greatest impact on the degree of injury of the elderly driver, followed by the presence or absence of physical isolation facilities, and some of the independent variables affecting the speed of the vehicle (such as weather Conditions, types of intersections, etc.) Therefore, improving road traffic infrastructure and adopting control measures such as bans are essential for road safety for elderly driver.

Keywords: Traffic safety; Accident analysis; Improved decision tree algorithm; Degree of injury

1 INTRODUCTION

With the economic development, the income of the elderly in China has increased and the lifestyle has changed. Compared with the original walking and bus trips, more and more elderly people choose to travel more conveniently and flexibly to drive their own vehicles (Shi Jing, J. M. Y. 2014). The "Regulations on the Application and Use of Motor Vehicle Driving Licenses (Order No. 139 of the Ministry of Public Security)" implemented in 2016 revised the previous Decree No. 123, and revised the original "motor vehicle drivers over 60 years of age should conduct an annual physical examination". Above 70 years of age, the medical examination requirements for elderly drivers have been relaxed. After adjustment, there are more than 6 million elderly driver in China from 60 to 70 years of age who will not have to undergo an annual physical examination (Liu Lei, 2017). This policy has brought convenience to the travel of the elderly. However, according to the "Statistical Annual Report of the Road Traffic Accidents of the People's Republic of China" (2009~2016), the number of elderly driver' vehicles has been on the rise. In the past 8 years, the number of elderly driver and the total number of accidents has increased. The increase in the number of elderly driver accidents has become a social problem that needs to be solved urgently.

The study of the characteristics of traffic accidents of elderly driver is the basis for ensuring the safety of driving for the elderly. A large number of studies have been conducted at home and abroad on traffic accidents involving elderly driver. In China, the research on traffic accidents is relatively mature. Zhang Yuchun et al (Zhang Yuchuan, H. C., W D X, 2009). studied the characteristics of highway tunnel accidents through investigation and analysis of highway tunnel traffic accidents. Qi Yulong et al (Pei Yulong, W L Z, 2009) used principal component analysis to analyze the characteristics of urban expressway traffic accidents. Wang Hong et al (Wang Hong, C J, W D D, 2013) constructed a corresponding traffic forecasting and analysis platform for urban agglomeration road network based on traditional grey prediction model. Meng Xianghai et al (Meng Xianghai, T W, 2017) used statistical distribution fitting and hypothesis testing to analyze the statistical distribution characteristics of traffic accidents and used the binomial distribution test method to give the probability calculation formula of the influencing factors of accidents. In foreign countries, Tefft et al. (Tefft B C. 2008) considered accident liability research based on statistical data on fatal traffic accidents in the United States. It was found that elderly drivers over the age of 85 faced the highest traffic safety risks leading to their own death. Clarke et al. (Clarke D D, Ward P, Bartle C, et al. 2010) used qualitative judgment methods instead of traditional statistical methods to study 2000 traffic accidents involving 60-year-old drivers in the UK. It was found that the sample middle-aged drivers had significant impacts at intersection crossings and reasonable avoidance. problem. Cicchino et al (Cicchino J B, Mccartt A T. 2015) based on the National Highway Traffic Safety Administration National Motor Vehicle Collision Accident Survey conducted data analysis found that 97% of the major causes of major traffic

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safety accidents involving elderly driver were driver's operational errors. Lombardi et al (Lombardi D A, Horrey W J, Courtney T K.2016) used a multivariate logistic regression model to assess age- and gender-related differences in fatal traffic safety accident risks at intersections.

At present, the classification prediction model studied at home and abroad lacks a reasonable evaluation basis, and usually one or several post-tests are performed after the end of the algorithm. Such an approach does not indicate that the classification prediction model is in an optimal state, and that over-fitting occurs in order to obtain an interpretable prediction result (over-fitting means that the assumption becomes excessively strict in order to obtain a consistent assumption) . Based on this paper, an improved CHAID decision tree algorithm is proposed. Based on the ROC evaluation, the algorithm uses AUC (area under the curve) as the evaluation index to provide an interpretable basis for the final classification prediction model, and for the elderly driver. Predictive analysis of the risk of accidental injuries to reduce the severity of injuries to road drivers in elderly drivers.

2 ACCIDENT DATA COLLECTION

2.1 Accident data collection content

The data of the elderly driver accidents studied in this paper is derived from the road accident statistics of a city in southern China from 2013 to 2015. The city covers an area of about 1,643 square kilometers and has a population of about 3.62 million. The climate is a humid climate with a north subtropical climate and a relatively developed economy.

According to statistics, there were 10,968 road traffic accidents in the city from 2013 to 2015, of which 502 were drivers (ages older than 60 years old). According to the requirements for on-site collection of road traffic accidents, the collection of traffic accidents mainly includes 12 items such as driver's injury degree, driver's age, road type, road physical isolation status, road cross-section position and lighting conditions, as shown in Table 1.

Table1. Data collection form for elderly driver in traffic accidents

Traffic element	Collecting content	Traffic element	Collecting content
Person	Old driver's degree of injury	Vehicle	Inter-vehicle accident collision form
	Old driver age		The other party's transportation method
Environment	Lighting conditions	Road	Road type
	Weather conditions		Road physical isolation
	Accident time		At the cross section of road
	Road conditions		Intersection type

2.2 Accident data variable setting

In the accident risk prediction study for elderly driver, the degree of injury of the elderly driver in the traffic accident is set as the target variable in the accident variable setting. The classification statistics of the accident data are shown in Table 2.

Table 2. Injury severity distribution for elderly driver in traffic accidents

		Frequency	percentage	Effective percentage	Cumulative percentage
Effective	Minor injury	230	45.8	45.8	45.8
	Death or serious injury	98	19.5	19.5	65.3
	No injury	174	34.7	34.7	100.0
	total	502	100.0	100.0	

Through basic statistical analysis, it can be found that there are 502 traffic accidents among elderly driver. Among them, there were 175 injuries, accounting for 35%; 231 minor injuries, accounting for 45%; 101 deaths or serious injuries, accounting for about 20%. Therefore, the degree of injury to an elderly driver's traffic accident can be classified into two categories: no injury or minor injury, death or serious injury (as shown in Table 3).

Table 3. Target variable definition

Target variable	Variable attribute
Classification of accident injuries	0 = No injury or minor injury
	1 = Death or serious injury

Through the preliminary research and analysis of the risk prediction of the elderly driver's accident, and according to the requirements of the CHAID decision tree algorithm, the age, road type, lighting conditions, road cross-section position, road physical isolation status, road surface condition, The type of intersection section, weather conditions, the form of accident collision between vehicles, the time of accident occurrence and the traffic mode of the other party are independent variables. The specific variable information is shown in Table 4.

Table 4. Independent variable definition

Independent variable	Variable attribute
Old driver age	1= 60~70 year old; 2= 70~80 year old;
Road type	1= city road; 2= Grade road; 3= Outer road; 4= Other roads
Road physical isolation	1= Isolated; 2= No isolation
At the cross section of the road	1= Motor vehicle lane; 2= Non-motor vehicle lane; 3= Machine non-mixing lane
Lighting conditions	1= daytime; 2= nighttime; 3= twilight
Intersection type	1= intersection; 2= Road section
weather conditions	1= sunny; 2= Bad weather
Accident time	1=6:00~11:59; 2=12:00~17:59; 3=18:00~5:59
The other party's transportation method	1= Large and medium vehicles; 2= Small vehicle; 3= non-motor vehicle; 4= walk
Road condition	1= In good condition; 2= Poor condition
Inter-vehicle accident collision form	1= Rear-end collision; 2= Frontal collision; 3= Side collision

3 IMPROVED CHAID DECISION TREE ALGORITHM THEORY

3.1 Traditional decision tree algorithm

The traditional decision tree algorithm is based on the principle of information gain. The Gini coefficient, the chi-square statistic or the information gain ratio is used as the basis for splitting. According to the parameter setting and the parent-child node grows layer by layer, the algorithm of forming a complete classification tree is finally formed. According to the classification, different decision trees have different algorithms such as CART, CHAID, C4.5 and C5.0.

The CHAID decision tree algorithm, also known as the chi-square automatic cross-checking decision tree algorithm, is a decision tree algorithm that determines the optimal branch attributes and segmentation points based on the significance test of the chi-square statistic. The chi-square statistic calculates the degree of dependence between variables. The larger the calculated chi-square statistic value, the higher the degree of dependence between variables, as shown in the following equation:

$$\chi^2 = \sum_{i=1}^l \sum_{j=1}^k \frac{(X_{ij} - E_{ij})^2}{E_{ij}}, E_{ij} = \frac{x_i \cdot x_j}{N} \quad (1)$$

Where E_{ij} is the expected value of the number of the i -th attribute and the j -th type of data in the contingency table; X_{ij} is the actual value of the number of the i -th attribute and the j -th type of data in the contingency table.

Therefore, the traditional CHAID decision tree splitting and growing process is as follows:

(1) Suppose there is a set of values of the information source $Y A = \{\alpha_1, \alpha_2, \alpha_3, \dots, \alpha_n\}$, where the probability of the occurrence of the signal α_i is $p_i = \{P|Y=\alpha_i\}$, and $I(\alpha_i) = -\text{Log}p_i$ is the amount of information of α_i . The

mathematical expectation of the amount of information is the average information amount or information entropy of the information source, recorded as $H(X)$, with:

$$H(X) = \sum_{i=1}^n p_i \log p_i \quad (2)$$

The amount of information gain is an indicator of feature selection in decision tree splitting. The contribution of each attribute to the information amount of the split data subset is measured by information gain.

(2) Assume that the training set T includes n samples, respectively, belonging to m classes, wherein the ratio of the i -th class appearing in T is p_i , then the total information entropy is

$$Info(D) = -\frac{x_1}{N} \log_2 \left(\frac{x_1}{N} \right) - \frac{x_2}{N} \log_2 \left(\frac{x_2}{N} \right) - \dots - \frac{x_k}{N} \log_2 \left(\frac{x_k}{N} \right) = -\sum_{j=1}^k p_j \cdot \log_2(p_j) \quad (3)$$

Assuming that attribute A is a branch attribute of the decision tree, the information entropy under attribute A_i is

$$Info(A_i) = -\frac{x_{i1}}{x_i} \log_2 \left(\frac{x_{i1}}{x_i} \right) - \frac{x_{i2}}{x_i} \log_2 \left(\frac{x_{i2}}{x_i} \right) - \dots - \frac{x_{ik}}{x_i} \log_2 \left(\frac{x_{ik}}{x_i} \right) \quad (4)$$

The information of attribute A is determined according to the number of data under each attribute value:

$$Info_A(D) = \frac{x_1}{N} Info(A_1) + \frac{x_2}{N} Info(A_2) + \dots + \frac{x_i}{N} Info(A_i) = \sum_{i=1}^n \frac{x_i}{N} Info(A_i) \quad (5)$$

Then the information gain of the A attribute is

$$Gain(A) = Info(D) - Info_A(D) \quad (6)$$

(3) The above two steps are the principle of information gain. The traditional CHAID decision tree algorithm determines the optimal branch attribute based on the significance test of the chi-square verification statistic, and is a multi-branch decision tree algorithm. That is, the merged threshold α_1 is set, and the divided threshold α_2 is set.

When the p value $> \alpha_1$, the two branches are merged into a new group;

When the p value $< \alpha_2$, it is divided into different branch nodes.

It can be seen that the traditional CHAID decision tree algorithm is a better classifier, but through repeated experiments, it can be found that the traditional CHAID decision tree algorithm is susceptible to the data itself. When the variance is large and the data is disturbed, The results will be affected to a large extent. In addition, it is prone to over-fitting in the application process, that is, the assumption becomes excessively strict in order to obtain a consistent assumption. In the traditional CHAID decision tree algorithm, in order to obtain interpretable results, the thresholds of merging, segmentation and the number of decision tree layers are changed many times without any basis.

3.2 Improved CHAID decision tree algorithm

In order to solve the problem that the traditional CHAID decision tree algorithm is susceptible to data fluctuation and over-fitting, this paper proposes an improved CHAID based on the traditional CHAID decision tree algorithm by ROC analysis and various statistical tests. Decision tree algorithm. The new algorithm combined with ROC analysis can perform iterative prediction accuracy test, which reduces the impact of data fluctuation and over-fitting on prediction accuracy.

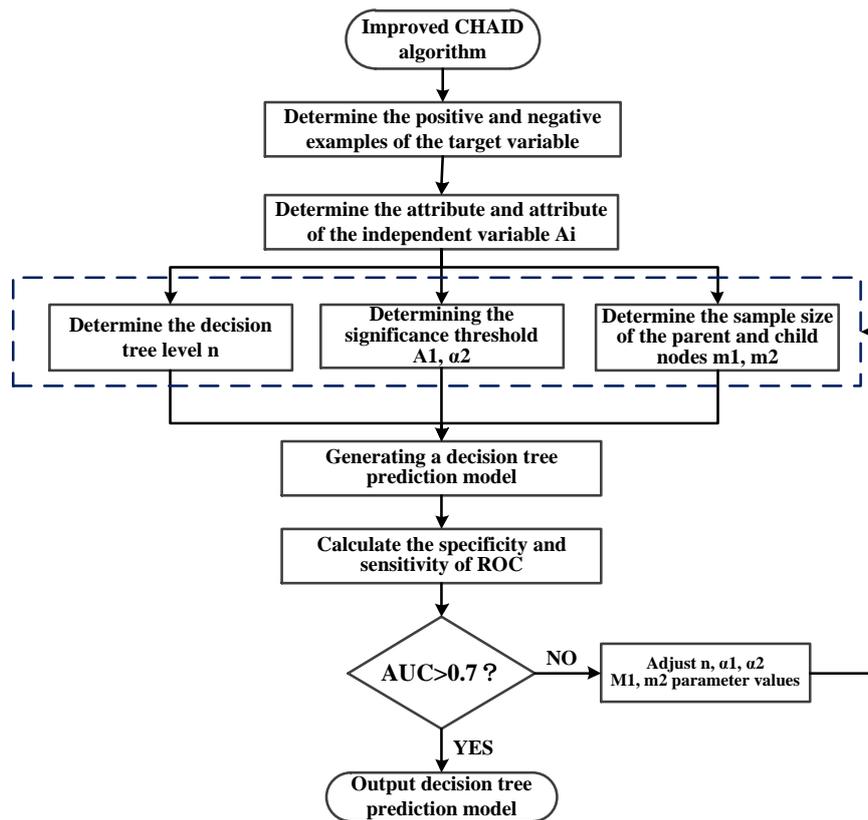


Figure 1. Flow chart of improved CHAID decision tree algorithm

Figure 1 shows the flow chart of the improved CHAID decision tree algorithm. Based on the traditional CHAID decision tree algorithm, based on the ROC evaluation, the area AUC under the ROC curve is used as the performance index reflecting the decision tree classification prediction model. Predictive analysis of the risk of accidental injury to elderly driver.

Table 5. Forecast grade value conversion classification table (part of the table)

Num	Actual Value	Predicted Probability-0	Predicted Probability-1	Predicted Value
01	0	0.59	0.41	0
02	1	0.42	0.58	1
03	0	0.42	0.58	1
04	0	0.76	0.24	0
05	1	0.85	0.15	0
.....

As shown in the above table, the true value of the degree of injury in the accident data is 0 without injury or minor injury, 1 for serious injury or death. The results of the classification of the CHAID decision tree above can be obtained as a "no injury or minor injury" prediction probability score and a "severe injury or death" prediction probability score as shown in "predictive probability score - 0" and "predicted probability score - 1". According to the number, the predicted classification value of each accident is transformed. For example, the true value of the accident is 0, the "predicted probability score - 0" is 0.59, and the "predicted probability score - 1" is 0.41, that is, the prediction of "no injury or minor injury" The probability score is greater than the predicted probability score of "severe injury or death", then the result of the predicted value is 0 and the true value is consistent, while the number 03 is the opposite of the predicted value. This process converts the classification value for the predicted rating value. The cross matrix is established based on the real value and the predicted value, as shown in Table 6.

Table 6. The cross matrix of real and predicted values

		Actual value	
		0	1
Predictive value	0	TP (2, 01and04)	PP (1, 05)
	1	FN (1, 03)	TN (1, 02)

Based on the cross matrix of real and predicted values, the following indicators can be obtained:

- (1) accuracy rate (accurate forecast quantity / total quantity) = $(TP + TN) / (TP + PP + FN + TN) = 3/5$
- (2) error rate (number of errors predicted / total number) = $(PP + FN) / (TP + PP + FN + TN) = 2 / 5$
- (3) Sensitivity (the number of positive cases correctly predicted / the total number of positive cases) = $TP / (TP + FN) = 2 / 3$
- (4) Specificity (the number of negative cases correctly predicted / the total number of negative cases) = $PP / (PP + TN) = 1/2$

Sensitivity is also known as positive coverage, and specificity is also called negative hit.

However, the final classification value and the determination of the cut value have a great influence. For example, the score of the predicted score in Table 5 is converted to a classification value of 0.5, that is, the default "no injury or minor injury" prediction probability score and the "severe injury or death" prediction probability score are equal to the prediction result weight. ROC analysis means that different segmentation values correspond to different positive case coverages and negative example hits. Table 7 shows some of the data shown in Table 7.

Table 7. ROC analysis

Cut-Off Value	Coverage Probability	Hit Probability	Error rate
0	1	0	1
0.01
.....
0.5	0.67	0.5	0.5
.....
0.99
1	0	1	0

In the ROC curve, the ordinate is the coverage and the abscissa is the error rate (1-hit). The diagonal line is the result of a random judgment (such as a coin toss). Therefore, the closer the curve is to the upper left corner, the higher the coverage of the decision tree classifier, the lower the error rate and the better the hit. At the same time, the ROC curve is relatively smooth, indicating that the sample size has reached the standard of ROC analysis. We use the Area Under Curve (AUC) to visually reflect the performance of the classifier. The larger the AUC, the better the performance.

The AUC reference values of different models are different. The decision tree classification model should belong to the behavioral risk prediction model with a lower limit of 0.7, as shown in Table 8.

Table 8. AUC reference value of a partial application model

Application model	AUC reference value
Market forecasting model	70%~80%
Loss prediction model (telecom industry)	80%~90%
Behavioral risk prediction model	70%~90%
Credit risk prediction model	70%~85%

4 ELDERLY DRIVER ACCIDENT DATA ANALYSIS AND RISK PREDICTION

According to the improved CHAID decision tree algorithm, 502 old driver road accident data are predicted and analyzed. The final result shows that the CHAID decision tree parameters with AUC greater than 0.7 are shown in the following table.

Table 9. Decision Tree Parameter List

	Decision tree parameter	Parameter value
Decision tree growth	Merged significance level threshold α_1	0.15
	Separate significance level threshold α_2	0.1
	Maximum tree level n	3
Decision tree pruning	Parent node minimum sample size m1	20
	Child node minimum sample size m2	10

Fig. 2. ROC curve map (Target variable: degree of injury)

Based on the prediction results of 502 sample data, the ROC curve based on the degree of damage prediction is obtained, as shown in Fig. 2. The AUC values obtained by ROC analysis are shown in the table below.

Table 10. Area Under Curve

Area	Standard error a	Progressive Sig.b	Asymptotic 95% confidence interval	
			Lower limit	Upper limit
0.767	0.025	0.000	0.688	0.802

As shown in the table, the classification model AUC value is 0.767, and the prediction result is more accurate.

As shown in Table 11, some of the results extracted from the improved CHAID decision tree model according to the "IF-THEN" rule indicate that the five independent variables of the traffic mode, weather conditions, road physical isolation, intersection segment type and age of the elderly driver are introduced into the classification rules. Among them, the traffic mode of the other party is the most relevant and is located on the first floor of the decision tree; the weather condition and the physical isolation of the road have secondary influencing factors, which are located on the second floor of the decision tree; the intersection type and the old driver have the lowest age correlation. Located in the third floor of the decision tree; the time of the accident, the form of accident collision between vehicles, the condition of the road, the lighting conditions, the type of road, and the condition of the cross section of the road that have not reached the set are not selected.

(1) When the collision object is a non-motor vehicle and a pedestrian, the confidence of the elderly driver in death or serious injury is 3.9%, and the confidence of minor injury is 17.1%; when the collision object is a small vehicle, the elderly driver is killed or seriously injured. The confidence level is 22.7%, and the confidence of minor injuries is 54.9%. When the collision target is large and medium-sized vehicles, the confidence of the elderly driver in death or serious injury is 37.5%, and the confidence of minor injury is 60.7%. It shows that when the traffic mode of the collision object is a motor vehicle, the probability of serious injury or death of the elderly driver will increase, and the medium and large vehicles are the most serious.

(2) In the environment of walking and non-motor vehicles and small cars, physical isolation facilities cause the elderly driver to be injured less than the roads without physical isolation facilities. However, when the collision targets are large and medium-sized vehicles, there is physical Isolation facilities can increase the likelihood of an elderly driver being injured.

(3) When the collision object is a small vehicle, the confidence level of death or serious injury of the elderly driver caused by sunny environmental accident is 25.8%, and the confidence of minor injury is 54.1%; the confidence of the elderly driver in death or serious injury caused by bad weather environment At 14.3%, the confidence level of minor injuries was 57.1%.

This phenomenon is largely due to the fact that the speed of the vehicle during sunny weather is likely to be higher than in bad weather, so the probability of serious injury increases.

Table 11. The rule extraction of the degree of classified accident injury (part)

Num	IF	THEN	Number of accidents	Confidence level
1	The other party is a non-motor vehicle	No injury or minor injury	72	75%
		Death or serious injury	19	19.8%
		Death or serious injury	5	5.2%
2	The other party is a small vehicle & sunny&60~70 years old	No injury or minor injury	120	76.1%
		Death or serious injury	47	23.9%
		Death or serious injury	47	23.9%
3	The other party is a small vehicle & sunny&70~80 years old	No injury or minor injury	23	63.9%
		Death or serious injury	13	36.1%
		Death or serious injury	13	36.1%
4	The other party is small vehicle & bad weather & no isolation	No injury or minor injury	44	78.6%
		Death or serious injury	12	21.4%
		Death or serious injury	12	21.4%
5	The other party is a medium and large vehicle & no isolation	No injury or minor injury	16	51.6%
		Death or serious injury	15	48.4%
		Death or serious injury	15	48.4%
6	The other party is a medium and large vehicle & has isolation & intersection	No injury or minor injury	11	91.7%
		Death or serious injury	1	8.3%
		Death or serious injury	1	8.3%
7	The other party is a medium and large vehicle & has isolation & section	No injury or minor injury	8	61.5%
		Death or serious injury	5	38.5%
		Death or serious injury	5	38.5%

(4) Under the sunny environment where the collision target is a small vehicle, the confidence of death or serious injury of the 60-70-year-old driver is 23.9%, the confidence of minor injury is 53.8%; the 70-80-year-old driver is dead or seriously injured. The confidence level was 36.1%, and the confidence of minor injuries was 55.6%. Explain that elderly drivers who are older in certain circumstances are more likely to be seriously injured or die than elderly drivers who are relatively younger.

(5) When the collision object is a large and medium-sized vehicle and the road has physical isolation facilities, the confidence level of death or serious injury to the elderly driver at the intersection is 8.3%, and the confidence of minor injury is 91.7%; The confidence level of death or serious injury is 38.5%, and the confidence of minor injury is 61.5%.

The main reason for this phenomenon is that the intersection will have speed limit and restraint on the vehicle. The accidents at the intersection are mostly rubbing accidents, and the injuries are lighter.

5 CONCLUSION

From a micro level, this paper proposes an improved CHAID decision tree algorithm for predicting the risk of injury to elderly driver from the over-fitting of traditional CHAID decision tree algorithm. Based on the prediction results, the following conclusions can be drawn:

(1) The other party's transportation mode is always the most influential aspect of the elderly driver's injury. Due to the physical characteristics of the large vehicle itself, the accident is more likely to cause damage to the elderly driver. Therefore, it is necessary to take some large-scale vehicle bans in residential areas.

(2) Complete road facilities, such as physical barriers, have a great effect on reducing the degree of injury to elderly driver in road accidents. It can be seen that improving road transport infrastructure is of great significance.

(3) A reasonable control is needed on the speed of the elderly driver's vehicle. The results indicate that the vehicle speed independent variables such as weather conditions and intersections will affect the degree of injury of the elderly driver. Therefore, reasonable deceleration management should be considered.

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Simulation and Analysis of Kinematic Parameters of Vehicle Offset and Rear End Accident

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Abstract

In order to deeply study the motion behavior of vehicles in rear end collision, a vehicle rear end collision accident model is established in PC-Crash simulation environment. Consideration with the relative velocity, offset, the speed of the rear end vehicle, the acceleration, yaw angle and the yaw rate of the vehicle are obtained. The research results show that when the bias degree is 20%, the yaw angle of rear end vehicle and rear end vehicle is the biggest, and it is easy to induce two types of traffic accidents such as rollover or crash fixtures. In addition, the larger the relative collision speed of the two vehicles, the greater the acceleration and the shorter the duration of collision. The research results can provide theoretical basis and data support for driver's behavior decision-making, accident reconstruction and vehicle safety design.

Keywords: rear end collision; kinematic parameter; Relative collision velocity; The bias angle; Yaw angle

1 INTRODUCTION

Rear end collision has always been a frequent type of accidents on high-grade highways. Due to the relatively high collision speed and deformation of vehicle body, it often leads to more serious casualties and property losses. Scholars at home and abroad have carried out a lot of research work on the cause of rear end collision (1), accident reappearance (2) and rear end collision prevention (3). In the research field of the cause of rear end collision, methods and theories such as equivalent accident number method, principal component analysis, system cluster analysis, traffic conflict theory and system cause are mainly used to analyze the cause of rear end collision by qualitative analysis and quantitative calculation, and the main influencing factors of rear end collision are obtained, and the risk calculation model of rear end collision is established. In the research field of rear end collision reappearance and analysis, we mainly use the means of traffic accident scene trace reasoning (4), collision dynamics model (5) and computer simulation (6,7) to infer the initial conditions of the accident and restore the speed, angular velocity and yaw angle of the vehicle during the accident occurrence and development. In the research field of rear end collision prevention, a great deal of research work has been carried out mainly from the aspects of considering driving behavior, driving intention (8) and accident warning (9,10). Traffic accident warning model is mainly established by means of traffic information acquisition technology, an accident factor influence set is established through data investigation, and a traffic accident early warning device established by dynamic video camera technology and computer image processing technology, etc.

These research results provide a certain theoretical basis for the analysis, reproduction and prevention of rear end collision. However, in the actual accident case, because the initial conditions such as the instantaneous speed, collision position and contact point of the two vehicles before the rear end collision and the driver's operation behaviors such as braking and steering before and after the accident are quite different, it is necessary to analyze the vehicle's movement behavior in depth according to the information on the scene of the accident and accurately analyze the accident occurrence and development process.

Based on PC-CRASH simulation software and combined with actual accident cases, this paper establishes a typical rear end crash model, and analyzes the kinematic parameters such as vehicle

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speed, acceleration, yaw angle and yaw rate during the crash, considered such factors as offset, relative collision speed, braking and steering.

2 REAR-END CRASH CASE ANALYSIS

2.1 Case description

There was a traffic accident on a straight road in Beijing in which a small car rear ended a small bus, resulting in a deformation of the front of the small car with an equivalent deformation of 0.43 m; The small bus was hit and moved forward about 15m, and both cars were deflected. The sketch of the scene of the accident and the damage to the vehicle are shown in fig. 1 and fig. 2. The accident is not a centripetal one-dimensional collision, but a typical offset rear end collision.

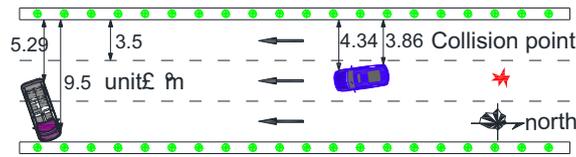


Fig.1 Traffic Accident Scene Diagram

Fig.2 Vehicle damage

2.2 Accident reconstruction

This paper uses PC-CRASH software to simulate the accident reproduction. PC-CRASH software is mainly based on dynamics, energy conservation theory and momentum conservation theory, and reconstructs and simulates the whole accident according to the information such as the parking position of the accident vehicle, tire marks, body deformation, etc.

2.2.1 Simulation model and parameters

The coordinate system in the PC-CRASH simulation environment includes the earth coordinate system $OXYZ$ and the automobile coordinate system $Ox^i y^i z^i$, where the center of mass of the automobile is the origin O^i of the automobile coordinate system, as shown in fig. 3. The $X^i Y^i Z^i$ three-axis velocity is v_x, v_y, v_z and the roll-over angular velocity w_x , the pitch velocity w_y , and the yaw angular velocity w_z .

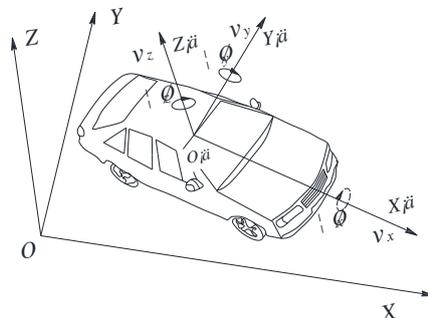


Fig.3 Motion state parameters of automobile

The dynamic equation is as follows

$$m_1 v_{10x} + m_2 v_{20x} = m_1 v_{1x} + m_2 v_{2x} \quad (1)$$

$$m_1 v_{10y} + m_2 v_{20y} = m_1 v_{1y} + m_2 v_{2y} \quad (2)$$

In the formula: m_1 、 m_2 is the total mass (kg) of the front car and the rear car at the time of the accident. v_{10x} 、 v_{10y} is the component (m/s) of the front vehicle speed on the OX axis and OY axis at the moment of collision contact. v_{20x} 、 v_{20y} is the component (m/s) of the vehicle speed on the OX axis and OY axis after the moment of collision contact. v_{1x} 、 v_{1y} is the component (m/s) of the front vehicle speed on the OX axis and OY axis at the moment of collision and separation. v_{2x} 、 v_{2y} is the component (m/s) of the speed of the rear car in the OX axis and OY axis at the moment of collision and separation.

Here, a concept is introduced: offset degree, the specific formula is shown in (1-3):

$$\psi = 1 - \frac{d}{\frac{w_1}{2} + \frac{w_2}{2}} \tag{3}$$

In the formula: ψ is the offset (%); w_1 is the front car body width (m); w_2 is the rear car body width (m); d is the distance (m) between the longitudinal central axes of the front and rear cars at the time of rear end collision. The schematic diagram is shown in fig. 4.

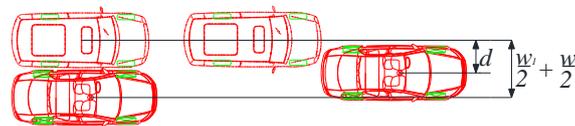


Fig.4 The bias angle sketch

Using PC-CRASH software to carry out accident simulation modeling requires a large number of parameters, which are mainly divided into three categories according to the different ways of obtaining the parameters, as shown in Table 1.

Table1 Simulation model parameters

Category	Parameter
Accurate parameters	Vehicle length / width / height、front suspension parameters、tread、axle base、tire model、drag coefficient、engine maximum power and speed, etc.
Measurement parameter	Front/rear occupant quality、trace parameters of accident scene、vehicle trajectory、horizontal/longitudinal movement distance、route change direction、collision point position、direction、gravity center height, etc
Empirical parameters	Road friction coefficient、 acceleration、 wheel angle、 driver response time、 pre-collision speed、 body friction coefficient, etc

2.2.2 Establishment of simulation model and accident reconstruction

Bring up the small cars and small passenger cars in the accident case from the vehicle database of the PC-Crash software. And according to the specific parameters of the vehicle to adjust the parameters of the vehicle in the model. The coefficient of friction between the vehicle and the ground is set to 0.7. The model established is shown in Figure 5. After repeated simulation tests, when the rear end vehicle speed is 86 km/h, the accident reconstruction results basically coincide with the accident scene map. The comparison between simulation test and real case is shown in Table 2.

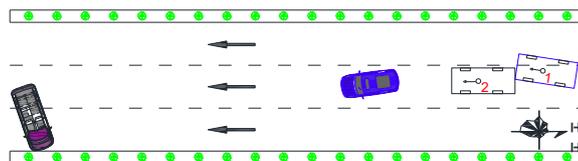


Fig.5 Rear end crash model

Table 2 Comparison between simulation test and real accident results

Test	Yaw angle (°)		Motion locus		Collision point	Vehicle deformation (m)	
	Rear end vehicle	Front vehicle	Rear end vehicle	Front vehicle		Rear end vehicle	Front vehicle
Measurement	14	131	Match	Match	Match	0.40	0.42
Simulation	15	129	Match	Match	Match	0.41	0.40

2.2.3 Calibration of the simulation model

The effective collision speed refers to the speed change from the collision of traffic accident vehicles to the vehicles reaching the same speed. The effective collision velocity theory is used to analyze the case as follows:

The effective deformation velocity of rear end vehicle $x_1 = 40m$, according to empirical formula, the effective collision velocity is as follows: $v_{1e} = 105.3x_1 \approx 42km/h$

The quality of small cars and minibuses are: $m_1 = 2090kg, m_2 = 1895kg$, according to the definition of effective collision speed, the effective collision velocity of the front vehicle is:

$$v_{21} = \frac{m_1 v_{1e}}{m_2} \approx 46km/h$$

The instantaneous speed of rear end collision vehicle and the vehicle in front of the collision is v_{11} and v_{21} respectively, according to the definition of effective collision velocity can be obtained: $v_{11} - v_{21} = v_{1e} + v_{2e} \approx 88km/h$

Compared with the calculation result of empirical formula, the instantaneous velocity precision of the simulation model is 97.73%, which verifies the feasibility and validity of the simulation model.

3 REAR-END CRASH SIMULATION AND ANALYSIS

This paper adopts the method of model simulation to deeply analyze the micro motion behavior of vehicles under different offset degrees、 collision speed and operating behaviors. And obtains the basic data of vehicle kinematics under a certain accident case. Providing theoretical support for reappearance of rear end accident and cause analysis.

3.1 Vehicle kinematics parameters and settings

Based on the rear end accident simulation model established above, studying the relationship between the kinematic parameters of the following vehicle and the degree of vehicle offset and the driver's operating behavior and different relative collision speeds in the rear end collision accident.

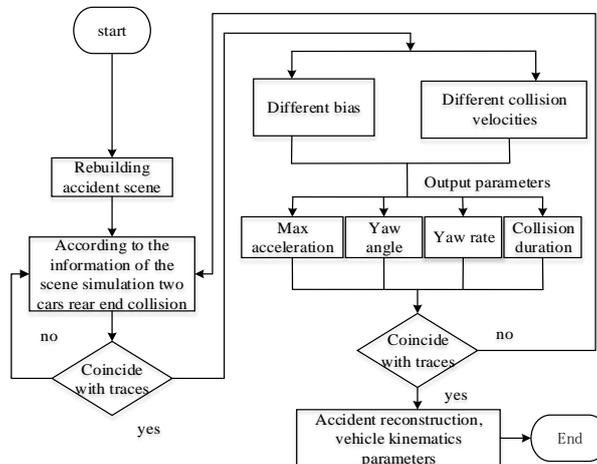


Fig.6 Flow chart of simulation experiment

According to the weight method, several relatively important parameters are selected from the relevant parameters affecting the vehicle motion to analyze the vehicle kinematics parameter sensitivity. The model parameters are shown in Table 3. The setting of collision model parameters is shown in Table 4. And the simulation test flow is shown in Figure 6.

Table 3 Vehicle kinematics parameters

Model independent variable	Two vehicle speed、 bias、 relative collision speed、
Model dependent variable	Maximum plus / minus speed、 vehicle yaw angle、 yaw rate and collision duration.

Table 4 Crash model parameters

Collision type	Parameter	Numerical value	
		Front car	After car
Small car rear end minibus	Driving state	Parking brake	Emergency braking
	Initial velocity	0km/h	50km/h
	Deceleration	4m/s ²	7.154m/s ²

3.2 Simulation test of rear end collision in different offset degrees

In the PC-Crash simulation environment setting bias degree is 0~90% respectively. The specific parameter settings are shown in table 4. The output after collision is shown in Table 5 and Figure 7, Figure 8.

Table 5 Vehicle kinematics parameters in different offset degrees

Bias degree (%)	Maximum acceleration (m/s ²)		Maximum yaw angle (°)		Collision duration (s)
	Front car	After car	Front car	After car	
10	26.89	26.89	-6.36	0.22	2.29
20	65.67	65.67	-59.33	45.29	2.96
30	66.64	66.64	-47.61	46.82	2.92
40	67.5	67.5	-34.42	42.23	2.86
50	68.25	68.25	-23.27	27.22	2.87
60	68.89	68.89	-14.43	14.09	2.87
70	69.42	69.42	-8.34	6.70	2.83
80	69.78	69.78	-4.94	3.26	2.77
90	70.00	70.00	-2.41	1.42	2.63

As shown in table 5, the maximum acceleration of rear end vehicles and the front vehicles gradually increases with the increase of offset at the same collision speed. The variation range of both front and rear vehicles is the same. When the bias is less than 20%, the range of variation is larger. When the bias is greater than 20%, the change range is smaller. The collision duration remains basically unchanged. Indicating that the duration of collision is independent of the offset degree.

As can be seen from Fig. 7, the yaw angle increases gradually to the maximum value during the collision at each offset level. The yaw angle reaches the maximum value (59.33 degrees) when the offset is 20%. The yaw angle of the rear-reaching vehicle is higher than the front vehicle at the same offset level.

It can be seen from Fig. 8 that after the rear end collision of the two vehicles, the yaw rate of the rear end vehicle quickly reaches a peak value, and the yaw rate of the preceding vehicle changes slightly. At the same rear end collision speed, when the offset is 20%, the yaw angle of the vehicle is the largest, and the maximum yaw angle of the rear end vehicle is greater than that of the preceding vehicle. At this time, the vehicle is prone to rollover or collision with the roadside obstacle.

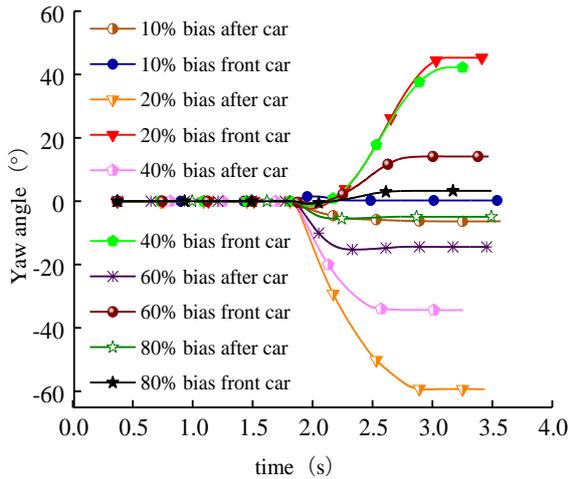


Fig.7 Vehicle yaw angle with different bias

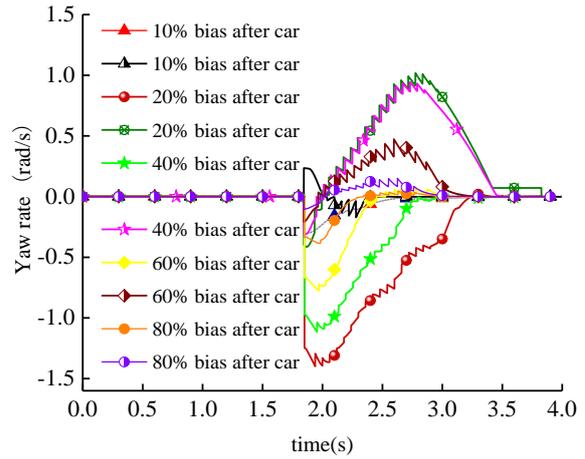


Fig.8 Yaw rate of vehicle under different bias

3.3 Simulation test of rear end collision at different relative collision velocities

In the simulation environment of PC-Crash, the collision speed of rear end vehicles was set as 10km/h~100km/h, with a bias degree of 40%. Other specific parameters are shown in table 4. The output results after collision are shown in table 6, figure 9 and figure 10.

Table 6 Vehicle kinematics parameters in different relative collision velocity

After car speed (km/h)	Maximum acceleration (m/s ²)		Maximum yaw angle (°)		Collision duration (s)
	After car	Front car	After car	Front car	
10	13.61	13.61	-0.61	-0.06	9.78
20	27.17	27.17	-2.93	0	5.34
30	40.64	40.64	-7.7	1.52	3.82
40	54.11	54.11	-15.9	9.29	3.29
50	67.5	67.5	-34.39	42.16	2.86
60	80.83	80.83	-65.83	48.98	2.44
70	94.11	94.11	-99.91	40.41	2.28
80	107.33	107.33	-125.41	6.03	1.94
90	120.19	120.19	-173.77	-5.34	1.53
100	133.5	133.5	-188.33	-11.2	1.32

As shown in Table 6, The maximum acceleration of two vehicles decreases with the increase of braking strength. As the relative collision speed of two cars increases, the collision duration decreases.

As can be seen from figure 9, the maximum yaw Angle of rear end vehicles grows gradually with the increase of collision speed. When the relative collision speed is less than 40km/h, the maximum yaw Angle grows slowly; when the relative collision speed is higher than 40km/h, the yaw Angle grows rapidly. The rear end vehicles yawing Angle with the increase of the relative impact velocity increases and then decreases. When the relative collision speed of 60km/h, yawing Angle (48.98°), the largest relative collision speed above 70 km/h, decreases the maximum horizontal pendulum Angle. From the perspective of time, the rear end vehicle should deflect before the front-end vehicle, and the yaw angle of the rear end vehicle should be larger than that of the front-end vehicle at the same relative collision speed, indicating that the rear end vehicle often bears greater risks in rear end accidents.

It can be seen from figure10, in the collision process, the yaw angular velocity of the two cars first increases and then decreases. Under the same relative collision velocity, the maximum of the yaw angular velocity of the rear car is higher than that of the front car.

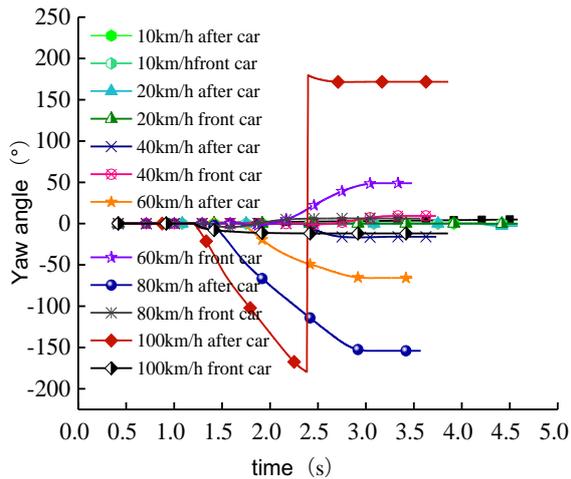


Fig.9 Vehicle yaw angle at different relative collision speeds

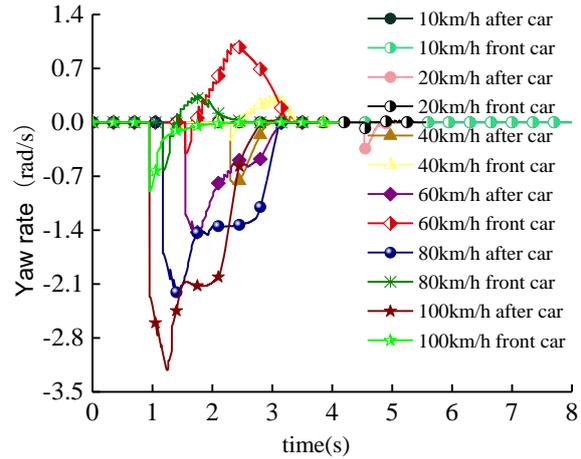


Fig10 Yaw rate of vehicle under different relative collision velocities

4 CONCLUSION

In this paper, a real traffic accident was simulated in the PC-Crash simulation environment, and the conclusion was basically consistent with the actual crash collision speed. The model is proved to be feasible and correct by using effective collision velocity theory. Then under the environment of PC - Crash vehicles offset collision model is set up, by changing the parameters of the movement of vehicles in the simulation model for simulation, and analyzing the simulation output data.

We draw the following conclusions: bias degree was 20%, Front end vehicles and rear end vehicles have the biggest yawing angle, and this predisposes to rollover or secondary accidents such as collision with fixture. In addition, the greater the relative collision speed, the greater the maximum acceleration of the front-end vehicles and the rear-ended vehicles, and the shorter the collision duration. The results will provide theoretical basis and data support for the driver's behavior decision, accident reconstruction, judicial identification and safety design of the vehicle. This paper only studies the change of vehicle kinematics parameters in the rear end collision between two vehicles. Due to the complex influence factors and control parameters of multi-vehicle rear end collision, the research on multi-vehicle collision will be carried out successively in the following studies.

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Improve Traffic Death Statistics in China

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Abstract

Sustainable Development Goal 3.6 aims to “halve the number of global deaths and injuries from road traffic accidents” by 2020 (1). Accurate statistics are crucial to monitoring the progress toward this goal. According to current data, China contributed 23% of global road traffic deaths in 2016 (2). However, Chinese police departments have been criticized for underreporting road traffic deaths (3, 4) and consistently attributing more than 99% of fatal crashes to road users’ behavior rather than vehicle or environmental factors (5). Incomplete and distorted fatal crash data not only mislead policy-makers and researchers, but also misdirect prevention efforts.

Police-reported data suggest that China witnessed a 46% decrease in road traffic deaths from 2002 to 2016 (6), but other data contradict this trend (4, 7, 8). Such discrepancies raise questions about the efficacy of national prevention efforts. The distorted cause spectrum statistics, which indicate that human error causes more than 99% of Chinese road traffic crashes (6) [compared with India, where human error cause rates hover in 75 to 85% range (9)], mistakenly lead national prevention efforts to focus on safety education rather than multifaceted programs that incorporate legislation, engineering, and environmental approaches (10).

Improving the accuracy of Chinese road traffic injury statistics is achievable. The Chinese central government should establish and fund an independent body to collect crash data. China should also correct methodological oddities that yield inaccurate data, including adopting the more commonly used window of 30 days post-crash for a mortality to be classified as a road traffic injury death (11), replacing exclusive-cause with multi-cause classification systems, and integrating other health and occupational surveillance data with traffic crash data to improve mortality estimation. Finally, China should develop a publicly available crash data database, modeled on other national systems such as the Fatality Analysis Reporting System in the United States (12), to allow researchers, practitioners, and the public to cite and use valid data for road traffic injury prevention.

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Road Traffic Injury in Urban Areas: Understanding the Complex City

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Gideon Aschwanden^a and Haifeng Zhao^a

Abstract

Over the past 4 decades considerable efforts have been taken to mitigate the growing burden of road injury. With increasing urbanisation along with global mobility that demands not only safety but equitable, efficient and clean (reduced carbon footprint) transport, the responses to dealing with the burgeoning road traffic injury in low- and middle-income countries has become increasingly complex. In this paper, we apply unique methods to identify important strategies that could be implemented to reduce road traffic injury in the Asia and Pacific region; a region comprising large middle-income countries (China and India) that are currently in the throes of rapid motorization. Using a convolutional neural network approach, we classified cities around the world based on urban characteristics related to private motor vehicles and public transport networks. We then identified 689 cities situated within the Asia-Pacific region and assessed the global burden of disease attributed to road traffic injury for urban design clusters. The modelling identified 9 urban cluster types. The majority (64%) of cities in the Asia-Pacific region fall within Clusters 1 and 2 namely, urban form that is sparse with low capacity road infrastructure and limited public transport. Clusters 1 and 2 comprises cities predominantly from China and South Asia with many low- to middle-income cities that are in the throes of considerable urban development. Urban cluster types with both dense road networks (e.g., Clusters Intense and Cul de sac) and public transport (e.g., Clusters High Transit and Motor City) demonstrated lower rates of DALYs lost per 100,000 population for road traffic injury. This study demonstrates the utility of employing image recognition methods to discover new insights to better understand the complex city and how it relates to road traffic injury.

Keywords: Neural networks, urbanisation, city clusters, road traffic injury

1 INTRODUCTION

The burden of road injury is well documented with global trends highlighting between 1990 and 2013, a 15% decrease in the years of life lost and years lived with a disability due to road traffic injury (1). However, hidden behind the declining global rates of road traffic injury, is the fact that in many low and middle-income countries, the global burden of road injury is increasing. For example, the percent change in the rates of disability adjusted life years between 1990 and 2013 for countries in South Asia (comprising one quarter of the world's population) increased by 6% whilst in South and sub-Saharan Africa, it increased a staggering 35% (1). The increasing rates of road traffic injury in low and middle-income countries is explained, in part, by rapid motorization; a direct consequence of increasing urbanization (2).

Globally, the population is rapidly migrating to towns and cities and this is most pronounced in low and middle-income countries. Countries such as India, China and Nigeria, which account for 37% of the world's population, are expected to observe the greatest urban migration (3). For example, over the 10 years to 2010, 226 million Chinese residents migrated from rural to urban areas (4). Living in urban area offers opportunities that are not available elsewhere including opportunities related to greater access to health systems, employment and recreational facilities. However, increased urbanization also means increased exposure to an array of health risks. The health risks associated with rapid motorization in urban areas alone, accounts for an estimated 1.35 million deaths per year due to road injury (5) and 4.2 million deaths per year due to motor vehicle-related air pollution (6) with particulate pollution (PM_{2.5}, PM₁₀) reducing average life expectancy by 1.8 years per person (7).

Much has been done to mitigate the growing burden of road injury with many countries implementing road safety strategies that include detailed road safety action plans that are based on decades of established road safety approaches (8). Despite the comprehensive road safety strategies which have targeted (and continue to target) safer roads, road users, speeds and motor vehicles, road safety in the twenty first century is becoming

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more complex. Global mobility is rapidly changing with growing levels of uncertainty. The recent Global Mobility Report 2017 (9) highlights that in the twenty first century not only is there a need to focus on road safety but at the same time transport needs to be equitable, efficient and importantly, it must deliver a considerably reduced carbon footprint.

To achieve not only reductions in road injury whilst at the same time deliver transport systems that are equitable, efficient and 'climate responsive' (9, p 7) a broader response to mitigating the exponential growth in road injury in low- and middle- income countries is needed. This requires a systems-oriented approach as rapidly motorizing low- and middle-income countries are dynamic sociotechnical systems (10). Recent advances in the availability of geospatial information, remote sensing, artificial intelligence, and complexity science provide a unique opportunity to explore the relationships between sociotechnical systems and road injury (11) and thereby begin to understand the complexity of cities with respect to this important health outcome.

This paper applies a unique combination of approaches to classify cities based on urban characteristics related to private motor vehicles and public transport networks. Global burden of disease data attributed to road traffic injury is then examined to assess the extent to which a city's design affects the nature and extent of road traffic injury. We have chosen to focus on cities in the Asia and Pacific region as this region not only includes high-middle- and low-income countries but importantly, the region comprises the largest middle-income countries (China and India) which are currently in the throes of rapid motorization with China comprising more than one quarter of the global road deaths (12).

2 METHOD

A total of 1,667 cities from across the globe with populations exceeding 300,000 residents was identified from the 2015 United Nations world population prospect (3). A subset of these cities namely 689 cities from the Asia and Pacific region were the specific focus; comprising 40 countries ranging from Mongolia in the North, Pakistan in the West, New Zealand in the South and Fiji in the East. Map images from each city were obtained using a 2-stage approach. Details of the 2-stage approach are described in detail in a recent publication (13).

A convolutional neural network (CNN) modelling approach based on 'Inception V3' architecture (14) was applied to the database comprising the map images for each city. CNN is an image classification approach whereby various observations are detected from the original data with each layer in the CNN approach recognizing increasingly detailed features of the data. The convolutional neural network modelling was capable of identifying whether cities could be correctly classified based on the city design characteristics related to road transport. The following characteristics were obtained from the maps namely each city's road network and public transport networks. Other city design elements were also obtained namely, green and blue space. The model was calibrated using 2 stages that involved a supervised learning procedure (15) namely a 'training' stage whereby the model learned which images were associated with which city, and a second stage which validated the performance of the model. During the validation stage, the model assessed the probability that the validation image comes from the map image of the actual city or from one of the remaining cities in the image dataset. In our earlier paper, the validation stage was found to accurately classify images 86% of the time (13).

A graph-based analysis using the Force Atlas 2 algorithm (16) was applied to the database which comprised 1.667 million map images. A spatially representative network graph was then developed. The graph depicts cities that are grouped together meaning such cities are often confused for one another in the model and therefore they appear closer together in the graph. In contrast, cities that are not alike (based on the transport design features) are represented further apart.

The various city groupings were then assessed and described relative to the transport attributes of interest namely the road and public transport networks. To estimate the comparative risk of road injury posed by the transport network design of individual city types, we estimated the intensity of the road and public transport networks in each city by estimating the proportion of the pixel colour count for the respective urban characteristics for each city image.

Disease burden associated with road transport injury (ICD-10-CM V00-V89) was estimated for each city within the various cluster types using data from the Global Burden of Disease (GBD) study (17). As GBD data is only available at the country level, health burden associated city design types was estimated based on the mean country-level data available for individual cities contained within each cluster type. For comparative purposes, road traffic injury was reported as DALYs (Disability Adjusted Life Years) lost, which is a combination of the sum of the years of potential life lost due to premature mortality (YLLs) and years of productive life lost due to a disability (YLDs) per 100,000 people (18).

3 RESULTS

The findings from the convolutional neural network analysis identified nine global clusters of cities in which 1667 cities with populations greater than 300,000 population were classified. Table 1 describes the 9 urban cluster types and lists the proportion of Asia-Pacific cities that fall within the respective clusters. The majority (64%) of low- and middle-income countries in the Asia-Pacific region fall within Clusters 1 and 2. These Clusters comprise cities predominantly from China and South Asia with many of the cities considered low- to middle-income. In contrast, cities from the high-income countries in the Asia-Pacific region namely, Japan, South Korea, Australia and New Zealand are classified in Cluster 6 – the Motor City and Cluster 8 (Intense city cluster).

Figure 1 categories Asia-Pacific countries based on the proportion of city cluster types within each country based on the results of the convolutional neural network analysis. It is evident from Figure 1 that there is considerable variation in cluster types within some countries and absolutely no variation in other countries. For example, among the countries within the Asia-Pacific region (denoted by an asterisk next to the country) there is considerable variation among cities in Vietnam with 4 city clusters identified and similarly in China. In contrast, cities in Papua New Guinea and Mongolia only fall within one cluster – namely the Informal Cluster. This cluster reflects urban form that is sparse, with a low capacity and informal road infrastructure, little public transport, and little formal green space.

Table 1. Urban design clusters and the Proportion of Asia Pacific Cities in each Cluster

Urban Design Cluster Title	Cluster Description	% of Asia Pacific Cities in Cluster
Cluster 1 - Informal	Sparse, low capacity informal road infrastructure, limited rail transport, low formal green space	30.5% (210 cities)
Cluster 2 – Irregular	High green space, mixed formal and informal infrastructure, few high capacity road networks, limited mass transit	33.5% (231 cities)
Cluster 3 - Large blocks	Medium density, formal low and high capacity road networks, medium railed transport	2.8% (19 cities)
Cluster 4 - Cul de sac	Very high density, low capacity mixed formal and informal road networks, low mass transit.	3.8% (26 cities)
Cluster 5 - High transit	Medium density, high capacity, formal road networks, high public transport	0.7% (5 cities)
Cluster 6 - Motor city	Medium to low density, high capacity, grid-based, road networks, medium railed transport	1.7% (12 cities)
Cluster 7 - Chequerboard	High density, medium capacity mixed formal and informal road networks, medium public transport	4.9% (34 cities)
Cluster 8 – Intense	Very high density, mixed formal high capacity and informal road networks, high public transport	4.1% (28 cities)
Cluster 9 – Sparse	Low capacity, low density formal and informal road networks, low public transport	18.0% (124 cities)

The range between the urban cluster types with respect to the proportion of road networks allocated to city land-use is minimal (6.4% to 12.6%) with the Cluster Type – Intense, having the greatest proportion of road network. The urban cluster - Intense has land-use allocated to road networks that is two times greater than the urban cluster type with the lowest proportion of road networks namely, Large Blocks. Interestingly, two thirds of Asia-Pacific cities fall within the Cluster types Informal and Irregular which have only 6.8% and 6.9%, respectively, of the various cities land-use allocated to road networks; this is similar to the cluster with the lowest proportion of road network (Large Blocks with 6.4%). Public transport networks specifically rail networks, are most prevalent in the High Transit city cluster and the Motor City cluster. Both of these clusters have cities from high-income countries including those from the Asia-Pacific region namely, Australia, New Zealand, South Korea, Japan and Singapore.

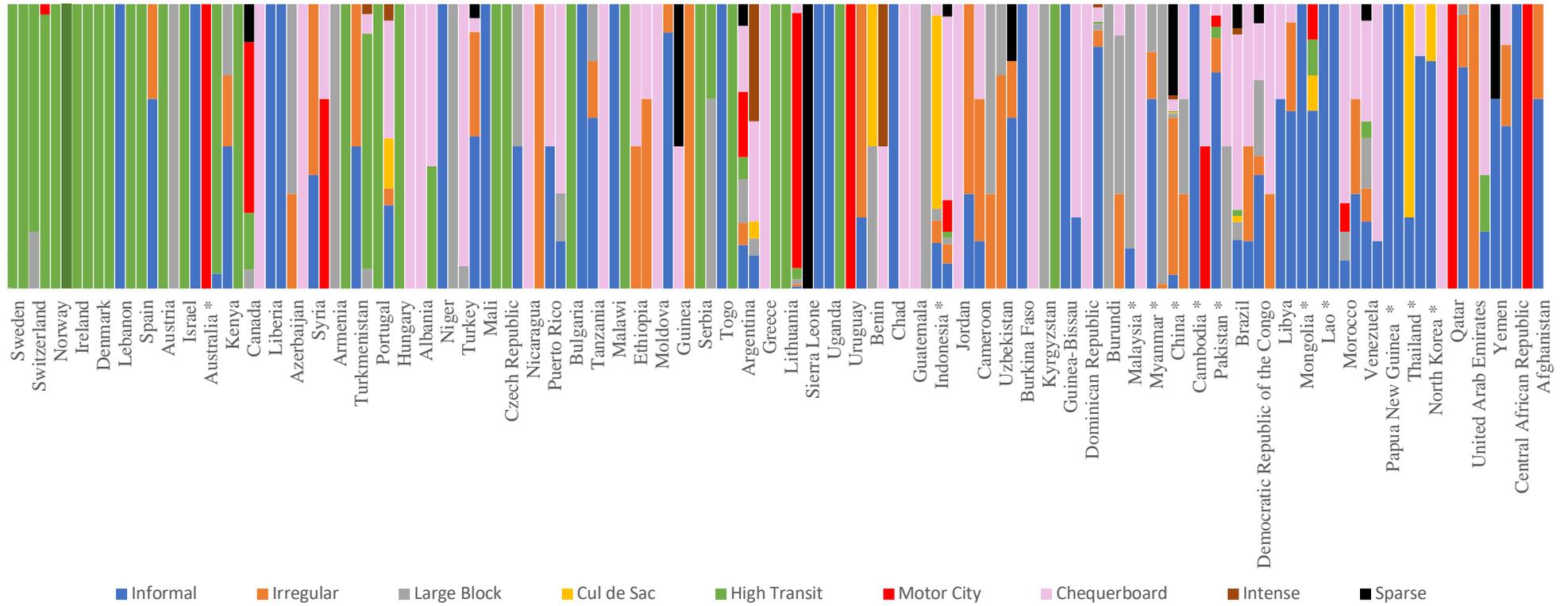


Figure 1. Urban design clusters by country. Asia Pacific Countries denoted by *

A relationship was observed (see Figure 2) between the DALYs attributed to road traffic injury and the proportion of road and public transport networks observed in the respective urban cluster types. Urban cluster types with both dense road networks (e.g., Clusters Intense and Cul de sac) and public transport (e.g., Clusters High Transit and Motor City) demonstrated lower rates of DALYs lost per 100,000 population for road traffic injury. By contrast, urban cluster types that contained sparse road networks (e.g., Clusters Informal and cul de sac) have higher road traffic injury DALYs lost per 100,000 population and this is particularly the case in relation to DALYS lost due to motorcycle related road injury. This relationship was robust with more than 2.5 times difference in DALYS lost to road traffic injury per 100,000 population between the best performing urban cluster types (Clusters 5 and 6, High Transit and Motor City) and the poorest performing urban cluster city types (Clusters 1, 2 and 4 – Informal, Irregular and Cul de Sac).

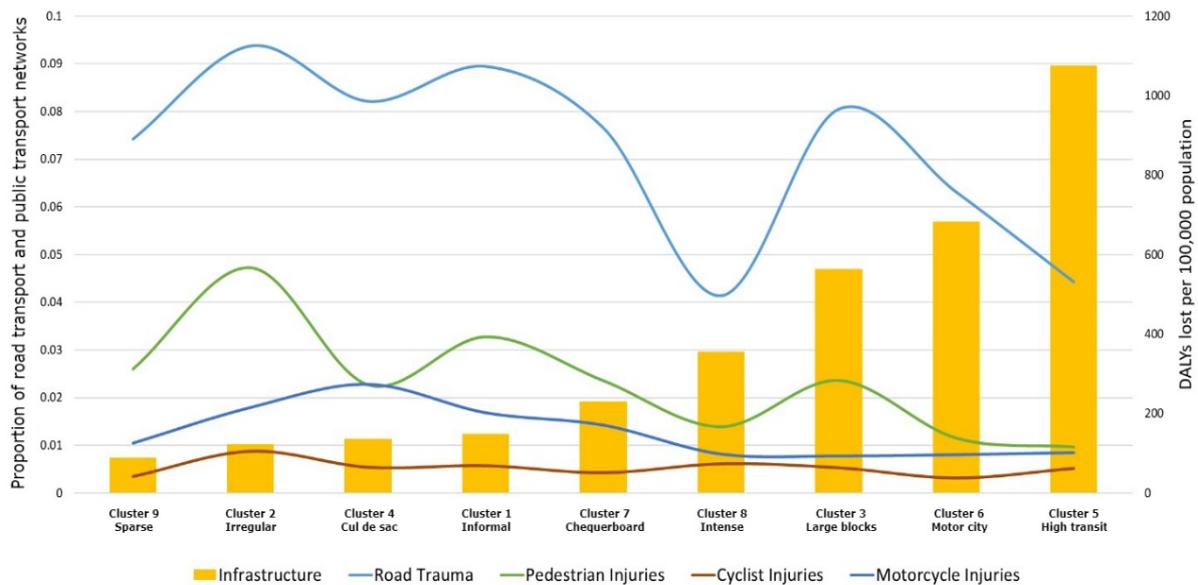


Figure 2. Proportion of road transport and public transport networks by urban cluster type and the estimated DALYS lost per 100,000 population for road traffic injury.

4 DISCUSSION

This study demonstrates the utility of employing image recognition methods to discover new insights related to urban design that are associated with road traffic injury. Furthermore, it focuses on cities in the Asia-Pacific region which is critical given countries in the region account for more than one third of global road deaths (19).

A 2-fold difference in road traffic injury was observed between cities with distinctly different road networks. For example, cities that have invested in public transit have a reduced burden of road traffic injury compared with cities that have limited high capacity road networks, and almost no mass transit systems; the majority of cities in the Asia-Pacific region fall within the latter clusters. Such findings highlight not only that urban form is important in mitigating road traffic injury but also investment in low-risk (relative to private motor vehicle use – including motorcycle use) transport systems is necessary.

This study demonstrates a relationship between land-use associated with road and public transport networks and road traffic injury suggesting that a systems-approach to designing and delivering 21st century cities is of utmost importance to road safety in urban areas. Importantly, such an approach will need to be embraced in the region if global goals such as those established in 2010 by the United Nations General Assembly namely, the Decade of Action for Road Safety which set a target to prevent 5 million road deaths and 50 million serious injuries from road traffic injury by 2020 (20), are to be achieved.

There are a number of limitations in using the image recognition approach to draw causal inferences. These limitations relate specifically to the fact that measures are at an ecologic level and therefore can be influenced by numerous uncontrolled factors including a cities economy and or road safety management practices (21). Nonetheless, the approach highlights the potential utility, at a global level, of such an approach.

The Asia Pacific region is dominated by low- and middle-income countries in which urbanisation and therefore motorization is growing exponentially. The region is currently targeted by Development Banks for infrastructure programs that promote road safety. Despite the focus of the programs on safer speeds, safer people, safer roads and safer vehicles there is limited, if any, focus on reducing motor vehicle use through changes to urban design or land use planning (22). An urgent shift in funding focus is needed in order to mitigate the increasing levels of road traffic injury.

ACKNOWLEDGEMENT

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Building Road Safety Institutions in Low- and Middle-Income Countries: The Case of Argentina

Kavi Bhalla^{1a}, and Marc Shotten^b

Abstract

Traffic injuries remain a leading health concern in most low- and middle-income countries (LMICs). However, most LMICs have not established institutions that have the legislative mandate and financial resources necessary to coordinate large-scale interventions. Argentina provides a counterexample. Argentina is a federal country where the decentralization of authority to provincial governments was a key barrier to effective national interventions. In 2008, Argentina passed a law establishing a national road safety agency, and subsequently received a World Bank loan to build the agency's capacity to coordinate actions. Although traffic injuries in Argentina have not yet begun to decline, these developments raise important questions: *Why did Argentina come to view road safety as a problem? Why was institutional reform the chosen solution? What was the political process for achieving reform? What are the broader implications for institutional reform in LMICs?* We explore these questions using a descriptive case study (single-case, holistic design) of Argentina.

The case illustrates that focusing events, like the Santa Fe tragedy that killed nine children, and advocacy groups are important for raising political attention and creating an opportunity for legislative reform. It highlights the importance of policy entrepreneurs who used the opportunity to push through new legislation. While the political dynamic was predominantly local, international actors worked with local advocates to build demand for safety, and develop solutions that could be deployed when the opportunity arose. Most importantly, the case emphasizes the importance of developing institutions with the resources and authority necessary for managing national road safety programs.

Keywords: Road traffic injuries; health systems; Safe System; agenda setting; institutional reform

1. INTRODUCTION

Road traffic injuries remain a leading health and development concern in most low- and middle-income countries (LMICs). While LMICs have made substantial progress in improving longevity and reducing infectious diseases, traffic injuries are either increasing or remain stable at a high level. Globally, traffic injuries are the sixth leading cause of population health loss, slightly higher than in 2000 (ranked 8th) (1). The global traffic death toll has remained at approximately 1.3 million for the last two decades and now exceeds that from HIV/AIDS, tuberculosis or malaria, all of which have seen large declines of 30%, 30%, and 22%, respectively, over this period (2).

Traffic injuries in LMICs remain a serious problem despite a substantial and coordinated global response over the last 15 years. In 2004, the World Bank and WHO jointly issued the World Report on Road Traffic Injury Prevention (3), followed by a series of eight resolutions (approximately one every two years) by the UN General Assembly and the World Health Assembly calling for global action on road safety (4–11). The 2012 UN resolution proclaimed the period 2011–2020 the global Decade of Action to stabilize and reverse the rising trend in traffic deaths and urged LMICs to adopt the global action plan developed by the UN Road Safety Collaboration. The guiding principle underlying the action plan are the five pillars of road safety. The first of these pillars—building institutional capacity for road safety management—receives the least attention in the current global advocacy efforts. The other pillars are technical focusing on improved roads, cars, road user behavior, and post-crash care. Among these, current global advocacy focuses primarily on changing driving behaviors through enforcement and, to a lesser extent, on road and car design.

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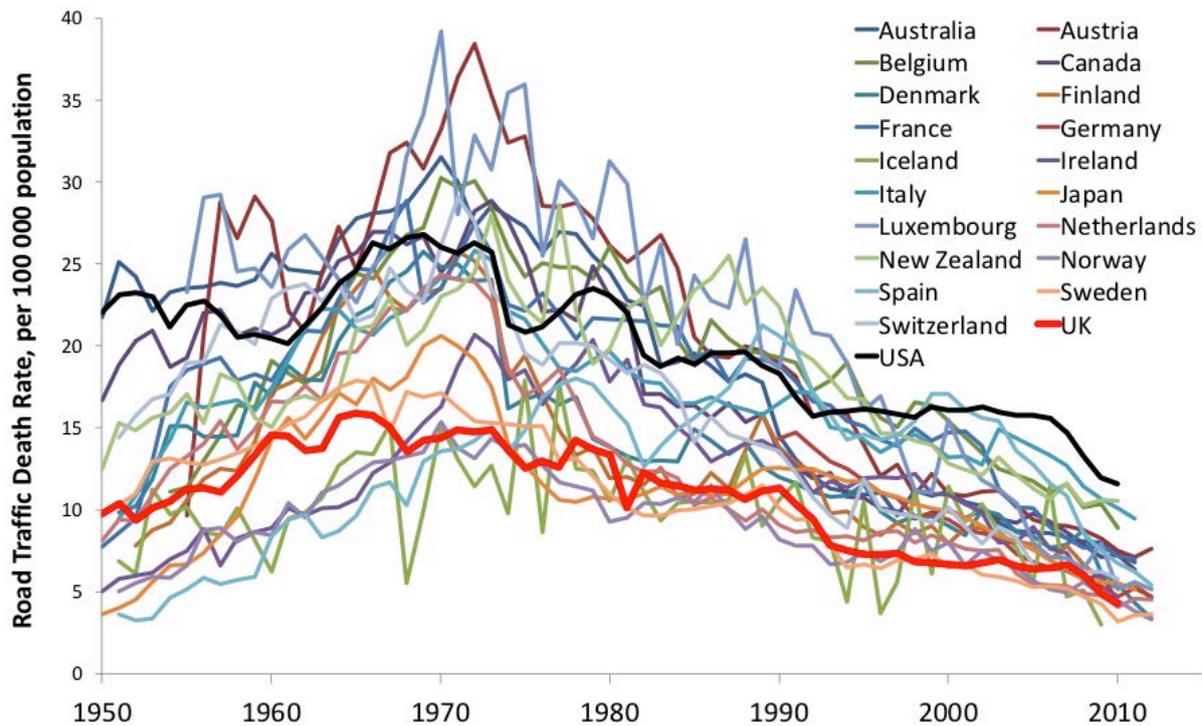


Figure 1. Road traffic death rates in OECD countries since 1950
 Source: Author’s analysis of national vital registration statistics

Unlike LMICs, high-income countries (HICs) of North America and Western Europe have had steadily declining traffic deaths for five decades (Figure 1). By the 1960s, traffic death rates in these countries had risen to levels similar to those in LMICs today (12). However, the 1960s saw a paradigmatic shift in how HICs addressed road safety—a shift away from trying to change reckless road users and towards the use of state institutions capable of regulating transportation risk at the national level. For instance, in the US, the period saw road safety become a political priority and the passage of the Motor Vehicle Safety Act and the National Traffic and Motor Vehicle Safety Act in 1966, which, among other things, led to the establishment of the US national road safety agency with the resources and a mandate to regulate road safety nationally (13). Thus, the 1960s saw a reinterpretation of the problem of road safety in HICs, and a repositioning of the solution within the regulatory authority of the state. The new regulatory approach that developed in these countries eventually came to be called the Safe System approach (14,15), which focuses strongly on the role of institutions and institutional processes in allowing large-scale interventions to be deployed effectively for reducing injuries. This institution-building approach has clearly had a substantial effect on road safety in HICs, where the approach allowed long-term investments in large (population-wide) safety interventions that have been remarkably successful (12).

Although institutional reform for road safety receives relatively little attention in LMICs, the case of Argentina provides a useful counterexample. In 2008, the president of Argentina sent a national road safety bill to congress that was passed unanimously. The bill created a new national road safety agency with sustained funding and a legislative mandate to manage road safety across the country. Next, the government approached the World Bank for a loan to strengthen the capacity of the agency to effectively coordinate national road safety programs. The project that was supported by the loan aimed to implement the Safe System approach, which required addressing the problem that traffic and health in Argentina were under the authority of sub-national governments creating a structural impediment to the new agency’s ability to coordinate country-wide action. These developments raise several important questions for road safety in LMICs: *Why did Argentina come to view road safety as a pressing problem that needed policy attention? Why was institutional reform and, specifically, the Safe System approach, the chosen solution? Can other LMICs be coaxed into establishing national road safety agencies? If so, how?* This study explores these questions by studying the case of Argentina and drawing analytically generalizable lessons.

2. METHODS

We use a descriptive case study (single-case, holistic design) for study design because it provides context-specific description of the complex political economy of institutional reform (16). The case study focuses on

Argentina because it is one of the few examples of a completed World Bank loan structured to exclusively promote the implementation of Safe System road safety policies (17). These loans aim to support stand-alone (i.e., focus solely on road safety) multi-sectoral projects and ideally focus on strengthening institutional frameworks and the capacity to manage large-scale road safety initiatives. Argentina is often presented in World Bank documents and other global road safety advocacy literature as a successful example of a country that has recently adopted the Safe System framework (14,17–19). In 2014, the World Bank requested KB to assess the reasons for the perceived success of Argentina, which was the genesis of this case study.

The information presented in this study was obtained from a review of relevant documents, including academic literature, government reports, news stories, and World Bank loan documents. In addition, we conducted interviews with six key informants based in Argentina and Washington, DC, including researchers, government and public officials, and experts about their professional opinions related with road safety policy in Argentina. Interviewees were assured anonymity. Questions were designed to be open-ended and interviews included space for exploring emerging themes. Questions were adapted to match the expertise and experience of the participants. Researchers and policy makers who were familiar with how the national road safety agency was established were eligible to be interviewed. Maximum variation and snowball sampling was used to identify potential participants. All sampling decisions were taken by KB after early discussion among both authors. Interviews were typically approximately one hour long and were conducted by phone, Skype, or in-person, and were audio-recorded with permission of the participants. The review, informal discussions, and key informant interviews focused on the events that occurred in Argentina that led to the formation of the national road safety agency, the history of the Safe System approach, the World Bank loan, and the resulting Argentina Road Safety Project.

The primary focus of our analysis is on understanding why there was institutional reform for road safety in Argentina that led to the establishment of a federal road safety agency to coordinate national programs. Therefore, we examine the political economy of the events in Argentina that allowed [1] road safety to rise to prominence in the policy agenda, [2] the passage and ratification by provinces of a new federal law establishing the national agency, and [3] the implementation of the law and the activities of the newly formed agency. The political economy of road safety policies in LMICs has received little attention, with a few notable exceptions, such as the work by Hoe (2015)(20) that examined why tobacco control received political priority in Turkey but traffic injuries did not. However, there is a broader literature on agenda setting in public policy (20–23) that can provide a useful lens for understanding what happened in Argentina. Notable theories of the policy process include Kingdon's metaphor of multiple streams (20), top-down and bottom-up implementation (22), and punctuated-equilibrium (21). Among these, we draw especially on Kingdon's model of multiple streams (20), which is useful for explaining the roles of focusing events in bringing attention to a problem like road safety on the policy agenda and opening a window of opportunity for policy action (24), policy entrepreneurs in developing ideas about how problems could be addressed, interests groups in maintaining political pressure, and high-level political leadership for mobilizing policy action. A crisis such as a disaster can be a catalyst for these streams to converge and briefly open a window of opportunity for policy reform. At this moment, if a viable policy alternative is available, policy entrepreneurs can seize the opportunity to push through policy change.

3. WHAT HAPPENED IN ARGENTINA?

3.1. Decentralization of politics, economics, transport, and health: a brief history

Argentina was classified as an upper-middle-income country by the World Bank until recently before being reclassified as high-income (25). It ranks high-middle on the Institute of Health Metrics and Evaluation's Socio-Demographic Index (SDI), which is a composite indicator of national development that includes income, education, and fertility (26). (The SDI is a new indicator that does not include population health as an input because it is intended for comparing national health performance.) Argentina is a federal country with 23 provinces whose governments have substantial autonomy over laws and policies that affect the economy, transport, and health. As we shall discuss, this decentralization of state power was a key barrier to effective road safety management that needed to be addressed through institutional reform.

Until recently, Argentina's political and economic history has been marked by boom-and-bust economic cycles and frequent periods of military rule (27). This instability has had an important effect on decentralization of political power, resources, and responsibilities to subnational units of government, which (as we discuss below) has been a key barrier to implementing national safety programs. In general, countries globally have had a trend towards dispersion of political power driven partly by a decline in credibility of the centralized state (28). In Latin America, the transition from military centralism to civilian control was another important driver of devolution of power to the provinces (28,29).

In addition to political decentralization, the deep economic crisis of the 1980s was followed by fiscal decentralization in Argentina. For instance, the 1989 transport sector reforms involved decentralization of expenditure and financing to local governments (30–32). Economic reforms in the 1990s led to the privatization of about 70% of the national roads with the highest traffic volume (32). Private contractors were allowed to build, maintain, and operate roads in exchange for the right to charge tolls to road users. Thus, government role in road infrastructure shifted towards regulation of privatized monopolies (30). Paralleling these developments in the transport sector, the 1990s saw several efforts at restructuring the health sector towards managed care and market-oriented policies (33,34). Nevertheless, the health system remains fragmented with one-third of the population having no health insurance and relying solely on the public health sector, which is decentralized to the provinces. The role of the federal ministry of health is narrow with tax-supported funds flowing directly to provincial budgets with little federal influence (35).

Despite these systemic challenges related to federal structure, population health in Argentina has undergone a dramatic and rapid epidemiological transition, with a health profile that has shifted away from infectious diseases of childhood to chronic diseases and injuries that affect adults (Figure 2). Since the 1990s, life expectancy at birth has grown by 4.6 years, and death rates from neonatal disorders and maternal disorders have declined by 68% and 40%, respectively (2). Like many middle-income countries, however, Argentina has struggled to manage chronic diseases and injuries.

3.2 Argentina's Road Safety Problem

Traffic injuries were the seventh leading cause of health loss in Argentina in 2016, slightly higher than in 1990 (ranked eighth) (1). Traffic death rates during this period have grown and by the mid-2000s corresponded to a death rate of 14 per 100,000 (Figure 2). Local nongovernmental organizations, such as *Luchemos por la Vida* (“Let's fight for life”), had been advocating vocally for improving road safety. Their seatbelt campaign got front-page coverage in major newspapers in 1999 when the former President Raúl Alfonsín was involved in a near-fatal crash in which he was ejected from his car because he was not wearing his seatbelt. However, without adequate police enforcement these social marketing campaigns had relatively little success (36). Although the traffic death rate in Argentina during this period was not exceptionally high for an LMIC, it was nevertheless about three times the death rate of the best performing European countries and similar to that in the 1960s in many OECD countries (Figure 1) when they underwent a paradigmatic shift that redefined road safety as a problem that needed to be addressed through state regulation and led to the establishment of national road safety agencies with the resources necessary to implement large-scale safety programs (12,14).

Figure 2. Road traffic deaths in Argentina
Source: Author's analysis of national vital registration statistics

Like many LMICs, Argentina has made several unsuccessful attempts to address its national road safety problem. Notably, in 1995, a National Traffic Act was passed in the face of dramatic growth in traffic deaths during the recovery after the 1988 economic collapse (37). Decentralization of the authority to regulate traffic and health to provincial governments was understood to be the central issue that made coordinated action across the country difficult. Therefore, the legislation aimed to establish a common code of traffic and safety regulations across all provinces. However, this was not an easy task. Consider, for instance, that there are about 1600 centres that issue driver's licenses in the country. Ultimately, the legislation failed to address this problem partly because sufficient resources were not made available to establish and oversee the new harmonized practices. In 2005, the National Ombudsman, 14 civil society organizations, and the WHO released a report that highlighted the high social costs of traffic crashes, the failure of the state to effectively regulate safety, and notably, the need for a national road safety authority to coordinate a multi-sectoral road safety program (38,39). A year later another opportunity arose for the national government to address the issue of decentralization.

3.2. The Santa Fe tragedy

On October 8, 2006, a truck crashed into a bus in the province of Santa Fe, killing nine students and a teacher (40). The students had been returning from a solidarity mission to Chaco, an impoverished province of the country, where they had distributed food and clothes to poor children. The truck driver was not properly licensed and was drunk. The driver had been drinking at a roadside bar while watching a soccer match and had consumed so much alcohol that his blood alcohol concentration was more than three times the legal limit. The incident received extensive coverage on national news, with television stations interrupting regular programming to give updates on the tragedy. President Nestor Kirchner's government sent an airforce transport plane to Santa Fe to bring the remains of the victims back to the capital. The event became known as the "*Tragedia de Santa Fe*" (The Santa Fe Tragedy) and became a watershed in the history of road transport in Argentina. The national education ministry incorporated October 8 into the school calendar as the national day of student solidarity. The families of the students founded a group, the Family and Friends of the Tragedy of Santa Fe, that played an important role in pressing for a major shift in road safety perception and policy in the following years. The group repeatedly met with the president, and high-level political leaders responsible for education, transportation, and interior affairs, demanding that road safety be treated as a state policy, and, notably, emphasizing the need for a national road safety authority (41).

3.3. A new road safety law and a new government agency

The Santa Fe Tragedy created an opportunity to cut through the jurisdictional barriers that had plagued coordinated action in road safety in Argentina. In the months that followed, President Néstor Kirchner, who was close to the end of his term, used the tragic event to push through new reforms. Working with citizens society groups, his government declared 2007 the "Year of Road Safety" in Argentina, obliging public administration documents to carry the slogan on their letterhead (42). The National Ombudsman, Eduardo Mondino, with support from several NGOs, launched a campaign ("Porque la Vida Vale") to collect 400,000 signatures in support of a national road safety bill that aimed at institutional reform (39,43). The campaign presented road safety as a human rights issue ("violation of the rights to safety, health, and to the enjoyment of a dignified life"). By April 2008, the campaign had collected over 300,000 signatures. Later, the Ombudsman declared the week of 23 April 2007 as Road Safety Week. The President charged the Federal Road Safety Council to develop new legislation on road safety. The Council, which had representation from all provincial governments, also received substantial input from the newly mobilized victim groups (37). In August 2007, a new law, the Federal Agreement on Traffic and Road Safety, was signed by the federal government and the provinces. A few months later, Cristina Kirchner, the spouse of Néstor Kirchner, was elected president. She brought the law to congress as one of the first items on her policy agenda and the law was unanimously approved. NGOs and victims' groups had maintained such a prominent media presence since the Santa Fe crash that political opposition to the proposed law did not emerge.

Next, adherence to the new law needed to be ratified by each of the provincial legislatures. This was an arduous process that required sustained pressure from politicians, bureaucrats, and advocacy groups. It took four years before all the provinces were onboard. Pressure from the victims' groups and high-level political leaders played a critical role. During this period, it was common for the Minister of the Interior, Florencio Randazzo, to appear on TV to present the road death toll. The province of Santa Fe was among the last to ratify. In part, the reason was that local officials and legislators felt that they had already been working to address road safety with some success. However, in September 2010, a van carrying children from a dance troupe collided with a truck leaving 14 dead in Santa Fe (44). In the intense media coverage that followed, safety advocates appeared on TV and blamed the government for not ratifying national legislation. The province of Santa Fe then fell in line.

Arguably the most important aspect of the 2008 law was the creation of a new federal national road safety agency, the Agencia Nacional de Seguridad Vial (ANSV). The law gave the agency jurisdiction over regulating road safety and also established a secure funding stream for the agency, allocating 1% of vehicle insurance fees, initially for a period of 10 years but made permanent in 2018 (Law No 27431) (17,45). Sustained funding is important because it allows long term investments in road safety programs. Equally importantly, a secure funding stream buffers the lead agency against political currents and waning commitment to road safety. Specific tasks for ANSV included the coordination of security officers and drivers licensing. Partly for this reason, ANSV was located within the Ministry of Interior, which was led by Minister Florencio Randazzo, who was a vocal champion for road safety and had been instrumental in the creation of the agency. Since negotiating power with provinces was the first obstacle confronting the agency, the first administrator of the agency (Felipe Rodriguez Laguens) was chosen partly for his reputation as a consensus builder. Within months of his appointment, Rodriguez Laguenz traveled to Washington, DC, to explore the possibility of a World Bank loan focused on building the institutional capacity of the new agency to coordinate road safety.

3.4. A World Bank loan for building the capacity of the new road safety agency

During the early 2000s, the World Bank had been developing a new approach to road safety in its projects in LMICs. In 2002, the Bank hired Tony Bliss, who was the former General Manager of the Strategy Division of the New Zealand’s transport safety authority, where he had led the development and delivery of a remarkably successful national road safety plan. Bliss was a leading figure in the development of the Safe System approach to road safety, which was credited with dramatic reductions in traffic death rates in OECD countries (46,47). The Safe System approach (14,15) has several important differences from traditional road safety approaches. Most importantly for this case study, the Safe System prioritizes the development of institutions that can coordinate large-scale safety programs. At the core of the framework (Figure 3) are institutional management functions, which guide and produce interventions, which affect road safety performance. Under Bliss’ leadership, the World Bank’s Global Road Safety Facility developed a step-by-step approach to help countries assess their institutional capacity and develop an investment strategy that aimed to continuously improve national road safety performance through successive projects based on results (48,49). This new emphasis on institutions for road safety at the World Bank dovetailed with the most pressing needs of the newly formed road safety agency in Argentina (17).

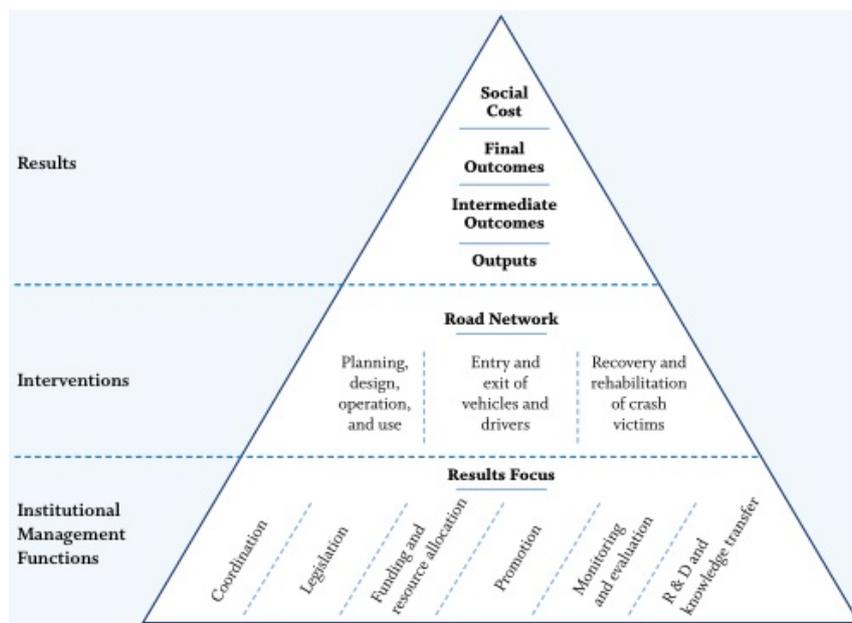


Figure 3. Road safety management in the Safe System approach
Source: World Bank, 2013 (49)

Following the creation of the national safety agency, the government of Argentina approached the World Bank for a loan of \$30 million (two-phase, Adaptable Program Loan) (50) to support a national road safety program from 2010 to 2019 by “strengthening the Borrower’s institutional framework and management capacity for road safety.” Although not explicitly stated, examining the workplan of the Argentina Road Safety Project that was financed by the World Bank loan (Table 1) helps explain how the loan sought to address the key issues of

decentralization and road safety management in the country (50,51). First, the project emphasized institution development rather than implementing interventions. This is an important distinction. The largest component of the project and its largest subcomponent (Components 1 and 1.1) focus explicitly on strengthening institutional capacity to conduct large scale interventions. World Bank staff familiar with this loan note that the Argentina project was unlike other projects in that it wasn't a "Christmas tree" that simply included a list of everyone's favourite interventions (what health systems researchers call the "laundry list" approach (52)). In fact, if viewed solely through the lens of effective interventions, Component 1.1 has questionable value. The component focuses on creating national registries for drivers' licenses, traffic records and violations. The effect of such registries on injury rates is impossible to measure through impact evaluation studies and many road safety researchers would likely argue that in isolation such registries have no direct impact on road safety. However, these registries weren't intended as road safety interventions and, in fact, the World Bank's economic appraisal of the loan made no attempt to attribute any health benefits (i.e., lives saved or disability) to this component (50). Instead, the purpose of the component was to strengthen the leadership role of the national agency and place the provincial and local governments in productive partnerships. This is not to say that the registries do not have a useful function in the management and administration of road safety. They undoubtedly do. However, their role in the ARSP was much less about their direct impacts on road safety outcomes, and more about legitimizing the authority of the national agency to coordinate action with the provinces in the longer term (53).

The ARSP also created the opportunity for provinces and municipalities to undertake specific road safety interventions through an incentive fund (Component 2.1 in Table 1). However, even here, the core objective was to strengthen the ANSV's role as the lead agency and to coax the provinces to cooperate. In fact, adherence to the 2008 law was made a precondition for the provincial governments before they could get access to the funds. The component aimed to speed up the roll-out of road safety action plans by providing performance-based reimbursements for implementing road safety interventions from a pre-determined list. Over the course of the project, the incentives fund financed hundreds of projects including the development of local strategic plans replicating national plans, mass media campaigns, infrastructure improvements, and road safety workshops. The plethora of small projects also helped to keep road safety at the forefront of government agendas at the provincial and municipal levels.

Table 1. Components of the Argentina Road Safety Project (US\$ 38.5 million; Bank share US\$ 30 million)

Component 1: Institutional Capacity Building (US\$ 19.985 million)

1.1: Support to strengthen ANSV institutional capacity (US\$ 6.62 million)

Including, creation of national driver license registry system, national traffic records, and infractions registry system and preparation of 2010-2015 strategic plan

1.2: Communication, awareness and education campaigns (US\$ 4.7million)

1.3: Improve emergency response capacity (US\$ 0.965 million)

Including, implementation of improved emergency coordination systems, equipment and training for emergency response personnel

1.4: Strengthen capacity of the traffic control and enforcement agencies (US\$ 5 million)

Including training, equipment (alcoholmeters, speed control radar guns, and other fixed or mobile radar technology), and development of a national speed control plan.

1.5: Project management (US\$ 2.7 million)

Including support for ANSV staff, and operational expenditures to support project management.

Component 2: Demonstration corridors and Incentive Fund program (US\$ 11.140 million)

2.1: 'Safe Corridors' demonstration program (US\$ 1.14 million)

2.2: Incentive Fund (US\$ 10 million)

For the implementation of road safety policies and practices to finance innovative provincial and municipal road safety initiatives

Component 3: Support for the National Road Safety Observatory (US\$ 3.3 million)

Source: World Bank's Project Appraisal Document for the loan

In 2018, at the end of the loan, the World Bank's review of the project deemed the project a success, noting that it *"had made significant contributions toward institutionalizing enhanced road safety policies in Argentina and allowing the country to stabilize road traffic fatalities for a number of years If this trend continues, it would mean that the country has reached a tipping point and is on track to reduce crashes in the medium term."* That last caveat is noteworthy. The institutional reform that occurred in the US and Europe in the late 1960s was marked by clear evidence of decline in deaths in a decade in most countries. This is not yet true of the death toll in Argentina.

4. LESSONS FOR ROAD SAFETY IN LMICs

There are several broad lessons for understanding road safety policy in LMICs that can be drawn from this study of a major change in political priority for road safety in Argentina.

4.1. Importance of focusing events and the role of mass media

Problems can rise to the attention of policy makers because of changes in systematic indicators (such as a rising national traffic death toll, which precipitated the 1995 National Traffic Act (37)), feedback from ongoing programs, or by focusing events like disasters. In most countries, a wide range of health and social issues, including traffic injuries, have been understood to be important problems for a long time. Therefore, for a particular issue like road safety to rise to prominence from among the set of issues competing for attention often requires a real crisis (20,21). In Argentina, the Santa Fe tragedy provided a focusing event that attached a powerful symbol of dead children to the issue. Policy entrepreneurs were alert to the symbolism and opportunity and acted rapidly to push through major new legislation. Mass media played a critical role in bringing the event to people's attention. Usually media attention tends to change rapidly and often has little effect on policy agendas. In this case, media attention was sustained over time and was critical for the new law to be ratified by the provinces.

Disasters are not the only kind of focusing event. For example, in the mid 1960s in the US, the focusing event was the revelation that General Motors had hired private investigators to follow consumer advocate Ralph Nader with the intent of blackmailing him. Nader had written a book called "Unsafe at Any Speed" that exposed a safety design flaw in the Chevy Corvair. The book may have gone relatively unnoticed except that General Motors' response resulted in extensive media attention and hearings in the US Congress (54). These events forced a direct confrontation with the auto industry's hegemonic control of the problem of auto safety. Until then the industry, which was the primary sponsor of road safety research, had ensured that road safety was seen as a problem of driver behaviour and successfully marginalized critics concerned with vehicle design (13,55). After GM's overzealous response to Nader, this was no longer possible, and in 1966 the US Congress unanimously voted to approve two motor vehicle safety acts, which established the national road safety agency.

4.2. The paramount importance of local politics

While the Santa Fe tragedy was clearly important in focusing attention on road safety in Argentina, mass casualty traffic crashes occur fairly regularly across the region and are usually quickly forgotten. For instance, only a few months earlier, a tour bus in neighboring Chile had plummeted into a canyon killing 12 tourists (56). In 2002, a bus carrying Roman Catholic pilgrims had plunged into a gorge in Catamarca, Argentina, leaving 47 dead including many children (57). The Santa Fe tragedy mattered because policy entrepreneurs, advocacy groups, and the political leadership used the event to galvanize action. In fact, the problem (road safety) had been on the political agenda for many years, and there was consensus among key actors about the solution (institutional reform). In 2005, prior to the Santa Fe tragedy, a prominent report from the National Ombudsman, had explicitly called for a road safety authority to coordinate national efforts (38). Following the disaster in Santa Fe, the families formed an activist group that created bottom-up pressure for changes in policy (14). Néstor Kirchner's government, who already had a high-sensitivity to the problem, saw the policy window created by the Santa Fe tragedy and the resulting citizen group mobilization to push through the institutional reform that was needed. Fortunately for these reforms, at the end of his term, Cristina Kirchner, his spouse, was elected president, which helped maintain policy continuity to complete the legislative process her husband had started. Ratification of the new law by the provinces took another two years of intense political bargaining, negotiating and power play. In fact, the first administrator of the national road safety agency was picked partly for his ability to navigate national politics. Thus, the politics that allowed meaningful policy action on road safety was entirely domestic within Argentina.

With the recent growth of an international road safety movement, it is common for researchers and practitioners to highlight the large public health burden of traffic injuries in LMICs and express frustration at the lack of national policy action. The case of Argentina highlights, however, that the political processes that affect policy

agenda are often domestically rooted and depend on such things as public mood, advocacy campaigns, national disasters, and changes in political administration.

4.3. Role of international actors: Creating a demand for safety and sensible solutions

Of course, local policy entrepreneurship can only succeed if there are meaningful policy alternatives available when the opportunity arises. For instance, while the GM's response to Nader's book created a focusing event in the US in the 1960s, there was already more than two decades of advocacy and technical work that had been done by engineers (e.g., Hugh DeHaven and John Stapp), surgeons (e.g., Claire Straith), and public health professionals (e.g., William Haddon). This work had established that car design flaws led to injuries and there were inexpensive design modifications that could lead to substantial reductions in injuries. This technical work made it possible to have a substantive discussion on the importance and process of regulating car design when the opportunity arose (13).

In LMICs, international actors can play an important role in working with national advocates, academics, and policy entrepreneurs to do the long-term work of building a demand for road safety among the general public and in policy communities, and developing sensible proposals for solutions. In the case of Argentina, World Bank staff members and national advocates had been working together for years before the national agency was created (17). This work involved sensitizing and persuading the government and the public about the scale of the impact on health and wellbeing and potential solutions. Often this dialogue was in the context of road infrastructure loans from the World Bank that had road safety components that were poorly executed. In project meetings and in discussions with various ministries and the Chief of Cabinet's office, World Bank staff members emphasized the need for a coordinating agency to address the sectoral and jurisdictional barriers faced by their road safety projects. Simultaneously, the World Bank through its Global Road Safety Facility helped develop solutions to the road safety problem framed in the Safe System approach. Prior to the loan, the Facility had issued a grant to conduct road safety capacity management reviews in two provinces, which focused on assessing institutional weaknesses from a Safe System perspective. The Facility also funded safety ratings of three national highway corridors by the International Road Assessment program. These ratings highlight best practices in road design. Similarly, a Memorandum of Understanding between the Facility and the International Road Traffic Accident Database (IRTAD) facilitated a collaboration between the new national agency and experts from Spain to help design the framework of the national safety strategy and the road safety observatory (17,51). Strong data systems are a fundamental underpinning of successful road safety management systems (14). Thus, international actors and national policy entrepreneurs did the long-run work on developing solutions before the opportunity for reform was created by the Santa Fe Tragedy. In both the US and Argentina, the chances for meaningful policy attention to road safety were much higher when the opportunity for reform arose because the problem came with a solution attached.

It is worth noting that from the perspective of the World Bank—the main international actor in this case study—the creation of the national agency was a key development that allowed them to engage effectively in road safety in the country. Transport is the largest sector in the World Bank's portfolio of loans to LMICs (in 2016, there were 493 active projects and total net commitments of \$58 billion, 20% of the Bank's total lending portfolio) (58). While the World Bank advocates strongly for the inclusion of road safety components in road projects (59), these are loans to the country government and ultimately the ideal outcome is for the country to decide to routinely include safety measures like median barriers, guard rails, and other safety infrastructure. As road safety institutions in countries become stronger, so does the ability of international actors to ensure safety components in their transport, health, and infrastructure projects. For instance, the European Investment Bank (EIB) is able to enforce stringent guidelines for road safety as part of their road loans to EU countries in part because the EIB operates in a fairly mature market for road safety. In this sense, the formation of the national road agency in Argentina made it much easier for the World Bank to engage in road safety in Argentina. However, this does not mean that the World Bank waited for a political climate conducive to road safety institutions before engaging with the country on the issue. Instead, World Bank staff members worked with local advocates over many years to create demand for road safety, identify institutional reform as the key to progress, and develop a framework for a solution. These efforts bore fruit when a focusing event in the country mobilized civil society and created a political environment in which the institutional reform could be attained.

4.4. The importance of putting institutions ahead of interventions

Arguably, the most important lesson for road safety in LMICs offered by this case study is the need to address institutional barriers that stand in the way of building effective road safety programs. The academic literature and the policy dialogue on road safety are dominated by technocratic evaluations of interventions with relatively little acknowledgment that coordinating these interventions at the scale of a city, province, or a nation, requires the creation of effective institutions with trained manpower, financial resources, and legislative mandates. A

common problem faced by federal states is that traffic management and health are often under the purview of provincial governments.

Decentralization of power may have some advantages because local governments may know and be able to respond to the needs of people better than a central government, but that may not always happen in practice. Indeed, in arenas of specialized knowledge, such as road safety, centralization is important for developing technical expertise. Furthermore, successful action in road safety usually involves large-scale programs with coordinated action by government bodies across the nation, requiring a strong central agency with the authority to manage road safety. This was the core issue that Argentina had sought to address through the legislative process that established the national road safety agency, and the subsequent loan the country requested from the World Bank that gave the agency funds to use to incentivize cooperation with the provinces. There was precedent for such an approach in the health sector. In the health sector, two previous loans from the Bank to Argentina (Essential Public Health Functions Project, and support for Plan Nacer (60,61)) had similarly aimed to renegotiate the relationship between the provinces and the national government by using funding to lock-in important institutional changes. The loan for the Argentina Road Safety Project extended the logic of these institution building loans to road safety. At the World Bank, such loans represented a shift away from fragmented, one-off interventions, to more comprehensive solutions (“second generation projects”) aimed at creating an institutional environment conducive for road safety interventions in a Safe System framework (59).

There is a parallel here with the long-lasting debate in public health between proponents of vertical programs for single diseases (e.g., HIV or malaria) versus horizontal programs that strengthen health systems and hence address multiple diseases (62). In this context, the Safe System approach resembles the “diagonal approach” in health systems that seeks to strengthen institutions while simultaneously implementing the most important interventions (63). This approach has allowed OECD countries to successfully regulate road safety even though they continue to struggle with other multi-sectoral health issues such as tackling NCDs. Rolling out the Safe System approach to all low- and middle- income countries should be the main priority for road safety advocates.

5. CONCLUSIONS

The case study highlights the importance of addressing systemic issues that impede the ability of countries to intervene effectively to improve road safety. In the case of Argentina, decentralization of authority to provinces and municipalities created a structural barrier for large-scale coordinated interventions. While a previous legislative attempt (the 1995 national traffic act establishing a national traffic code) failed because of insufficient resources, in their second attempt, Argentina ensured that resources were commensurate with the scale of the problem. The 2008 legislation established a national road safety agency with dedicated resources and a mandate to coordinate safety programs across the country. The government next approached the World Bank for a loan that was primarily focused on creating incentives and mechanisms to establish the national agency in a leadership role. While there is no doubt that these actions have helped address the structural impediments to effective safety interventions, traffic deaths in the country have not yet started declining. In order to achieve progress in reducing road traffic deaths, the agency now needs to take a rational approach to its road safety programming, which includes setting ambitious targets, and using an evidence-based approach to identifying risk factors and prioritizing interventions within a Safe System framework.

This case study provides an encouraging lesson for how road safety researchers and subject-matter experts can engage effectively in the policy process. In Argentina, professionals who cared deeply about improving safety, worked for years to raise awareness, develop solutions, and disseminate good ideas to potential champions, while being cognizant of the political environment so that when the opportunity for road safety reform came to Argentina, they were ready to mobilize and push through institutional reform. With a national road safety agency established, the focus of road safety efforts now needs to shift to the technocratic aspects of attributing injuries to risk factors, identifying evidence-based interventions, assessing their cost-effectiveness, setting meaningful road safety targets, and rolling out interventions to achieve them. Ultimately, the only real measure of success of these efforts is a reduction in the traffic injury and death toll in Argentina which hasn't occurred yet.

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Exploring Factors Affecting Motorcycle Crash Severity in Ghana Using Multinomial Logit Regression Model

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Abstract

This paper develops a multinomial logit (MNL) model to investigate and identify significant contributing factors that determine the motorcycle-vehicle crash severity in Ghana. Motorcycle-vehicle crash data from the Building and Road Research Institute's database from 2011 to 2015 were collected and used in this study. Crash injury severities are classified into four categories: fatality class, hospitalized injury class, injured injury class, and property damage only (no injury class). A multinomial logit modeling framework was developed using STATA and marginal effects were also calculated. Within the study period, a total of 8,516 motorcycle crashes were recorded, of which 22.9% were classified as fatal, 42.1% were classified as hospitalized injuries, 29.4% were classified as slight injuries, and 5.7% were classified as damage only crashes. The estimation results indicate that the following factors increase the probability of fatal injuries: at junction; weekend; signage; poor road shoulder; village settlement, tarred and good road surface and collision between motorcycle and heavy goods vehicle (HGV). About hospitalized injury of a motorcycle crash, crash occurring during the daytime and those occurring during the weekend increases its probability. The results also suggest that motorcycle crashes occurring during the daytime, those occurring at a curved and inclined portion of the roads and unclear weather conditions decrease the probability of fatal injuries. The developed model and analysis results provide insights on developing effective countermeasures to reduce motorcycle-vehicle crash severities and improve traffic system safety performance in Ghana.

Keywords: Motorcycle crash injury severity; Multinomial logit model; Ghana.

1 INTRODUCTION

The use of the automobile is increasing globally particularly in developing countries. Along with this growth of the use of the motor vehicle, the ownership and use of motorcycles and other two-wheelers are collectively swelling in many countries and relatively high in most low-income and middle-income countries. Motorcycles account for 95% of motor vehicles in Vietnam (1) and 67% in Taiwan (2). Similarly, 63% and 69%, respectively, of all motor vehicles in China and India (3) and 52% in Nigeria (4) are Motorcycles. The cumulative number of registered motorcycles and three-wheelers in Ghana as at the of 2012 stood at approximately 23% (5). The number of newly registered motorcycles in Ghana annually increased by 315% from the year 2008 to 2014, whereas the number of newly registered vehicles increased by just 85% within the same period (6). Due to low purchasing and running costs and convenient parking, demand for motorcycles has continuously risen in these countries.

The high rates of motorcycle ownership and usage are accompanied by problems such as traffic congestion, crashes, parking disorder, and air pollution. In the context of crash analysis, because of limited protection design of motorcycles in comparison to cars, motorcycles are considered the most dangerous form of motorized transport, with injury rates eight times, and fatality rates 35 times that of car occupants (per vehicle mile traveled) (7). Low-income and middle-income nations bear a disproportionate burden of road traffic deaths, and menace of a road traffic death is the peak in the African Region (WHO 2015). Road traffic deaths among pedestrians, cyclists, and motorcyclists are intolerably high (7). In Ghana, the use of motorcycle has significantly impacted positively on the social and economic lives of the people, the accompanying number of reported cases of road traffic crashes involving motorcycle has also seen a phenomenal increase (8).

The issue of traffic safety is a global problem at an alarming level which severely affects developing countries as well as advanced countries. The adverse effects of traffic safety problems are more devastating in developing countries than in developed ones from many apparent reasons. One of such reasons is that little, or nothing is done to guarantee the safety of road users in developing countries including drivers of motorized and non-motorized vehicles, passengers, and even pedestrians (9). The existing literature on road traffic crash in Ghana sees (10–17). These studies have focused mainly on the analysis of fatal road traffic crashes and pedestrian crashes in Ghana. However, where attempts have been made to study the motorcycle crashes (14,18–21), the concentration has always been on helmet usage by the motorcyclists and commercial motorcycle operations

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among others without considering the factors that influence the severity of motorcycle crashes. These studies have therefore created a knowledge gap that needs to be filled. The primary objective of this research is to explore the factors impacting negatively on motorcycle crash severity in Ghana using a multinomial logit model. The findings from this study can lead to more effective countermeasures that can substantially mitigate motorcycle-related injuries and fatalities in Ghana.

2 METHODS

2.1 Data

In Ghana, the source of data for statistics on road crashes is provided by BRR (Building and Road Research Institute) of the CSIR (Council for Scientific and Industrial Research) Ghana. The data used in this work were extracted from the National Road Traffic Accident Database at BRR of the CSIR, Ghana. The database is compiled from road traffic crash files from the Motor Traffic and Transport Unit (MTTU) of the Ghana Police Service by highly trained technicians in road traffic safety using a standard crash report form. Most of the information has been coded and stored in computers at the BRR using the Micro-computer Accident Analysis Package (MAAP, windows version) software developed by the Transport Research Laboratory (TRL), UK.

The data contains detailed information about motorcycle crashes, including crash severity, location type (not at a junction or at a junction), time of collision (night-time or daytime), road description (straight and flat or Curved and Inclined) day of week (weekend or weekday), traffic control (signage or no signage), and road separation (median or no median). The others are weather condition (other or clear), road shoulder condition (good, poor or no shoulder), road settlement (urban, village, or rural), road surface type (tarred with potholes, untarred or tarred and good) as well as collision partner (Car, HGV, Bus, Motorcycle, Pick-Up, Bicycle or Other). The crash data recorded by BRR has four types of motorcycle injury severities: Fatal Injury (F); injuries were recorded as fatal if the victim died within 30 days, Hospitalized Injury (H); injuries were recorded as hospitalized if the victim was hospitalized for more than 24 hours for medical attention, Injured Not-Hospitalized Injury (I); injuries were classified as injured not-hospitalized injury if the victims were hospitalized for less than 24 hours, and Damage Only (D); crashes were classified as damage only if no death or no injury is recorded. The data used in this study cover the period 2011–2015.

2.2 Statistical Model Specification

Methodologies used in this study follow the processes described by other researchers such as (22–24). The statistical modeling framework employed in this study to determine the possible factors influencing motorcycle crash severity was the Multinomial logit model because the assumptions of the ordered logit/ proportional odds model were not met. The choice of this type of model was also influenced by the polytomous nature of the response variable (motorcycle crash severity). This form of the model is comparable to the ordinal logit model, but it does not consider the ordinal nature of the response variable. The multinomial logit model is specified as:

$$V_{ij} = \beta_i X_{ij} + \varepsilon_{ij} \quad (1)$$

Where, V_{ij} is injury outcome i for motorcycle j ; β_i is the vector of coefficient estimates; X_{ij} is the vector of parameters, and ε_{ij} is an independently and identically distributed generalized extreme value error term. Manski and McFadden (25) assumed that the error components are extreme value distributed and the probability of a discrete event (severity of crash) is given by:

$$P_{ij} = \frac{e^{v_{ij}}}{\sum_{j=1}^J e^{v_{ij}}} \quad (2)$$

Where P_{ij} is the probability of motorcycle crash i to result in severity j , and J is a total number of injury severities. This assumption simplifies the probability equation; it also adds the property of independence from irrelevant alternatives (IIA) in the multinomial logit model. The IIA property of the multinomial logit model requires that the relative risks associated with the regressors in the outstanding classes will not affect the addition or elimination of classes (26). The estimated coefficients of the independent variables do not show the dynamics among the outcomes. To deal with these questions, the exponentiated values of the estimated coefficient (e^{β}) referred to as the relative-risk ratio (RRR), can be used to explore how variables affect the choice of one outcome compared with another outcome (26). The RRR of an independent variable refers to the increase ($RRR > 1$) or decrease ($RRR < 1$) in risk of a specific injury severity level relative to the base category (27). In this study, the multinomial logit model and the associated RRR are estimated using Stata (version 14.0).

The likelihood ratio test is applied to evaluate the significance of the estimated model by comparing the estimated model to the null (model without any independent variables). The test statistic is given by:

$$\chi^2 = -2[LL(\beta_T) - \sum_G LL(\beta_g)] \tag{3}$$

Where $LL(\beta_T)$ is the model’s log likelihood at the convergence of the model estimated on all risk factors being tested, $LL(\beta_g)$ the log likelihood at the convergence of the model estimated on the subset data injury severity group g and G is the set of all injury severity groups. This likelihood ratio test statistic is χ^2 distributed with degrees of freedom equal to the sum of parameters estimated in the total data model less the sum of coefficients calculated in the subset data model (28).

2.3 Marginal Effects

The inferences about the effect of a variable on a particular type of motorcycle crash severity outcome are determined by its marginal effect. Marginal effects are estimates of the change in an outcome for a change in one independent variable, holding all other variables constant (26). Following the discussion in (29), the direct and cross-marginal effects are calculated following equations (4) and (5), respectively:

$$\frac{\partial P_{ij}}{\partial x_{ijk}} = \beta_{jk} P_{ij} (1 - P_{ij}) \tag{4}$$

$$\frac{\partial P_{iq}}{\partial x_{ijk}} = -\beta_{jk} P_{ij} P_{iq} \tag{5}$$

The direct marginal effect (Eq. (4)) represents the effect that a unit change in x_{ilk} has on the probability of motorcycle crash i to result in severity j (denoted by P_{ij}). The cross-marginal effect (Eq. (5)) shows the effect of a unit change in variable k of alternative j ($j \neq q$) on the probability (P_{iq}) for crash i to result in outcome q .

3 RESULTS

Table 1 below illustrates the variables available for model development, with the proportions of the categorical variables.

Table 1. Distribution of variables included in the models.

Variable	Attributes	Count (%)
Injury severity	Fatal	1952 (22.9%)
	Hospitalized	3581 (42.0%)
	Injured	2500 (29.4%)
	Damage	483 (5.7%)
Location type	Not at junction	6297 (73.9%)
	At Junction	2219 (26.1%)
Time of collision	Nighttime	4488 (52.7%)
	Daytime	4028 (47.3%)
Road description	Straight and Flat	7768 (91.2%)
	Curved and Inclined	748 (8.8%)
Day of week	Weekday	5727 (67.2%)
	Weekend	2789 (32.8%)
Traffic control	No Signage	4206 (49.4%)
	Signage	4310 (50.6%)
Road separation	Median	2074 (24.4%)
	No Median	6442 (75.6%)
Weather condition	Clear	7588 (89.1%)
	Other	928 (10.9%)
Road shoulder condition	Good	4529 (53.2%)
	Poor	771 (9.0%)
	No Shoulder	3216 (37.8%)
Settlement type	Urban	5310 (62.4%)
	Village	2618 (30.7%)
	Rural	588 (6.9%)
Road surface type	Tarred with potholes	2716 (31.9%)
	Untarred	1854 (21.8%)
	Tarred and good	3946 (46.3%)
Collision partner	Car	3452 (40.5%)
	HGV	674 (7.9%)
	Bus	1166 (13.7%)
	Motorcycle	2382 (28.0%)
	Pick-up	504 (5.9%)
	Bicycle	171 (2.0%)
	Other	167 (2.0%)

First subcategory in the categories is the referent

Within the study period, a total of 8,516 motorcycle crashes were recorded, of which 22.9% were classified as fatal, 42.0% were classified as hospitalized injuries, 29.4% were classified as slight injuries, and 5.7% were classified as damage only crashes as shown in Table 1.

The likelihood ratio test of independence was conducted to ensure that each added variable significantly improved the overall model performance. The results revealed that only road separation is not statistically significant, therefore was not included in the final multinomial model being fitted. The rest of the variables under consideration are statistically significant, i.e., they are strongly associated with the motorcycle crash injury severity. The variance inflation factor (VIF) analysis for variables was conducted before the development of the multinomial model. This analysis is to confirm that no strong multi-collinearity among independent variables existed in the dataset. The results showed that no multicollinearity among the explanatory variables.

The estimated parameters and relative risk ratios of the fitted multinomial model of motorcycle crash injury severity are presented in Table 2. The maximum likelihood procedure is used for the estimation of the parameters, and the coefficients of all the variables are estimated relative to the selected reference category. A 95% level of significance was used as the threshold to determine whether the parameters differed from zero. Insignificant variables were removed from the final models. The overall significance of the fitted model was evaluated by performing a likelihood ratio test. The goodness of fit of the model was considered to be satisfactory based on a p-value <0.001 (Table 2). As shown in Table 2, the model fitted the data reasonably well overall with a significant chi-square statistic ($\chi^2 = 2514.533$) and a very small P-value (0.000) for the goodness-of-fit. The outcome of the estimated model is interpreted using the RRRs and confidence intervals (CI) in Table 2 and the marginal effects in Table 3 to assess the effects of all the independent variables in the model. Because the estimated coefficients of the independent variables do not show the dynamics among the outcomes (26).

4 DISCUSSION

The fitted model indicates that the fatal injuries of motorcycle crashes are more likely to occur relative to the other injuries arising 'at the junction.' On the average, a crash occurs at junction compared with that of not at a junction increases the probability of fatal injury by 46.8%. Specifically, the results on crashes involving motorcycle at junctions are consistent with previous studies (30–32). Based on these resultant findings, more efforts should be made to increase roadway facility strategies such as road signage and speed hump at junctions are proposed as reasonable ways to reduce motorcycle injury severity.

Motorcycle crashes in Ghana occurring at daytime are almost 5 times more likely to result in hospitalized, injured 17 times or damage 15 times compared to fatal crashes. This result supports the findings of other studies (23,33,34). This result implies roadway design factors such as clear and straightforward roadway delineation and visibility enhancement strategies such as street lighting should be enhanced to reduce motorcycle injury severities.

Concerning the road description, hospitalized, injured and damage crashes occur at curved and inclined parts of the road are nearly 2.5 times, 5 times and 5 times respectively, more likely to occur than fatal crashes. Previous studies have found that when the road is curved, the visibility and manoeuvrability reduce and consequently influence the crash severity (23,35–37). Accordingly, increase visibility on roadway segments involving horizontal and vertical curves and enforcement of speed limits should be improved at such locations to mitigate the level of injury. The probability of injured or damage injury increases by 13.2% and 3.8% respectively when crash occurs at curved and inclined portions of the road.

The estimation results suggest that motorcycle crashes that occur on the weekend are at a higher risk of having fatal crashes relative to hospitalized crashes, injured crashes or damage crashes. On the average, weekend crashes compared with that of weekday crashes increases the probability of fatal or hospitalized injury by 9.9% and 6.5%. Consistent with previous studies (24,34,35) our study found that motorcycle riding on weekends were generally more injurious. This result implies that temporary traffic control policies during the weekend would be effective in reducing fatalities.

Crashes at signage are at a higher risk of having fatal injuries relative to hospitalized, injured or damage. On the average, crash at signage compared with that of no signage increases the probability of fatal or hospitalized injury by 3.9% and 1.2% respectively. However, a similar result was observed in some studies as well (34,38,39) that crashes at intersection increased the likelihood of injury and fatality. Education campaign can be used to increase drivers' awareness of motorcycle, particularly at intersections.

Motorcycle crashes in Ghana are nearly twice more likely to result in hospitalized injury, 4 times more likely to result in an injured crash and 4 times more likely to result in damage crash than fatal injury when the crash occurs during the unclear weather conditions such as rainy, foggy, misty, dusty, and smoky. This result shows that unclear weather was positively correlated with motorcycle crash severity which was consistent with the findings of other studies (34,38–40). More efforts should be made to enhance visibility on roadway especially the use of street lighting and promote the use of reflective clothing. However, clear weather condition increases the probability of injured or damage injury by 16.9% and 3.4% respectively.

Table 2. Estimated parameters of the fitted multinomial logit model

Variables	Estimated coefficient ^a	t-Statistic	Risk ratio ^b
Hospitalized injury			
Location Type: At junction	-2.178 (0.098) **	-22.12	0.11 (0.09, 0.14)
Time of Collision: Daytime	1.631 (0.098) **	16.70	5.11 (4.22, 6.19)
Road Description: Curve and Inclined	0.929 (0.134) **	6.94	2.53 (1.95, 3.29)
Day of Week: Weekend	-0.405 (0.146) **	-2.77	0.67 (0.50, 0.89)
Weather Condition: Other	0.482 (0.150) **	3.22	1.62 (1.21, 2.17)
Settlement Type: Village	-0.549 (0.065) **	-8.38	0.58 (0.51, 0.66)
Constant	1.261 (0.236) **	5.35	
Injured injury			
Location Type: At junction	-4.585 (0.128) **	-35.88	0.01 (0.01, 0.02)
Time of Collision: Daytime	2.852 (0.106) **	27.03	17.32 (14.09, 21.30)
Road Description: Curve and Inclined	1.579 (0.156) **	10.13	4.85 (3.57, 6.59)
Day of Week: Weekend	-1.250 (0.173) **	-7.23	0.29 (0.20, 0.40)
Traffic Control: Signage	-0.402 (0.129) **	-3.12	0.67 (0.52, 0.86)
Weather Condition: Other	1.421 (0.176) **	8.05	4.14 (2.93, 5.85)
Road Shoulder Condition: Poor	-0.519 (0.186) **	-2.79	0.60 (0.41, 0.86)
Settlement Type: Village	-0.879 (0.081) **	-10.92	0.15 (0.36, 0.49)
Road Surface Type: Tarred and Good	-0.520 (0.200) **	-2.59	0.60 (0.40, 0.88)
Constant	1.045 (0.277) **	3.78	
Damage injury			
Location Type: At junction	-3.007 (0.155) **	-19.42	0.05 (0.04, 0.07)
Time of collision: Daytime	2.706 (0.143) **	18.90	14.93 (11.31, 19.82)
Road Description: Curve and Inclined	1.640 (0.227) **	7.22	5.15 (3.30, 8.04)
Day of Week: Weekend	-1.163 (0.269) **	-4.32	0.31 (0.18, 0.53)
Traffic Control: Signage	-0.518 (0.200) **	-2.59	0.60 (0.40, 0.88)
Weather Condition: Other	1.339 (0.272) **	4.92	3.82 (2.24, 6.50)
Road Shoulder Condition: No shoulder	1.073 (0.381) **	2.81	2.92 (1.39, 6.17)
Settlement Type: Village	-0.536 (0.119) **	-4.52	0.59 (0.46, 0.74)
Collision Partner: HGV	0.804 (0.403) *	1.99	2.23 (1.01, 4.92)
Collision Partner: Motorcycle	0.754 (0.382) *	1.97	2.13 (1.01, 4.49)
Collision Partner: Pick-up	0.878 (0.446) *	1.97	2.41 (1.00, 5.77)
Collision Partner: Other	1.766 (0.480) **	3.68	5.85 (2.28, 14.97)
Constant	-1.727 (0.460) **	-3.75	
<p>Number of Observations: 8,516 Log-likelihood at Zero: -10427.911 Log-likelihood at Convergence: 9170.645 LR Chi-Square Test: 2514.533 Pseudo R-squared: 0.121 p-value: 0.000</p>			

* >95% level of significance. ** >99% level of significance. a is Standard error is in parentheses. b is Lower and upper limits at the 95% confidence interval are in brackets. The fatal crash is the base case with coefficients restricted at zero.

With respect to the road shoulder condition, crashes occur at poor and/ or overgrown shoulders are more likely to result in hospitalized, injured or damage compared to fatal injuries. On the average, crash at poor and/or overgrown shoulders compared with that of good road shoulder condition increases the probability of fatal injury by 4.5%. Hospitalized crashes, injured and damage are more likely to occur than fatal injury when the crash scenes are roads with no shoulder. On the average, crash on the road with no shoulder compared with that of good road shoulder condition increases the probability of damage injury by 6.1%. This result implies that

periodical road maintenance such as clearing and maintaining of road shoulder should be enhanced especially during rainy season.

Table 3. Marginal effects of the variables included in the multinomial logit model.

Variables	Marginal effects on probabilities of the severity outcomes (%)			
	Fatal	Hospitalized	Injured	Damage
At junction	46.8 (0.000)	-6.7 (0.000)	-36.9 (0.000)	-3.3 (0.000)
Daytime	-24.7 (0.000)	4.2 (0.000)	24.7 (0.000)	4.3 (0.000)
Curved and inclined	-13.5 (0.000)	-3.6 (0.000)	13.2 (0.000)	3.8 (0.015)
Weekend	9.9 (0.000)	6.5 (0.013)	-13.8 (0.000)	-2.6 (0.017)
Signage	3.9 (0.011)	1.2 (0.530)	-3.7 (0.027)	-1.5 (0.116)
Weather: Other	-10.4 (0.000)	-9.8 (0.000)	16.9 (0.000)	3.4 (0.067)
Poor	4.5 (0.068)	1.1 (0.698)	-5.7 (0.008)	0.1 (0.932)
No Shoulder	-3.0 (0.230)	-3.4 (0.302)	0.3 (0.912)	6.1 (0.032)
village	9.8 (0.000)	-2.3 (0.063)	-7.7 (0.000)	0.1 (0.889)
rural	0.3 (0.875)	-2.9 (0.193)	1.9 (0.350)	0.7 (0.538)
Untarred	-0.8 (0.595)	-0.4 (0.847)	2.6 (0.193)	-1.3 (0.224)
Tarred and good	5.1 (0.029)	0.3 (0.934)	-4.9 (0.059)	-0.5 (0.733)
Motorcycle	2.1 (0.404)	-3.5 (0.271)	-3.2 (0.243)	4.7 (0.015)
HGV	2.9 (0.086)	-0.4 (0.873)	-3.6 (0.074)	1.0 (0.464)
Bus	1.2 (0.436)	-1.2 (0.521)	-0.9 (0.591)	0.9 (0.416)
Pickup	-0.1 (0.978)	-5.5 (0.050)	4.9 (0.047)	0.7 (0.740)
Bicycle	5.3 (0.228)	-5.5 (0.218)	-2.6 (0.431)	2.8 (0.400)
Other	-3.3 (0.423)	1.9 (0.687)	-9.3 (0.001)	10.7 (0.007)

P-values are in parentheses

The motorcycle crashes occurring on roads within village settlement are at a higher risk of having fatal injuries relative to hospitalized crashes, injured crashes or damage crashes. On the average, crashes occurring on roads within village settlement compared with those occurring on roads within urban settlement increases the probability of fatal injury by 9.8%. Previous studies have found that crashes are happening in rural or village settlement significantly increased the likelihood of a motorcycle crash (23,32,41). A practical safety suggestion for mitigating this problem is to employ perceptual cues such as gateways and traffic calming devices.

Concerning the road surface type, crashes occur at untarred roads are more likely to result in hospitalized injured or damage compared to fatal injuries. Similarly, hospitalized crashes, injured and damage more likely to occur than fatal injuries when the crash scenes are roads with a tarred and good surface. On the average, crash on the road with tarred and good surface compared with that of a road with tarred with potholes surface increases the probability of fatal injury by 5.1%. This result may be due to a good surface condition result in higher vehicle speeds and thus may increase the likelihood of higher crash severities (23). Based on this result, public education strategies regarding safe motorcycle riding and enforcement of speed violations should be enhanced to reduce motorcycle injury severities.

The motorcycle crashes involving heavy goods vehicles (HGV) are at a higher risk of having fatal injuries relative to hospitalized crashes, injured crashes or damage crashes. Averagely, comparing crashes between motorcycle and HGV increases the probability of fatal injury by 2.9%. This result supports the findings of other studies (24,34,40,42). Also, motorcycle crashes involving bus are more likely to result in hospitalized, injured or damage compared to fatal injuries. With respect to motorcycle-to-motorcycle crashes, hospitalized crashes, injured crashes or damage crashes are more likely to occur than fatal crashes. The motorcycle crashes involving pick-up are at a higher risk of having fatal injuries relative to hospitalized crashes, injured crashes or damage crashes. On the average, crashes between pick-up and motorcycle increases the probability of injured injury by 4.9%. Motorcycle crashes involving bicycle are more likely to result in hospitalized, injured or damage compared to fatal injuries. Also, motorcycle-to-other crashes, hospitalized crashes, injured crashes or damage crashes are more likely to occur than fatal crashes. Comparing crashes between a motorcycle and other vehicles increases the probability of damage injury by 10.7%. On the average, crashes between motorcycle and car increases the likelihood of damage injury by 4.7%. Based on these resultant findings, enhance the enforcement of motorcycle rider violations and violations by the drivers of other vehicles, and the use of reflective clothing to increase motorcyclist visibility to other roadway users are suggested to improve motorcycle safety in Ghana.

Lastly, the results of the estimated multinomial logit model concerning crash injury severity of the motorcycles in Ghana were mostly consistent with those of previous studies on the injury severity of motorcycle crashes

from other regions. With respect to the contributing factors, our study found that location type, time of the collision, road description, the day of the week, traffic control, weather condition, settlement type, and collision partner have a similar impact on motorcycle crashes in other regions (23,24,32,34,35,38,40). However, it can be claimed that contributing factors such as road shoulder condition and road surface type are infrequent in other studies making these contributing factors novel and significant in the Ghanaian situation.

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Impact of Pillion Passengers on Motorcycle Crashes

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Abstract

Motorcycle safety in China have not received enough concern. For this reason, this study investigates the impact of passengers on driver's crash potential in Hunan China. To find out the impact, a set of binary logit models were developed using the police-reported crash dataset obtained from the Traffic Administration Bureau of Hunan Provincial Public Security Ministry. The results show that there exist significant correlations between passenger and motorcycle crash characteristics. It was found that drivers generally display safer behavior when passengers are present and this may reduce driver's crash potential. Overload is found not significant in the model, which may mean over pillion passengers lead to the safety compensation effect. It was also found that younger drivers are more likely to be at-fault part. The crash type analysis indicated that riders driving without passengers are more likely to be involved in single-vehicle crashes. Male drivers and young drivers are adverse. We found passenger's injury severity is highly relevant to the driver's and we identified passenger's characteristics (i.e., gender, age) also affect driver's injury severity in crash occurrence. The study investigated in which condition drivers are more likely to carry passengers and how the pillion passengers affect driver's behavior and their crash potential. The findings could be used for the evidence-based interventions for policy-making decisions, which would lead to a reduction in the fatality risk of motorcycle crashes.

Keywords: Motorcycle pillion passengers; Crash potential; Injury severity; Binary logit.

1 INTRODUCTION

Motorcycles are one of the most popular modes of transportation across the globe. In the previous research, motorcyclists and their passengers are particularly vulnerable of the road users in the developed countries (1) but the motorcycle passenger problems don't get enough attention in the previous investigations. Motorcycle problem is also serious in developing countries such as China. China Road Traffic Accident Statistics show that the number of motorcycles registered in China increased overwhelmingly from 2.5 million (23% of all registered motorized vehicles) in 1987 to 49.9 million (nearly 65%) in 2002, then 91.5 million units (about 35%) in 2014. In accordance with this growth, the number of crashes in particular for traffic fatalities related to motorcycle raised by about 6.7 fold, from 3078 in 1987 to 20,773 in 2002. Although this figure reduced to 10,411 in 2014, the proportion of traffic fatalities sustained by motorcyclists is still relatively high, accounting for approximately 20% of all vehicle crashes. Hence, this study would investigate the relationship between drivers and pillion passengers and help to reduce the death rate of this road user group.

Most previous research on motorcycle safety problems tends to present in two directions, first on crash severity and second on crash risk. They have identified the relationships between motorcycle crashes severity and explanatory factors, but most of these issues have not considered the impacts of passengers to crash occurrence since most of these studies have been conducted in western countries and in these countries pillion passengers are very uncommon (2). However, motorcyclist carrying passengers is very common in developing cities. In developing countries, there is a career which is rare in developed countries called "ojek" riders (motorcycle taxi drivers) (3) who make a profit by carrying others to their destinations. In China, due to local governors' concern about motorcycle-related issues including traffic casualties, traffic chaos, and pollution, motorcycles are prohibited on public roads in many large cities such as Beijing, Shanghai, and Guangzhou but motorcyclist carrying pillion passengers are particularly common in developing cities and rural areas. Thus, it is important to identify conditions where drivers tend to carry passengers and the correlation between passenger and crash occurrence to evaluate the effect of passengers on crash potential and crash injury severity.

The objects of this paper are (1) to identify the difference between driving with/without pillion passengers. (2) To determine in which conditions drivers tend to carry passengers more. (3) To develop the models that consider

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the correlation of inter-related associated with the presence of passengers and crash factors. From this analysis, we could better understand the complex interactions among driver/passenger characteristics, impact of passengers to crash risk factors. The findings could be used for policy-making about carrying passengers.

2 METHOD

Discrete choice models including binary logit, ordered logit, ordered probit, and multinomial logit are commonly applied to analyze the factors that influence crash injury severity and pre-crash violation behavior. In this study a set of binary logit models and Chi-square test were developed to analyze the crash data in Hunan province and to investigate the influence of the passengers on the motorcycle crashes. We need to predict the probability of crashes given that passengers are present or not. P-Values of <0.05 were considered statistically significant. Using the outcomes: presence of passenger, driver citation and crash type as the response variables, the problem can be well formulated using a set of binomial/binary logit models. In this study we used a set of retrospective approaches to identify the different impacts of passengers in motorcycle crash involvements. The dependent variables in this study are presence of passenger, injury severity, driver citation and crash type. Since these variables are clearly binary and significantly related to crash occurrences. It is also a suitable technique to use because it is developed to predict a binary dependent variable as a function of predictor variables. The logistic regression model is widely used in road safety studies where the dependent variable is binary. (4). The independent variables in these models are the environmental factors, driver and passenger characters, and other crash risk factors, including peak-time, helmet use, light condition, driver’s age, and presence of passenger.

We choose presence of passenger, driver citation and crash type as dependent variables in three logistic regressions, through these three analysis we could identify the association of passengers with crashes and determine in which conditions drivers are more likely to carry passengers. The detailed descriptions of each variable are noticed as follows.

3 RESULTS AND DISCUSSION

3.1 Presence of passengers model

At first we investigated in which conditions drivers are more likely to carry passengers. In this model, we investigated contributes to improving the tendency of drivers carrying passengers. As shown in Table.1, it was found that drivers are more likely to carry passengers in good light condition. This is may be because good light condition is more appropriate and safe for drivers to carry passengers. We also found young drivers are more likely to carry passengers. The results also indicated that at peak time, drivers are less likely to carry passengers. This may be because drivers deal with their own things at peak time and we didn’t find drivers tend to wear helmet when passengers are present, which is inconsistent with the findings of Geyer and Ragland (5).

Table 1. Estimated parameters of binary logit models (presence of passenger).

	Coefficient	Odds Ratio	p-value
Presence of passengers			
Constant	-1.077	0.341	<0.0001
Peak time (1=7 am-9 am, 5 pm-8pm)	-0.181	0.835	0.003
Helmet use (1= helmet use)	-0.104	0.902	0.141
Good light condition (1= good light condition)	0.200	1.221	0.002
Young driver(1= younger than 24)	0.378	1.460	<0.0001
Number of observations = 6311			

3.2 Driver citation model

In this model, the correlation of rider citation and presence of passengers was estimated. The results showed that the presence of passenger is negative to driver citation. This result is opposite to the finding of Haque et al. (6) and it indicated that the presence of passengers partially contributes to reducing crash potential and risky behaviors of drivers. At good light conditions drivers are more likely to be not-at-fault part.

Table 2 Estimated parameters of driver citation model.

	Coefficient	Odds Ratio	p-value
Correlation between the presence of passenger and driver citation			
Model: Driver citation (1=at-fault)			
Constant	0.671	1.955	<0.0001
Peak time (1= peak time 7 am-9 am, 5 pm-8 pm)	0.072	1.075	0.188
Good light condition	-0.307	0.736	<0.0001
Young driver (1= 16-24)	0.355	1.426	<0.0001
Passenger (1= drive with passengers)*	-0.642	0.526	<0.0001
Number of observations = 6311			

These results mean that drivers will drive more carefully when passenger is present, and at good light conditions they could avoid risk effectively. Thus, this result can be considered as a strong evidence of a positive impact of passengers on driver safety of motorcycle. However, apart from presence of passengers, younger drivers (16-24) are more likely to be at-fault part. The models correlating the overload of passengers to driver citation were found not to be statistically significant and this may be because the proportion of the overloaded crash data is too small.

3.3 Crash type model

In this model, the association of presence of passenger and crash type was estimated. In this analysis of crash type in the Table.3, since the purpose of this analysis is to identify typical traffic conditions when drivers are more likely to cause certain type of crash, the data of at-fault drivers was used only. Significantly, the presence of passengers was found to be negatively associated with single-vehicle crashes in this result and we also found young drivers and male drivers are more likely to increase single-vehicle crashes potential because young drives are more aggressive than other drivers when driving. Good light conditions are helpful in reducing driver crash potential in uncongested conditions. For single-vehicle, crashes more frequently occurred because of driver’s error and distraction during uncongested traffic conditions than congested conditions contradicted to multi-vehicle crashes. This results implied that pillion passengers of motorcycle are helpful in reducing driver’s crash potential during uncongested traffic conditions, i.e. they are more likely to help drivers ride more carefully or remind drivers when the obstacle is closing. This result is inconsistent with the impact of passengers to drivers in motor vehicles (4). In addition, this result can be also interpreted that pillion passengers may impact on driver’s operation in congested conditions.

Table 3 Estimated parameters of crash type model

	Coefficient	Odds Ratio	p-value
Correlation between the presence of passenger and crash type			
Model: Crash type (1=single-vehicle crash)			
Constant	-0.943	0.390	<0.0001
Young driver (1= 16-24)	0.679	1.972	<0.0001
Passenger* (1= drive with passenger)	-0.775	0.461	<0.0001
Gender (1= male)	0.801	2.228	<0.0001
Good light condition (1= good light condition)	-1.060	0.346	<0.0001
Number of observations = 3677			

3.4 Presence of passenger-injury severity

The results implied that there are lower likelihoods of driver’s fatal/severe injuries when passengers are present. This may be another significant evidence of a positive impact of pillion passengers on motorcycle driver safety. Since injury severity is greatly affected by the speed of motorcycle at the time of a collision (7), it can be speculated that the speed of motorcycle tends to be lower (i.e. cautiously driving) when passengers are present in the crash involvement and the impact of collision on drivers is likely to be weaker if the speed is lower.

It is also identified that helmet usage significantly decrease the injury severity of riders. The protective effect of helmet use on injury severities has been well proved, which is consistent with this result. We also found driving in peak time and in good light condition can reduce the likelihood of fatality. It may be because of good views and low speed in these conditions. In China, the responsibilities of the parties involved in road traffic crashes are determined by police officers on the scene. If drivers are responsible for total, primary, equal duty they are at-fault part and if they are secondary and have no responsibility they are not-at-fault party. If drivers are the at-fault part in the crash occurrence, their injury will be more severe than not-at-fault drivers . Some studies focused on the specific high-risk driver age group (e.g. teenage drivers) and their crash risk associated with the presence of passengers. In this model result, the involvement of motorcyclist riders aged between 16 and 24 was found to have a significant effect on injury severity because riders of this age group lack of riding experience and they tend to commit risk driving behaviors.

In the second model, the association of passenger’s injury and driver’s injury was estimated as shown in Table 4. The model results show that driver’s injury is significantly correlated to passenger’s injury and a correlation test also indicates these two variables are significantly related. That is to say, pillion passengers are more likely to suffer in fatal injury when driver’s injury are severe in the crash occurrence and we found passengers’ gender may not affect the passenger’s injury severity in crash occurrence.

Table 4 Estimated parameters of driver's injury models.

	Coefficient	Odds Ratio	p-value
Model: driver injury (1= fatal)			
Constant	-1.388	0.250	<0.0001
Passenger gender (1= male)	0.382	1.466	0.003
Too young or too old passenger (1= <16 or >60)	-0.329	0.719	0.043
Driver citation (1= cited)	0.321	1.378	0.012
Light condition (1= good light condition)	-0.505	0.604	0.011
Number of observations = 1742			

3.5 Passenger characteristics-driver injury

In this model, the association of driver's injury and passenger's characteristics was estimated. The result implies that the gender of the passenger has strong correlation with driver injury severity in crash. It indicates that drivers tend to drive more cautiously with young and old passengers at lower speed than driving with other age groups of passengers and the consequence of crash is likely to be less severe. The result also indicates that different gender of passengers have different effects on driver's injury severity. Female passengers reduce the likelihood of driver's fatal and severe injuries and young or old passengers also reduce the likelihood of driver's fatal injury in the crash involvement because drivers ride motorcycle more carefully when carrying children and the elderly. Through this model, we found the results can be interpreted in a way that passenger characteristics have strong correlation with driver injury in the crash occurrence.

Table 5 Estimated parameters of binomial logit models (passenger characteristics and driver injury).

	Coefficient	Odds Ratio	p-value
Correlation between the presence of passenger and injury			
First Model: Driver injury (1=fatal)			
Constant	-0.962	0.382	<0.0001
Peak time (1= peak time 7 am-9 am, 5 pm-8 pm)	-0.203	0.816	0.002
Good light condition	-0.467	0.627	<0.0001
Young driver (1= 16-24)	-0.286	0.751	0.003
Passenger (1= drive with passengers)*	-0.186	0.803	0.047
Helmet use (1= use helmet)	-0.395	0.673	<0.0001
Driver Citation (1= cited)	0.243	1.275	<0.0001
Number of observations = 6311			
Second model: Passenger injury (1=fatal)			
Constant	-2.197	0.111	<0.0001
Driver citation (1=cited)	0.243	1.275	0.072
Driver injury* (1=fatal)	1.661	5.263	<0.0001
Passenger gender (1=male)	-0.061	0.654	0.941
Too young or too old passenger (1= <16 or >60)	0.349	1.417	0.026
Number of observations = 1742			

4 CONCLUSION

Based on the results in this study, it is strongly recommended that presence of passenger will decrease the crash potential in some conditions. This result is different from Kashani et al. (3) and when the passenger's gender is female, drivers will be more careful and suffer less severe injury in crash occurrence. So riding with passenger is acceptable, all drivers should be cautions and drive more safely, younger drivers are more likely to suffer in the single-vehicle crash since their driving behaviors tend to be more aggressive than older drivers. Obviously, the motorcycle education programs for younger drivers are needed to advise them to drive slowly in uncongested conditions. Through our analysis, we also found that passenger characteristics are strongly correlated with the crash injury severity of drivers in crash involvement. For instance, younger and elder passenger reduce the likelihood of driver's fatal injury in the crash occurrence, passenger's gender also has different impact on driver's injury severity in crash involvement.

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Characteristic analysis of the motorized two-wheeler collisions in county areas based on real world accident data in China

Xinghua Wang^{1a}, Yong Peng^a, Lin Hu^b

1 INTRODUCTION

Motorized two-wheelers powered by oil and electricity, as expedite and economical tools, have been widely applied to public transportation in China. Unfortunately, the number of the accidents involving motorized two-wheelers sharply increased in recent years. According to *Road Traffic Accident Statistics' Annual Report of PRC*, near 60 thousand people died in road traffic accidents, of which the cyclists of motorized two-wheelers accounted for 32%, in 2014 (1). The county areas, where most people adopt motorized two-wheelers as their primary mode of transportation, have higher incidence of such accidents. Therefore, it is a focus in road traffic safety research field how to improve the motorized two-wheeler rider safety.

At present, some relevant researches have been conducted to solve safety issues of motorized two-wheelers. In Europe, the *Safety in Motion (SIM)* project focus on the active and passive safety, by which an integrated approach to improve the safety of motorized two-wheelers was performed (2,3). In China, motorized two-wheeler accidents were analyzed based on actual accident data from the perspective of the prototypical accident scenarios, speed, possible prevention countermeasures and so on (4,5). The motorized two-wheeler accidents mainly occur in the county areas in China, but most of the research comes from Europe and cannot specifically consider the traffic conditions in county town. Therefore, it helps us in our efforts to develop suitable prevention countermeasures that analyzing the impact characteristics of motorized two-wheelers in county areas.

2 METHOD

2.1 Data set

The *Traffic Accident Investigation and Research in China (TAIRC)* project, which selects the Xiangtan County as a traffic accident data collection base, focuses on the accidents with monitoring video and police support for in-depth investigation. The monitoring videos can help investigators to clearly understand the movements, evasive maneuvers and impact responses of each participant. The police support for in-depth investigation contributes towards deeply analyzing the accident causes from the perspective of psychology. To guarantee the reliability of analysis results, all accidents used in this study are selected from the TAIRC database for its comprehensiveness and veracity. A total of 93 accidents occurring in Xiangtan County from 2017 to 2018 are obtained, and 63 accidents between vehicles and motorized two-wheelers are emphatically analyzed.

2.2 Motorized two-wheeler categories

In actual traffic, the motorized two-wheelers can be divided into five categories, which include the electric two-wheelers (top speed: 20-40 km/h, weigh: 40-60 kg) and motorcycles (top speed: 50-80 km/h, weigh: 70-80 kg). The specific categories are summarized in Table 1.

2.3 Accident variables

Some crash-related variables, such as accident site, accident type, view obstruction and so on, are extracted carefully for the purpose of developing the active safety system. The accident variables and categories are summarized in Table 2.

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Table 1 Motorized two-wheeler categories

Category	Picture	Description
Bicycle style electric two-wheelers		With pedal; E-/human-powered; Small wheels;
		With pedal; E-/human-powered; Big wheels;
Scooter style electric two-wheelers		Without pedal; E-powered only ; Small wheels;
Scooter style motorcycles		Without pedal; Gasoline-power only; Small wheels;
Style motorcycles		Without pedal; Gasoline-power only; Big wheels;

Table 2 Variable definition and category

Variables	Categories
Participant type	1. Vehicle-vehicle; 2. Vehicle-motor tricycle; 3. Vehicle-motorized two-wheeler; 4. Vehicle-bicycle; 5. Vehicle-pedestrian; 6. Other
View obstruction	1. No; 2. Running vehicle; 3. Parking vehicle; 4. Ego; 5. Construction; 6. Dusk; 7. Dazzle
Accident site	1. Straight section; 2. Lane junction; 3. Intersection; 4. Other
Driving state	1. General continuous driving (I); 2. Lane-changing (II); 3. Turning/turning-around (III); 4. Other (IV)
Accident type	1. Turning off accidents; 2. Crossing accidents; 3. Lateral accidents; 4. U-turning accidents
Traffic control	1. No; 2. Traffic light; 3. Zebra crossing

3 RESULTS

The accidents between vehicles and motorized two-wheelers are apparently the most frequent with a proportion of 67.7 %, which reflects the special characteristics of the traffic problems and traffic modality in county town (Fig.1). In these 63 accidents between vehicles and motorized two-wheelers, 46.0% of crashes occurred with visual obstruction, in which another participant was obscured by ego (2/29), parking vehicle (5/29), running vehicle (4/29), construction implementation (14/29), dusk (3/29) and dazzle (1/29) (Fig. 2). Statistic data indicates that the accidents occurring in lane junction or intersection encompass 79.4 % of all, with 25 cases respectively (Fig. 3). In terms of driving state before impact, the accidents in which at least one was turning/turning-around/changing lane accounts for 71.4 % (Fig. 4). And the accidents caused by the lane-changing of two-wheeler are more than that caused by the lane-changing of vehicle, with 8 and 1 cases respectively, so some traffic regulations should be developed to forbid two-wheeler to casually change lane. All of the accidents (I - I), in which two participants both generally continuously drove, occurred in lane junction (2) or intersection (14), and most of the accidents (11/16) were caused by the visual obstruction. 19 % of accidents (12/63) occurred when the vehicles or motorized two-wheelers were turning around (Fig. 5). More than

50% of the accident scenes were controlled by traffic light, and nearly half of accident scenes were not controlled in any way (Table 3). So it may be feasible to reduce the incidence of traffic accidents that setting suitable traffic control modes in different traffic scenarios.

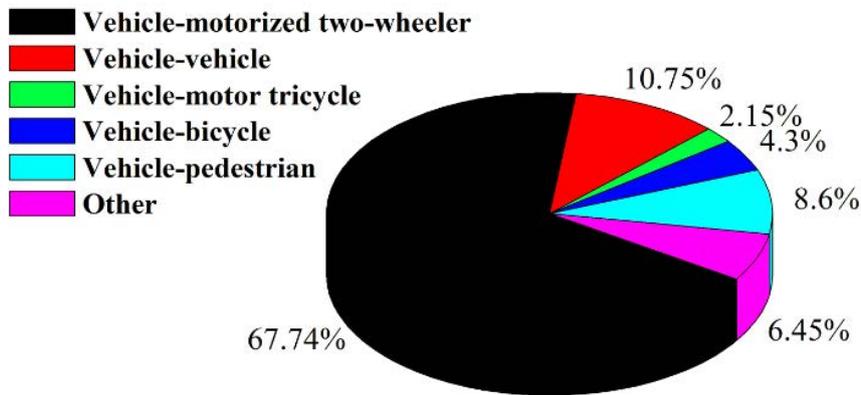


Fig. 1. Participant type

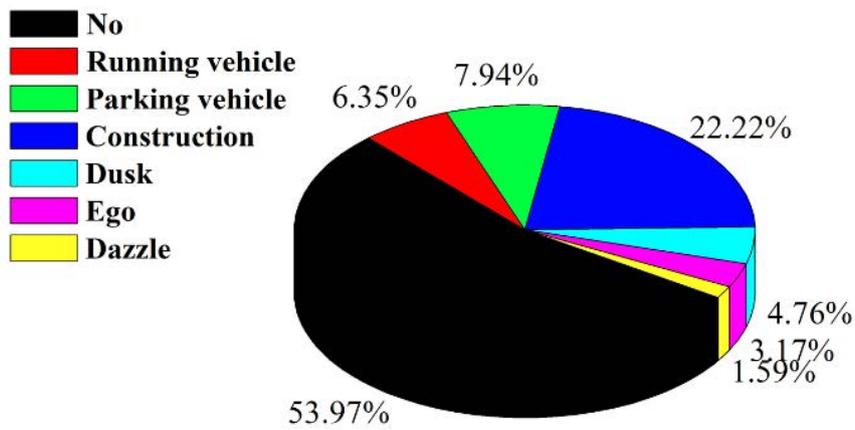


Fig. 2. View obstruction

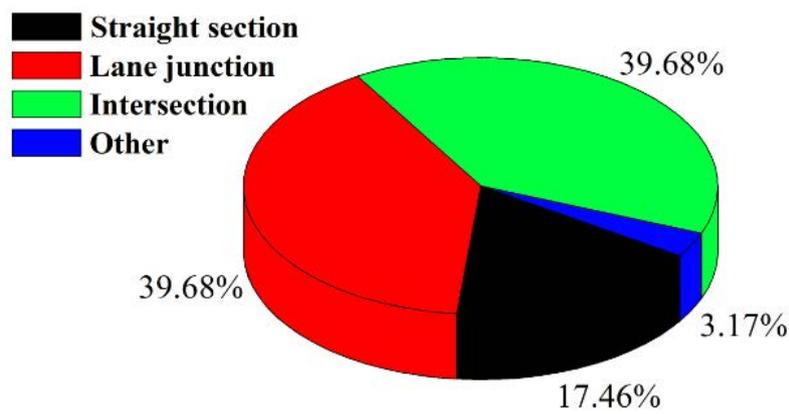


Fig. 3. Accident site

Table 3 Traffic control distribution

Traffic control	Number
Not available	28
Traffic light	25
Zebra crossing	10

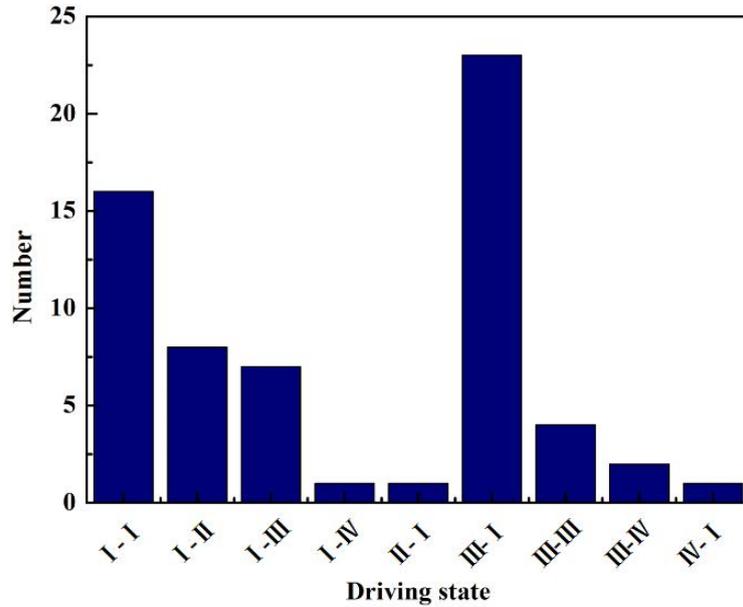


Fig. 4. Driving states of two participants before impacts

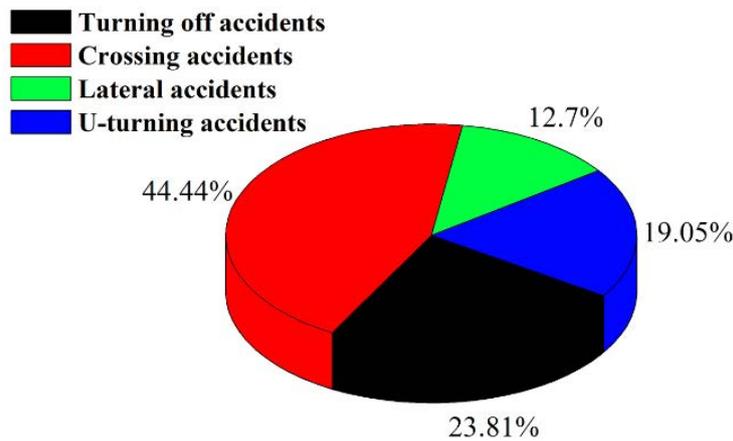


Fig. 5. Accident type

4 CONCLUSIONS

This study analyzes the characteristics of the impacts between vehicles and motorized two-wheelers in county areas. Some meaningful conclusions are obtained, which can be scaled to some areas similar to Xiangtan county in administrative rank, infrastructure construction, economic level and so on. However, the results might not accurately and comprehensively reflect the fact owing to some limitations. First, the number of accidents is relatively small. Second, the accidents used in this study were recorded by road traffic monitoring, so the distribution of monitoring videos may affect the distribution of accident sites.

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The Patterns of Riding Behaviors of Non-motor Vehicle in a District in Shanghai

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Abstract

This study aims to describe riding behaviors of non-motor vehicle in Shanghai Pudong New District. and to investigate the relationship between the prevalence of non-motor vehicle accidents and selected behaviors, then provide basis for developing targeted intervention programs. In July 2018, an observational study was conducted at 8 signalized intersections in Shanghai Pudong New District during a 14-day period, including 4 in the inner ring area (low accident area) and 4 in the outer ring area (high accident area). Six riding behaviors involve red-light running, riding against traffic, using dedicated motor vehicle lane, carrying passengers, no helmet of drivers and no helmet of passengers. Finally, 25198 e-bikes and bicycles were observed. The overall prevalence of no helmet of passengers, no helmet of drivers, carrying passengers, riding against traffic, red-light running and using dedicated motor vehicle lane were 97.89%, 92.17, 9.72%, 8.11%, 7.15% and 4.19%, respectively. Riding behaviors of non-motor vehicle varied by location, weekly time (weekend and weekday) and daily time (morning rush, non-rush, evening rush hours). Riding behavior patterns combined with location and time were also identified. In conclusion, spatial and temporal differences among riding behaviors of non-motor vehicles were found in the target areas. They can be recognized into four patterns according to weekly time, daily time, intersections and behaviors.

Keywords: Non-motor Vehicle, Riding Behaviors, Non-participatory observation

1 INTRODUCTION

Non-motor vehicle travel is an important and traditional option of transportation in China. As an important tool for commuting and learning, it has reduced the pressure of motor vehicle for a long time, and it is the crucial reason for adopting mixed traffic, sectional and hierarchical system in China's road planning and design system (). Although lower traffic safety, with its convenient and economical features, is explicitly classified into the category of non-motor vehicles requiring no driving license and annual inspection. Thus, it is heavily adopted by frequent riders as a great commute option between bicycle and motor vehicle. In China, the number of e-bikes is increasing by 30% per year (). In Shanghai, due to the looseness of traffic regulating policies, e-bikes are becoming important and all-pervading transportation tools. By the end of 2014, the number of registered mopeds was 4.64 million and the bicycles was 10.9 million (containing the scrapped part ()).

With the spread of non-motor vehicles, traffic injuries have increased. During 2007 to 2016, the number of road traffic accidents caused by non-motor vehicle doubled, with an average annual increase of 7.1%. Violations of non-motor vehicle accounted for 10.4% of all road traffic accidents in 2017, which rose from 4.8% in 2008 (). The role of non-motor vehicles (especially e-bikes) in traffic injuries cannot be underestimated. Chen et al. thought that road traffic accidents are caused by the adverse effects of road environment on drivers' psychology, physiology and behavior (). A study indicated that more than 60% of fatal injuries are due to moped violations: red-light running, riding against traffic and using dedicated motor vehicle lane (). It suggests a complex interaction between environment, individual and injury outcome. Therefore, it is of great value to study the patterns of riding behavior by combining specific space and time and environment for preventing road traffic injury.

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2 METHOD

2.1 Locations and Index behaviors

A cross-sectional observational study was conducted at signalized intersections in Shanghai Pudong New District. Three criteria were used to select the observational sites. First, the selected sites should represent the typical intersection design characteristics and traffic conditions of Pudong New District. Second, there must be a reasonably high number of two-wheeled traffic (both electric bikes and regular bicycles) during the observation period for the data extraction effort to be efficient. Third, we should base on the prevalence of road traffic accidents estimated using the official road traffic accident registry database by our study team in earlier internal report. Finally, four observation points in Shanghai Pudong New District were selected respectively both at the inner ring area (with a low rate of incidents) and the outer ring area (with a high rate of incidents). The following criteria were applied for observation point selections: 1) four-armed signalized intersections, 2) bidirectional roads, except that Pudian Road was a unidirectional road. The observation points at the inner-ring area included Minsheng Road Lingshan Road intersection (code as IL1, IL represents 'The inner-ring area & Low incident'), Yuanshen Road Yushan Road intersection (IL2), Dongfang Road Pudian Road intersection (IL3), and South Pudong Road Pujian Road intersection (IL4). The observation points at the outer ring area include Nianjiabang Road Kangshen Road intersection (code as OH1, OH represents 'The outer ring&High incident') and Nianjiabang Road Zhoukang Road intersection (OH2) located in Zhoupu Town, Gongji Road Jinghai Road intersection (OH3) and East Renmin Road Jinghai Road intersection (OH4) located in Huinan Town.

Select those non-motorized vehicle users who passed the selected roads as our observational objects.

Six behaviors categories as follows of non-motorized vehicle users were observed and recorded: red-light running, riding against traffic, using dedicated motor vehicle, carrying passengers, no helmet of drivers, no helmet of passengers. Red-light running was defined as crossing the intersection when the traffic lights were red. Riding against traffic was defined as riding at the left side of the road. Using dedicated motor vehicle was defined as riding in motorized vehicle lanes. Carrying passengers was defined as carrying one passenger over 12 years old or carrying more than one passenger. No helmet of drivers was defined as riding without wearing a helmet. No helmet of passengers was defined as passengers carried without wearing helmets ().

2.2 Observation method

Data collection at each intersection was conducted for three days of one week (two weekdays and one day on weekends). The observation lasted for three hours every day, averagely separating for morning rush, non-rush and evening rush hours (Table 1). And 1-hour observation session for each intersection was further separate into three intervals. One interval included a 10-minute observation for each road of one intersection (two roads).

Table 1 The schedule of observation in Shanghai Pudong New District.

Time	Team	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
First week	1	OH1	IL1		OH 2	IL2	OH 1	IL1
	2	OH 2	IL2		OH 1	IL1	OH 2	IL2
Second week	1	OH 3	IL3		OH 4	IL4	OH 3	IL3
	2	OH 4	IL4		OH 3	IL3	OH 4	IL4

All behaviors were recorded by both non-participatory observation and mobile phone video. Two observers stood in the same position of the intersection and faced opposite directions, recording the riding behaviors of non-motor vehicles in the designated intersection simultaneously (Fig. 1). review and comments.

Two mobile phones worked for gathering footage on tripods. They were set in the same position next to the road but toward different directions in accord with the observers. One was positioned where the entire length of the road could be viewed and recorded. The other one faced to the intersection.

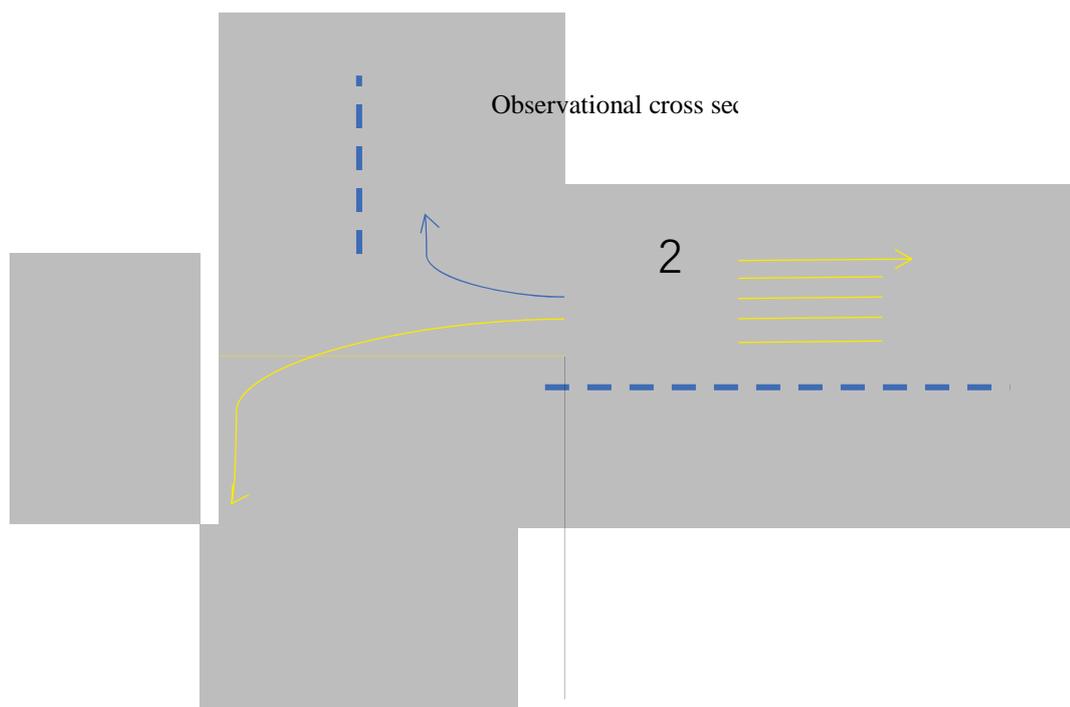


Fig.1. The observational method for each road of one intersection

2.3 Quality control

All observers had been well-trained and supposed to conduct a simulated observation before formal research. Two observers were assigned to record independently at each intersection. A special group checked the integrity and the consistency of their data everyday.

2.4 Related indexes

We defined violation rates as the recorded frequency of a violation in 100 non-motorized vehicles passing the selected roads. Especially, 'no helmet of passengers' was defined as the recorded frequency of passengers without helmets in every 100 passengers.

2.5 Statistical analysis

We used Excel 2016 to establish a database to log in and store our data. We used SPSS 21.0 and SAS to analyze our data. We assessed the statistical significance of differences between violation rates and categorical variables with the Chi-square Test. We did multiple-factor analysis by binary logistic regression analyses. Furthermore, related variables (intersection, weekly time, daily time and behavior) were brought into Latent Class Analysis (LCA) to obtain various association of variables, which were respectively denominated as diverse behavior patterns for further analysis.

3 RESULTS

A total of 144h of recordings (including video recordings) were collected and 25198 non-motorized vehicles were observed at 8 intersections. The number of male was 18185 while the female was 7013, showing a male female ratio of 2.59. The total traffic volume (amount/h) in morning rush, non-rush, evening rush was 185.02, 150.44, 189.50 (Table 2). The overall average traffic volume was larger on weekdays than weekends, and the ratio of weekday and weekend volume was less in the outer ring area (1.05) than that in the inner ring area (1.35). The highest rates of violation appeared in non-helmet (97.89% for passengers and 92.27% for drivers) and rate of carrying passengers followed (9.72%).

The selected roads had some common characteristics (Table 3). Except Pudian Road, other roads had four or more lanes. Most roads had good conditions, but more than a half were lack of a median strip. Although most roads had strips between motorized vehicle lanes and non-motorized vehicle lanes, some strips were broken or opened. The traffic facilities were generally complete.

Table 2 Non-motorized vehicle volume at intersections at different times (count of vehicles per hour)

路口	Weekly time	Morning rush	Non-rush	Evening rush	Total
OH1	weekday	300.00	260.50	290.00	283.50
	weekend	275.50	231.50	271.50	259.50
	average	291.83	250.83	283.83	275.50
OH2	weekday	279.50	186.25	245.25	237.00
	weekend	213.50	207.50	261.50	227.50
	average	257.50	193.33	250.67	233.83
OH3	weekday	192.75	154.75	195.75	181.08
	weekend	186.00	164.00	175.00	175.00
	average	190.50	157.83	188.83	179.06
OH4	weekday	160.50	132.00	156.50	149.67
	weekend	167.50	133.50	175.00	158.67
	average	162.83	132.50	162.67	152.67
IL1	weekday	251.75	127.25	176.25	185.08
	weekend	126.50	112.50	153.50	130.83
	average	210.00	122.33	168.67	167.00
IL2	weekday	139.50	96.50	200.00	145.33
	weekend	92.00	85.00	119.50	98.83
	average	123.67	92.67	173.17	129.83
IL3	weekday	115.25	163.75	192.25	157.08
	weekend	98.50	117.50	136.00	117.33
	average	109.67	148.33	173.50	143.83
IL4	weekday	141.75	103.25	119.25	121.42
	weekend	119.00	110.50	105.50	111.67
	average	134.17	105.67	114.67	118.17

There were various buildings around these roads. However, some observed roads had their own characteristics. For example, IL4 was the only one of the eight intersections with a pedestrian overpass, and Zhoukang Road of OH2 and Lingshan Road of IL1 were lack of a strip between motorized vehicle lanes and non-motorized vehicle lanes.

Table 3 The environment at signalized intersection

Number	Name	Type*	Road Condition	Media n strip	Motor-non-motorized lane separation	Other facilities	The surrounding environment
OH1	Nianjiabang Road	B	Good	No	Yes	Traffic lights	Shops,
	Kangshen Road	B	Good	Yes	Yes	Traffic lights	Banks
OH2	Nianjiabang Road	B	Good	Yes	Yes	Traffic lights	Shopping malls,
	Zhoukang Road	C	Good	No	No	Traffic lights	Residential
OH3	Gongji Road	C	Good	No	Yes	Traffic lights	Residential
	Jingji Road	C	Good	No	Not extend to the intersection	Traffic lights	
OH4	East Renmin Road	C	Potholes	No	Incomplete	Traffic lights	Restaurants,
	Jinghai Road	C	Good	No	Yes	Traffic lights	small shops, hotels
IL1	Minsheng Road	B	Good	No	Yes	Traffic lights	School,
	Linshan Road	D	Non-motorized lane was occupied	No	Yes	Traffic lights	Residential
IL2	Yuanshen Road	B	Good	Yes	Yes	Traffic lights	Gymnasium,
	Yushan Road	C	Good	No	Yes	Traffic lights	Residential
IL3	Dongfang Road	B	Good	Yes	Yes	Traffic lights	Metro stations,
	Pudian Road	E	Good	No	Incomplete	Traffic lights	park, Residential
IL4	South Pudong Road	A	Good	Yes	Yes	Traffic lights,	Business district
	Pujian Road	A turn to C	Good	Yes	Yes	Overpasses	

* 'A' means two-way eight-lane; 'B' means two-way six-lane; 'C' means two-way four-lane; 'D' means two-way two-lane; 'E' means one-way three-lane

The average rate of red-light running, riding against traffic, using dedicated motor vehicle, carrying passengers, no helmet of drivers, no helmet of passengers was respectively 7.15%, 8.11%, 4.29%, 9.79%, 92.27%, 97.89%.

For the spatial distribution, the differences of the rates of six behaviors among intersections were all statistically significant. The differences of the rates of red-light running, riding against traffic, using dedicated motor vehicle, carrying passengers, no helmet of passengers between the inner ring and the outer ring area were statistically significant. For the temporal distribution, the differences of the rates of the former five behaviors among daily time periods were statistically significant except no helmet of passengers. The differences of the rates of red-light running, using dedicated motor vehicle, carrying passengers, no helmet of passengers between weekly time periods were statistically significant (Table 4,5,6,7).

Table 4 The prevalence of behaviors in different daily time (N=25198).

	Morning rush (%)	Non-rush (%)	Evening rush (%)	X ²	P
Red-light running	6.77	8.03	6.83	11.849	0.003
Riding against traffic	8.34	9.03	7.15	20.186	<0.001
Using dedicated motor vehicle	3.36	5.30	4.41	37.249	<0.001
Carrying passengers	8.91	9.44	10.94	22.406	<0.001
No helmet of drivers	92.94	90.56	92.99	41.907	<0.001
No helmet of passengers (n=2478)	97.85	97.65	98.09	17.508	0.825

Table 5 The prevalence of behaviors in different weekly time (N=25198).

	Weekday(%)	Weekend(%)	X ²	P
Red-light running	6.77	7.97	11.735	0.001
Riding against traffic	7.89	8.40		0.174
Using dedicated motor vehicle	4.10	4.72	142.410	0.028
Carrying passengers	8.56	12.68	102.265	<0.001
No helmet of drivers	92.12	91.97		0.705
No helmet of passengers (n=2478)	96.48%	98.87	396.924	<0.001

Table 6 The prevalence of behaviors in inner and outer ring area (N=25198)

	Inner ring area (%)	Outer ring area (%)	X ²	P
Red-light running	6.32	7.70	17.315	<0.001
Riding against traffic	8.10	8.11		0.979
Using dedicated motor vehicle	6.16	3.05	142.410	<0.001
Carrying passengers	4.94	13.02	446.412	<0.001
No helmet of drivers	91.90	92.52		0.069
No helmet of passengers (n=2478)	95.17	98.58	17.508	<0.001

Table 7 The prevalence of behaviors in different signalized intersections (N=25198).

	Inner ring area (%)				Outer ring area (%)				X ²	P
	IL1	IL2	IL3	IL4	OH1	OH2	OH3	OH4		
Red-light running	8.07	5.50	5.86	5.76	1.60	1.83	2.24	22.62	1988.302	<0.001
Riding against traffic	5.95	10.16	5.99	10.15	9.79	11.82	6.05	6.60	170.035	<0.001
Using dedicated motor vehicle	10.58	8.18	2.61	3.69	5.93	2.33	2.00	2.97	476.071	<0.001
Carrying passengers	4.98	3.71	4.79	5.89	9.86	14.12	12.95	14.33	496.730	<0.001
No helmet of drivers	92.47	94.26	89.69	91.45	94.80	92.83	91.41	92.11	68.022	<0.001
No helmet of passengers (n=2478)	96.90	98.73	84.82	98.87	94.10	99.56	99.38	98.18	115.335	<0.001

Table 8. Logistic analysis of relevant factors of riding behaviors (N=25198)

	Red-light running	Riding against traffic	Carrying passengers	No helmet of drivers
	1	1	1	1
	0.257 (0.208- 0.317)	1.395 (1.251-1	2.621 (2.326-2.953)	1.328 (1.170-1.508)
Town	<0.001	<0.001	<0.001	0.053
	(1.729-	0.625 (0.539-0.728)	3.010 (2.701-3.354)	0.918
		0.376		2.799
Date	<0.001	0.008	<0.001	0.001
	(0.751-	0.943	0.675 (0.619-0.736)	1.021
		0.840		0.027
	1	1	1	1
	(0.867-	1.164	0.765 (0.692-0.844)	0.914
rush	0.005	0.004	<0.001	0.890
	1.885 (1.052- 1.335)	1.288 (1.150-1	0.813 (0.733-0.902)	0.722 (0.645-0.809)
		1.237 (1.071-1.429)		1.043 .572-1.902)

In addition, in order to investigate the factors associated with six behaviors, a binary logistic regression analysis was conducted, including sites (Huinan Town, Zhoupu Town, the inner-ring area), dates (weekdays and weekends) and daily time (morning-rush, non-rush and evening-rush). The results indicated that all three factors had a significant influence on red-light running. The odd ratios showed that red-light running was more likely to appear on Zhoupu Town, weekends and non-rush hours. Sites and daily time had a significant influence on riding against traffic. The odd ratios showed that riding to the opposite direction was more likely to appear on Huinan Town and off-rush. Sites, weekly time and daily time had a significant influence on using dedicated motor vehicle. The odd ratios showed that using dedicated motor vehicle was more likely to appear on the inner-ring area, weekends and non-rush hours. Sites, weekly time and daily time had a significant influence on carrying passengers. The odd ratios showed that carrying passengers was more likely to appear on the outer-ring, weekends and evening-rush. Sites and daily time had a significant influence on no helmet of drivers. Sites and weekly time had a significant influence on no helmets of passengers (Table 8).

Drivers and passengers without helmets had extremely high rate (>90%) both of time and sites in six observed behaviors. The potential strong interactions with other variables may interfere the LCA to the others. Since, we selected the data that did not involve these two behaviors in LCA. Four groups of non-motorized vehicle behavior patterns were recognized by LCA. They were denominated in accordance with the sequence of probability and each conditional probability as: Carrying passengers along Nianjiabang Road in evening-rush on weekdays, Riding to the opposite direction at the outer ring area and IL1 in daily time on weekdays, Running the red light at OH2 in daily time on weekdays, Using dedicated motor vehicle at the inner-ring area in non-morning-rush on weekdays. When combining the four groups with eight intersections, we found that the highest probability of carrying passengers was at OH1 in evening-rush on weekdays (group 1). The highest probability of riding against traffic was at the outer ring area and IL1 on weekdays (group 2). The highest probability of red-light running was at OH2 on weekdays (group 3). The highest probability of using dedicated motor vehicle was at IL3, IL4 and OH4 on weekdays (group 4). IL2 presented a low probability in these four behavior patterns (table 9). Furthermore, we added the probabilities at each intersection of four patterns respectively and made a comparison between the inner ring and the outer-ring. The results showed that the probabilities of the first (0.7986), the second (0.6011) and the third (0.6470) pattern at the outer ring area were significantly higher than those at the inner ring, while the probability of the fourth pattern was not significantly different between the inner ring (0.5730) and the outer ring area (0.4269).

Table 8 LCA of riding behaviors in Shanghai Pudong New District.

Classify		1	2	3	4
Inner ring area	Conditional probability	0.3337	0.2763	0.2437	0.1463
	IL1	0.0717	0.1493	0.0960	0.1026
	IL2	0.0454	0.0685	0.0760	0.0564
	IL3	0.0523	0.0754	0.1160	0.2532
	IL4	0.0320	0.1057	0.0649	0.1608
Total in inner ring*		0.2014	0.3989	0.3529	0.5730
Out ring area	OH1	0.2601	0.1468	0.0616	0.0915
	OH2	0.2443	0.1361	0.5283	0.1155
	OH3	0.1844	0.1865	0.0327	0.0693
	OH4	0.1098	0.1317	0.0244	0.1506
	Total in Outer ring**	0.7986	0.6011	0.6470	0.4269
Weekday		0.6058	0.6794	0.6604	0.6654
Weekend		0.3942	0.3206	0.3396	0.3346
Morning rush		0.3205	0.3627	0.3335	0.2754
Non-rush		0.2763	0.3191	0.3219	0.3540
Evening rush		0.4032	0.3182	0.3446	0.3706
Red-light running	Yes	0	0	1	0
Red-light running	No	1	1	0	1
Riding against traffic	Yes	0	1	0	0
Riding against traffic	No	1	0	1	1
Using dedicated motor vehicle	Yes	0	0	0	1
Using dedicated motor vehicle	No	1	1	1	0
Carrying passengers	Yes	1	0	0	0
Carrying passengers	No	0	1	1	1

* Total in inner ring= Sum of the conditional probabilities of certain behavior patterns occurring at four intersections of the inner ring

** Total in out ring= Sum of the conditional probabilities of certain behavior patterns occurring at four intersections of the out ring

4 DISCUSSION

Non-motor vehicles mainly include bicycle, e-bike, tricycle, animal drawn cart, wheelchair, children's car, trolley, battery car and fuel tanker (). Specially, e-bike and bicycle are dominate in Shanghai (1). Therefore, this study mainly focuses on above two.

In the 1970s, Planned Behavior Theory (PBT) was widely used in traffic safety. In this theory, attitudes are defined as 'the evaluative dimension of a concept'-e.g. is the concept 'good' or 'bad'? – and they are described as mediating evaluative responses (). TPB also thinks that accurate perceptual behavior control reflects the actual control condition, so it can be used as a substitute measure for the actual control condition (). According to this theory, we believe that riding behaviors can directly reflect personal and non-personal factors that influence behaviors. In addition, there are the following reasons for taking riding behavior as the research object: 1) Behaviors are more likely to be observed and recorded in a smaller space and time range than injuries; 2) The KAP model considers that information is a necessary condition for behavior change (). In other word, after exploring the rules of behavior occurrence and its triggers, dangerous behaviors can be controlled by corresponding health education, so as to reduce injuries and promote public health. Studies have shown that violation of traffic lights, occupation of motor vehicle lanes, riding against traffic, carrying passengers, non-wearing helmet,

The similar sampling protocol of this study has been adopted by several traffic safety themed studies (.,). We assumed that risky riding behaviors' occurrence would be proportional to traffic injuries. So that traffic injured data could be used to verified the representativeness of the current sampling protocol. A three-year non-motor vehicle involved traffic injury dataset (2014-2016) was retrieved from the traffic police system and 556 events were identified. The total injury incidents jumped to double digit on 7AM, then maintained on the plateau with small fluctuations and sharply returned to single digit from 10 PM. The events reported across the designed three-hour observation time windows were 109 events, which were counted for 25.1% of the events reported in a total of eleven hours time window from the start hour (8 AM) to the end hour (7PM) of the observation with 27.2% of sampled time (3 hours vs. 11 hours), or 23.2% of the events reported in a total of fourteen hours time window from the sunrise hour (5 AM) to the sunset hour (7PM) of the observed season with 21.4% of sampled time (3 hours vs. 14 hours). The reported risky riding behaviors' counts times four could be the approximates of the corresponding behaviors would be identified during daylight at the selected cross sections.

This study used non-participatory observation, and provided the prevalence and spatial and temporal characteristics of 6 riding behaviors of non-motor vehicles in Pudong new area. In average, the prevalence of red-light running, riding against traffic and using dedicated motor vehicle lane were 7.15%、8.11%、4.29%, which were higher than the video observation results in Suzhou, China (): 4.8%、3.4%、1.9% in turn; and the prevalence of carrying passengers was 9.79%, which was lower than the result in Suzhou (12.4%); the prevalence of no helmet of passengers, no helmet of drivers was 98.89% and 92.27%, which was close to Suzhou (the prevalence of no helmet of drivers was 91.0%).

In temporal distribution, this study found that the prevalence of red-light running was higher in weekends and non-rush hours. Zhao et al. reported the prevalence for red-light running was high in the morning, noon, and Tuesday in Jinhua, Zhejiang province (7). Whilst Yan et al. showed it is high in non-rush hours and working days in Changsha, China (17). Logistic analysis found the prevalence of riding against traffic was high in morning rush. It is consistent with the result in Nanjing and Kunming (14). The prevalence of carrying passengers was high in evening rush and weekends. Study in Jinhua, Zhejiang province indicated that carrying passengers was more happened in morning, non-rush hours and Sunday, but the prevalence in Pudong was significantly lower than in Jinhua (15.22%). This study also suggested that the prevalence of using dedicated motor vehicle lane was high in weekends and non-rush hours. Du et al. thought riding on a vehicle lane was related to the registration (19). The phenomenon, the rate of no helmet wearing was extremely high in any time, was similar with the result (97.8%) of Yang in Suzhou (18). Furthermore, this study found that the prevalence of no helmet of passengers was high in weekends and evening rush hours, and no helmet of drivers was slightly higher in evening rush hours. These differences may be attributed to differences in safety culture, road facilities and management between Shanghai and other cities (17).

In spatial distribution, this study found that the prevalence for red-light running, carrying passengers and no helmet of passengers in the outer ring area was higher than the inner ring area, but lower for

riding in a motor vehicle. Besides, riding against traffic and no helmet of drivers was also higher in the outer ring area without statistical significance, but it implied the susceptibility to dangerous behaviors in the outer ring area. There are few studies on the spatial characteristics of road using behavior of non-motor vehicles in China, thus there were poor data to compare. However, the differences in economy, population and traffic volume between Suzhou and Jinhua were similar with the differences between the inner ring and out ring area in Pudong, so use these two cities as a contrast. Compared with Suzhou, Jinhua has a higher prevalence of carrying passengers, red-light running and riding against traffic (Jinhua: 15.22%, 10.01%, 4.99 & Suzhou: 12.4%, 4.8%, 3.4%) (7, 18). This result is consistent with the differences between the outer ring area and the inner ring area, but the gaps is different in Pudong. There are different types of dangerous behaviors in the inner and the outer ring area, which may be related to the road environment, traffic management, economy, education and safety awareness (.).

In the 1960s, William Haddon Jr developed the HADDON Matrix model. In this model, three factors of the interaction of traffic accident in the three stages (before, during and after collision) are described: person, vehicle and environment (.). Studies in Australia also pointed out (5): The reasons of road traffic accidents caused purely by human, vehicle and road environment accounted for 67%, 4% and 4% respectively. It was also noted that about 24 % of accidents are caused by human behaviors which were influenced by road conditions. In a word, although there were few road traffic accidents purely caused by road environment, many road traffic accidents were caused by the adverse effects of the road environment to drivers' psychology, physiology and behavior. Chen et al. thought as the subject of traffic, people is one of the most important factors of road traffic injury (.). LCA showed that the probability of carrying passengers in evening rush hours on weekdays, riding against traffic on weekdays and red-light running on weekdays in the outer ring area was all higher than in the inner ring area. Zhao reported that the influence of traffic volume on non-motor vehicle behaviors is more significant at the signalized intersection (.). In the field, we found that it was easy to congest due to larger traffic volume in weekdays. Thus, it would cost more time to cross the intersection. Additionally, people rushed to work. These increased the possibility of violation. Meanwhile, the perceived danger of non-motor vehicle users was much greater than that of the outer ring area, because the traffic volume of the inner ring area (especially the motor vehicle) was significantly greater, which was easy to account for the above characteristics.

The possibility of riding against traffic was the highest at OH3 signalized intersection in any time on weekdays, which is close to the residential and not designed median strip and the motor-non-motorized lane strip extension is insufficient. In this case, riding against traffic is easy to happen. Otherwise, the clear purpose of the work (avoid being late and rush home) increased a perverse incentive. The possibility of red-light running was highest at OH2 signalized intersection adjacent to Wanda Plaza on weekdays, where the road environment is complex, the non-motor vehicle volume is large, and the signal lamp cycle is long. At this intersection, more time cost to wait for green light, which lead to the susceptibility of red-light riding. On the other hand, Han et al. emphasized that the longer to wait, the easier it is to run a red light (.). The possibility of using dedicated motor vehicle was highest at IL3 signalized intersection in any time on weekdays. This intersection is next to subway station, in which the motor-non-motorized lane strip is fragmentary, and non-motorized lane is narrow. In this case, the possibility of using dedicated motor vehicle increases.

In the limited traffic space, the rapid development of motor vehicles and non-motor vehicles is bound to form a complex mixed traffic phenomenon. Traffic accident data from public security departments in Suzhou, Nanning, Hangzhou and other cities as well as the investigation of hospital injury cases in China showed that e-bike accidents account for a large proportion of traffic injuries, which has become one of the major hidden dangers of road safety (,,,) This study was carried out under the background of "2016 Shanghai Traffic Renovation", and covered main risk factors referencing to domestic and foreign studies. Our study introduced 6 types of non-motor vehicle riding behaviors and provided the prevalence with abundant data. But there are several limitations: 1) we understand a huge gap exist between selected risk behaviors and injury outcomes from a causal perspective. Hence, it is not sufficient to explain the occurrence level of road traffic accidents by comparing behaviors; 2) Unobserved factors (such as age) may also post impact on the occurrence of road traffic accidents, our analyses were limited due to the non-participatory observation; 3) Although our study can better explain the level of traffic accident in the target area, our results are limited by time and location and specific road environment, so it should be cautious to extrapolate.

5 CONCLUSION

Riding behaviors of non-motor vehicle demonstrate spatial and temporal variations. Four patterns combining weekly time, daily time, intersections and behaviors are identified.

6 POLICY IMPLICATION

Although Shanghai has implemented the non-motor vehicle registration system in 2014, there are no clear and strict penalties for non-motor vehicle violations, which is the main reason for high level occurrence of road traffic accidents. Therefore, increasing the strength of punishment may play an important role in reducing non-motor vehicle accidents. In addition, based on the different characteristics of riding behaviors of non-motor vehicles at different intersections, time periods and dates, it suggests that department traffic should strengthen management for violation of traffic lights and manned violations in the outer ring area and for using dedicated motor vehicle in the inner area. Meanwhile, strengthen punishment for riding against traffic in both areas. Otherwise, promote traffic management in rush hours. Furthermore, safety education should be intensified for no helmet driving.

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Motorized two- wheeler mobility and safety: past, present and future.

Maria Isabel Gutierrez M.^{1a}

Abstract

Almost all papers about motorized two-wheelers (MTW) vehicles start with these statements: Between 1990 and 2020, it is estimated that road traffic crashes will move from the ninth to the third largest cause of death and disability globally. Also, over 90% of this, death and disability occurs in the low and middle income countries (LMIC), in which a large proportion of vehicles are two or three wheeled. This paper overviews the facts related with research, findings and legislation related with MTW. Awareness exists that these safety issues in MTW are due to the rapidly increasing population of cities worldwide, transport systems and road infrastructure which have not met the demand. In consequence, the use of MTW has increased, particularly as a method of formal and informal transport.

We are near the 2020, do the MTW crashes largely contribute to the fact that road traffic crashes have moved to be the third cause of death? Even though, road traffic injury in 2017 is still the 8th leading cause of death for all age groups, it is now the first cause of death in the 5-29 age group. It is also three times higher death rates in low-income countries than in high-income countries. Globally, deaths with those using two and three wheelers covering 28%. In South-East Asia and the Western Pacific, the majority of deaths are among riders of MTW who represent 43% of all deaths. In the Americas 23% and in Colombia is the 48.7% from the road traffic deaths. The main users of MTW are in the 5-29 age group mainly in LMICs. Urgent attention is needed in the current child and young adults political prevention agenda, which has been mainly neglected in road safety policies.

What has been done to prevent morbidity and mortality due to MTW crashes? One of the biggest contributions for injury prevention among MTW users is the compulsory helmet use. Helmets can reduce fatal injury by around 44%. But only 49 countries have helmet laws that align with best practice according with the 2018 Global Status Report on Road Safety. Other prevention measures are discussed in this paper. What are the authorities, public health and other sectors involved accomplished to decrease motorcycle crashes? Sustainable Development Goals for Road Safety (SDG) included in number 3 the goal that by 2020, to halve the number of global deaths and injuries from road traffic crashes, besides, Global Voluntary Performance Targets for Road Safety Risk Factors and Service Delivery Mechanisms, have been set in 2017.

Target 7: By 2030, increase the proportion of motorcycle riders correctly using standard helmets to close to 100%. Regardless of a better understanding of the problem and its solutions, political will to carry out the necessary actions is still lacking. Too many countries quietly lack funded strategies, lead agencies and good laws that are enforced mainly to protect or give alternatives to their increasing MTW users.

What is the future with MTW safety? Experience shows that sustained gains in road safety only happen when a more integrated approach is taken. Going forward, it will be important to learn from experiences to date and address the factors reported for researchers and experts grouped from around the world. Politicians and decision makers should listen to these groups to make more efficient their impact in their own communities to reduce injuries and deaths among MTW users. There is an urgent need for governments to scale up their road safety efforts in order to live up to their commitments made in the SDG Agenda 2030.

Preventative actions involve mounting surveillance systems, health promotion including the enforcement of effective personal protective equipment, smart road designs, improved MTW safety standards and the creation and enforcement of public policies and laws should be continuing in the near future and years to come improving rider's safety. MTW users safety should be addressed through a range of actions, improving awareness of MTW riders by other road users, encouraging research and technical developments aimed at increasing MTW's safety and reducing the consequences of incidents, such as standards for personal protective equipment, airbags, the use of relevant vehicle technical improvements such as installation of advanced

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braking systems, appropriate anti-tampering measures, roadworthiness testing and improvement of road infrastructure to MTWs and encouraging to continuing focus enforcement on speed, drink and driving, helmet use, tampering and riding without a proper MTW license.

This paper discusses what is known, what is used now and what is proposed to do in a near future to improve safety among MTW users.

Keywords: safety; motorized two-wheeler vehicles; motorcycles; motorcycles mobility

Trauma Care: A Continuum of Care

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Abstract

Trauma care has been compartmentalized into First aid, Bystander care, Pre hospital care, Emergency care, Definitive levels of care and rehabilitation. However, from the time of the impact at the injury site the patient is evolving physiologically and coping mechanisms of the body are responding successfully or unsuccessfully to the situation. Effective trauma care needs a *continuum* of care until the patient is back to his preinjury status. This paper discusses the need to evolve such a process and reviews recent advances in our understanding of the care process and how we need to improve it and how there is a pressing need to generate valid evidence on what we do in emergency care.

Keywords: Trauma Care, Emergency care, ATLS, Prehospital care, trauma system

1. INTRODUCTION

To begin, the story of a real patient: A young 14 year girl jumped off the 5th floor of the backside of a hospital building. Fortunately, a security guard saw her fall down. She came hurtling down and landed on her buttocks. As the alarmed security ran to her side, she kept crying and sitting as she had fallen. The security guard asked her name, she replied, fully conscious and continued to answer questions. In less than 10 minutes a trolley had come to carry her to the Emergency room in 10 minutes, where she continued to talk, had a Pulse rate of 110 per minute, BP of 100 mm. she had no external bleeding but a boggy swelling was already visible on both sides of her hips. Another 10 minutes her pulse was not palpable and BP was not recordable. In five more minutes she was gasping. Soon she had to be intubated and needed Ambu® Bag ventilation. An intravenous line was placed, one in the upper limb and one in the lower limb. In less than forty minutes of being discovered conscious and talking at the fall site she had arrested, and despite repeated CPR and Defibrillation she was declared dead.

Her post mortem radiographs revealed a shattered Pelvis, broken sacrum, and a broken hip on one side. She died of uncontrolled massive bleeding into her pelvis. The fall from 4th floor was a significant fall, very little chance that she could have survived that fall. She took only 40 minutes to manifest the consequences of her serious injury. The security guard was appalled that we could not save a patient found talking and fully conscious. Seriousness of the fall was estimated in this case not on how she was found but by the fact that she fell from the 5th floor, there is no way that such a fall could be survived by anyone as the energy transfer of a fall from that height would be beyond survival (unless someone had put a protective net to cushion her fall).

Trauma is like any disease except that instead of a bacteria or a virus the causative agent is energy. Higher the acute transfer of energy greater is the damage. Depending on which organ system is injured the manifestation may vary and the time taken also varies. Traumatic Brain Injury leads to loss of consciousness immediately from direct concussion, while a delayed loss of consciousness can happen from intracranial extradural or subdural collection of blood. Both TBI and Spinal cord injury can lead to long term consequences from paralysis and many such patients in low income countries die from chronic renal disease caused by an incontinent bladder and inappropriate bladder management.

Acute rupture of a great vessel may have dramatic death while rupture of intestines may take more than 48 hours to manifest with infection in the abdominal cavity (peritonitis). The initial anatomic damage from acute energy transfer leads to acute haemorrhage. This leads to systemic physiological compensations. Sometimes the physiological changes cannot cope, and then pathological changes take over. These changes are brought in through several mediators and many of these serve as markers for irreversible damage.

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So, as explained, the consequences of trauma, like any other disease, take time to evolve. Most physicians and surgeons often do not recognise this aspect of trauma. If the patient lands in a definitive care facility before the full impact of trauma has manifested there is a possibility that some of the clinical or diagnostic features may go unrecognized. Therefore, it is useful to know the nature of trauma, and how the injury happened in a trauma case to understand the severity of injury and understand the outcome of trauma. The outcome may vary depending on many factors including the age of the victim, co-morbidities, time to treatment, type and appropriateness of care given, level of support given for rehabilitation back to normal including psychological support, and finally his integration back into his primary job and back into society. Many trauma patients are not fit to join their primary jobs, even many months and years after their injury and therefore, there is a need to build in vocational and social integration before we can say the consequence of trauma is mitigated.

Outcome measures often deal with time to care or time to definitive surgery or time out from ICU or mortality statistics. While these are indirect measures, however, true outcome of trauma depends on long term function of the victim back in the community. There are very few long-term studies that deal with outcome of trauma. This true not only in low- or middle-income countries but also in high income countries. Despite the presence of seemingly sufficient resources and the evidence-based benefits of trauma systems, a 2017 review of trauma systems globally found only nine of the 23 high income countries had a well-defined and documented national trauma system (1). Although there is a lack of definitive evidence to support many of the current recommendations for the acute care of trauma patients, the historical development of trauma systems, their long experience and even the existing controversies, can help to establish other critical pathways and can guide performance evaluations so necessary to improve outcomes (2).

2. METHOD

This paper is based on author's experience of dealing with multiply injured patients over the last 30 years and a survey of literature available from PubMed and other sources that looks at different aspects of emergency care of trauma victims. This document is not a systematic review of literature.

3. TRAUMA CARE 'BOXED IN PACKAGES'

Historically care of the injured evolved in the battlefield and the idea of a 'flying ambulance' – a horse driven carriage to carry the injured to the non- combat area for care was conceived by Dominique Jean Larrey, a surgeon to the Imperial guard of Napoleon in 1792. The invention of motor car led to motorized vehicles instead of horse carriages to carry patients from the roadside to the hospitals. Evolution of modern medicine as we see it today happened only in the last 60 -70 years. The Ambulance which in the 50's provided little more than first aid now carries a vast number of technologies and equipment for interventions. Prehospital EMS encompasses a range of related activities, including dispatch, response to the scene by the ambulance, treatment and triage by EMS personnel and transport to a care facility via ground and/or air ambulance (3).

With the evolution of Cardio Pulmonary Resuscitation (CPR as it is commonly known) in the early 60's, EMS services rapidly evolved across US to become widespread in the 70's and further evolved with the introduction of ATLS or Advanced Trauma Life Support Programme. Started by James K Styner in 1978 in Auburn, Nebraska the first prototype Advanced trauma Life Support Course was held.²

Each of the decades thereafter saw advances in technology to be used on site, within the Ambulance, at the Emergency Room, in the diagnostic laboratories, Imaging Modalities (CT, USG, MRI), in the intensive care facilities, in the operating room, in rehabilitation. While evolution has helped our understanding, in many centres each area operates in silos without interacting with each other. We now see 'boxed in' specialties that deal with areas 1. Bystander Care 2. EMS ambulance Service (Run by different agencies), 3. Emergency Room/ Casualty Services, 4. Intensive care Services, 5. In-hospital Trauma team services to provide in-hospital care 6. Rehabilitation services, 7. Community and social services for long term disability rehabilitation. Lack of a unified accountability disperses responsibility for system failures and perpetuates divisions between public safety and medical-based emergency and trauma care professionals (3).

Current understanding indicates that care of the critically injured begins well before the patient arrives at a large academic trauma centre. It is important to understand the *continuum* of care from the point of injury in the prehospital environment, through the local hospital and retrieval, until arrival at a trauma center capable of definitive care (4). Trauma care does not end there. Similar recommendations were made almost three decades back by McMurtry (5) and his colleagues who said 'Trauma care is governed by two underlying principles:

² https://en.wikipedia.org/wiki/James_K._Styner

early definitive management and a continuum of treatment from the time of injury to the return to the activities of daily life.' Most important, a team approach is necessary in the treatment of the trauma patient. Medical care has become complex with need for specialised teams to care for the severely injured.

For a number of such critical care conditions, optimal management not only relies heavily on the talents of highly coordinated, multidisciplinary teams, but it also may require shared responsibilities across a continuum of longitudinal care involving numerous specialties and departments. This continuum usually needs to begin in the prehospital and ED settings with management extending through specialized in-hospital diagnostic and interventional suites to traditional ICU and rehabilitation programs (6). The authors Ghosh and his colleagues discuss the basis and rationale for the 'critical care cascade' concept, which contends that the optimal management of critically ill patients should be a *continuum of care through the healthcare system*.

4. PREHOSPITAL AND TRAUMA CARE GUIDELINES

Several types of guidelines have evolved over time. They have been classified as Basic level and Advanced level based on the level of intervention at the field level that each system is capable of. Ambulances have been categorised as Basic Life Support (BLS) and Advanced Life Support (ALS) ambulances based on the equipment and skills of the Emergency Medical Technician available on board. In high income countries Advanced Trauma Life Support (ATLS) programme has gained popularity and most surgeons go through an ATLS training programme. While many in Europe undergo the ATLS training, German trauma societies have got together and evolved their own guidelines for management of serious and multiply injured patients.

4.1. ATLS

As emergency care evolved most of what was done was added empirically based on what was felt to be useful. It was neither based on hard evidence nor was it based on any consensus. One of the earliest consensus based guideline was ATLS guideline. This has gone through several iterations of development and the American college of Surgeons committee on trauma that approves this has released the revised 10th edition of ATLS in June 2018.³

While the earlier versions were predominantly consensus based the newer versions have been incorporating evidence based practices. ATLS also has a Prehospital version called the PHTLS and a version for Nurses. The ATLS program provides participants with a safe, reliable method for immediate management of the injured patient and the basic knowledge necessary to:

1. Assess the patient's condition rapidly and accurately
2. Resuscitate and stabilize the patient according to priority
3. Determine if the patient's needs exceed a facility's capacity
4. Arrange appropriately for the patient's inter-hospital transfer (who, what, when, and how)
5. Assure that optimum care is provided and that the level of care does not deteriorate at any point during the evaluation, resuscitation, or transfer process.⁴

4.2. S3 Guidelines

S3 – Guidelines are guidelines on Treatment of Patients with Severe and Multiple Injuries issued by lead German Trauma Society in association with 10 other German surgical societies including the Radiology Society. Most of the recommendations were approved with "strong consensus" (agreement of > 95% of participants). The guidelines also evaluate quality outcomes and have listed the criteria for these in the prehospital, Emergency Room and overall in the hospital.

Process quality for evaluation in the prehospital phase

Duration of prehospital time between accident and hospital admission for severely injured patients with ISS \geq 16
Intubation rate in patients with severe chest injury (AIS 4-5) by the emergency physician
Intubation rate in patients with suspected traumatic brain injury (unconscious, Glasgow Coma Scale [GCS])

Process quality for evaluation of emergency room management

Time between hospital admission and performance of a chest X-ray in severely injured patients (ISS \geq 16)
Time between hospital admission and performance of an ultrasound scan of the abdomen/chest in cases of severe trauma (ISS \geq 16)

³ <http://bulletin.facs.org/2018/06/atls-10th-edition-offers-new-insights-into-managing-trauma-patients/>.

⁴ <https://www.facs.org/quality-programs/trauma/atls/about>.

Time until performance of a computed tomography (CT) scan of the cranium (CCT) in prehospital unconscious patients (GCS \leq 8)

Time until performance of a full-body CT scan on all patients, if carried out

Time from emergency admission arrival to completion of diagnostic study in severely injured persons if this has been completed normally (ISS \geq 16)

Time from emergency admission arrival to completion of diagnostic study in severely injured persons if this has been interrupted due to emergency (ISS \geq 16)

Outcome quality for overall evaluation

Standardized mortality rate: observed mortality divided by the expected prognosis based on RISC (Revised Injury Severity Classification) in severely injured persons (ISS \geq 16)

Standardized mortality rate: observed mortality divided by the expected prognosis based on TRISS (Trauma Injury Severity Score Method) in severely injured persons (ISS \geq 16)⁵

5. INTERVENTIONS IN CARE OF THE INJURED

In the 60 years or so of the EMS a lot of technology has evolved around the care of the injured. How has it influenced the outcome? Here in lies the main challenge. How do we objectivise the outcome and what parameters do we select? How long do we wait before we know the end point of outcome evaluation? While many of these are serious research issues, this section looks at some of the current literature on interventions in care of the injured.

5.1. Access to injured

In many low income countries, the police come into the scene first only then are the other providers of care called in. The traditional response paradigm of sequential response and scene entry by law enforcement, first responders, and emergency medical service (EMS) personnel produced delays in care and suboptimal victim outcomes (7). Universal access phone number like 911 known in case of emergency is simple with all modern telephone systems; however, this is not implemented across countries and even within states multiple numbers have to be accessed for emergency access.

5.2. Triage

Many injured patients are taken to hospitals that neither have the capacity, equipment or expertise to do complete management of their injuries. This leads to unnecessary delay in definitive treatment of the patient. Triage is a French word that means sorting. Triage is used to sort patients according to the severity of their injuries and risk to their life and match them to the care urgency and facility to which they are dispatched. Triage can be difficult and recognizing the evolving nature of the consequence of injury, a given patients triage category may change rapidly if the full picture is not understood.

Three phases of triage have emerged in modern healthcare systems. First, prehospital triage in order to dispatch ambulance and prehospital care resources. Second, triage at scene by the first clinician attending the patient. Third, triage on arrival at emergency department or receiving hospital (8). To reduce the errors in Triage different services use different protocols. Kane's "revised" checklist provided the largest improvement in odds against needing a trauma center when the triage instrument is negative. Of the triage instruments with a sensitivity greater than 70%, the respiratory/systolic pressure/Glasgow Coma Scale (RSG) score provided the largest improvement in odds for needing a trauma center when the triage instrument is positive (9). A CDC panel in 2009 also recommended transport to a trauma center if any of the following are identified: Glasgow Coma Scale of <14 , Systolic BP <90 , Respiratory rate <10 or >29 breaths per minute (Children, 20 in infants <1 year). The panel also recommends transport to a trauma center if the following were seen: 1. all penetrating injuries to head, neck, torso, and extremities proximal to elbow and knee; 2. flail chest; 3. two or more proximal long-bone fractures; 4. crushed, degloved, or mangled extremity; 5. amputation proximal to wrist and ankle; 6. pelvic fractures; 7. open or depressed skull fracture; or 8. paralysis.

In addition, the committee also recommended the mechanism of injury criteria: falls from height greater than 20 feet (6.1 Metres) > 10 feet for children, High-Risk Auto Crash --- Intrusion of >12 Inches at Occupant Site or >18 Inches at Any Site: High-Risk Auto Crash; Ejection (Partial or Complete) from Automobile, Death in Same Passenger Compartment: Auto Versus Pedestrian/Bicycle Thrown, Run Over, or with Significant (>20 mph) Impact: Motorcycle Crash >20 mph: and elderly and those on anticoagulants/ bleeding disorders (10). Some of

⁵ http://www.dgu-online.de/fileadmin/published_content/5.Qualitaet_und_Sicherheit/PDF/20110720_S3_LL_Polytrauma_DGU_eng_f.pdf

these have been further modified in the 2012 revision of this (11), for example GCS<14 is now changed to GCS<13.

These are technical criteria which cannot be expected to be known by lay persons, therefore, these are possible only in a mature trauma system with a mature EMS system in place. Until then this capacity will have to rest with the trauma teams operating from within hospitals.

5.3. Airway

Maintaining a clear airway is an essential part of basic life support. Can be problematic in patients with Traumatic Brain Injury(TBI), patients with facio-maxillary injury and those with cervical spine injury.

Breathing: assessment of voluntary breathing is important to assess the functioning respiratory centre and need for ventilator support. Airway related complications were defined as hypoxemia, unrecognized esophageal intubation, regurgitation, cardiac arrest, ETI failure rescued by emergency surgical airway, dental trauma, cuff leak, and main stem bronchus intubation. Of the patients included, 23.5% experienced at least one complication (12). Patients with severe TBI who needed to be intubated reportedly had poorer outcomes (13).

5.4. Out of hospital Cardiac Arrest

A trauma patient is usually younger and a majority have good Myocardium with good Myocardial function quite unlike a patient with MI or Angina. So, a cardiac arrest in such a patient is the result of continued hypoxia, severe exsanguination or severe Neuronal damage from Traumatic Brain Injury or Spinal cord injury. The Outcome of outside hospital Cardiac arrest in a traumatic patient is usually poor (14-16). Cardiopulmonary resuscitation itself is a psychomotor skill that needs to be learnt, practiced regularly and periodically retrained to keep the skills correct.

CPR technique itself has changed from the original description of Mouth to mouth breathing followed by compression, research has shown that the chest compression and spontaneous expansion is sufficient to provide the required oxygenation for the lungs. The newest development in the CPR guideline is a change in the basic life support sequence of steps from "A-B-C" (Airway, Breathing, Chest compressions) to "C-A-B" (Chest compressions, Airway, Breathing) for adults. Also, "Hands-Only (compression only) CPR" is emphasized for the untrained lay rescuer (17, 18). Mechanical devices have been invented to provide for mechanical compression of chest CPR using machines but there are no advantages over manual compression (19).

5.5. Bleeding control

Uncontrolled haemorrhage is the leading cause of potentially preventable death. Improving our ability to control haemorrhage may represent the next major hurdle in reducing trauma mortality. New techniques, devices, and drugs for haemorrhage control are being developed and applied across the continuum of trauma care: prehospital, emergency room, and operative and postoperative critical care (20).

Haemostatic agents are currently used in the form of special granules or soaked gauze. Their use is particularly advantageous in difficult body location (e.g. on neck, armpit or groin), where other methods of bleeding control are impossible to use or fail (21).

Tranexamic acid, a very old drug recently has found use as an effective drug to control bleeding. This was started after a major multicentric trial (CRASH 2 trial) of the drug (22, 23). It is increasingly being used in ambulances around the world (24). It is given as a 1gm bolus dose. The authors recommend considering a 1 g TXA bolus en route to definitive care in high-risk patients and withholding subsequent doses until hyperfibrinolysis is confirmed by thromboelastography (25). Available data support the efficacy and the safety of TXA. High-level evidence supports its use in trauma and strongly suggests that its implementation in the prehospital setting offers a survival advantage to many patients, particularly when evacuation to surgical care may be delayed (26). It is also recommended by the ATLS 10th Edition.

5.6. Intravenous Fluids

The concept of replacing loss of blood in trauma with Saline or Ringers started sometime in the 60's. Used as a volume replacer for lost blood the ATLS protocol recommended 1 – 2 Litres of Ringer's in a severely injured patient. Randomised trials started showing no benefit in the use of Prehospital Intravenous fluids(27). Several reports show the lack of any benefit of intravenous fluids on injured patients (28-30). The latest ATLS Protocol mentions 'The initial resuscitation with crystalloid fluid still begins with a 1 liter bolus of warmed isotonic fluid. Large volume fluid resuscitation is not a substitute for prompt control of hemorrhage. Infusion of more than 1.5 litres of crystalloid fluid has been associated with increased mortality'(31).

5.7. First aid

All that is done as first intervention done to a victim of trauma to protect his life and limb and to reduce suffering is called first aid. Often the person most likely to be around at the time of a road crash is likely to be a lay person. However, even lay persons can provide valuable help by calling for expert help, getting the patient to a safer place and positioning the patient and splinting him for reducing pain. They can also help reduce bleeding by simple elevation or compression bandage of the wound. They could trained and there are several programmes that help train lay people in providing bystander care. Lay first-responders effectively retained knowledge on prehospital trauma care and confidently used their first-aid skills and supplies for at least six months. participants had used at least one skill from the course: most commonly haemorrhage control, recovery position and lifting/moving and 96% had used at least one first-aid item (32). Training drivers First aid - a group of people most likely to be on the road to help in the time of a road crash has been used by many (33), (34), (35).

5.8. ALS vs BLS

As EMS evolved more and more interventions started to get done by the Emergency Medical Technicians. A lot of what was done was empirical and not based on hard evidence. Recent evaluations of these interventions have not shown any benefit. In fact there are some reports of causing harm in some patients. The American system of care in accordance with the advanced trauma life support (ATLS) standard of the American College of Surgeons (ACS) and by means of prehospital and advanced trauma life support (PHTLS) given according to the standards of the National Association of Emergency Medical Technicians (NAEMS) was considered to be the 'golden standard' (36). Advanced life support levels of care of patients with an Altered Level of Consciousness (ALOC) does not significantly change outcome compared with those receiving BLS care with the exception of shorter emergency department treatment times for hypoglycemic patients (37),(38). Some studies found harmful effects of ALS in severe trauma. The OPALS (the Ontario Prehospital Advanced Life Support) study found 'that during the advanced life-support phase, mortality was greater among patients with Glasgow Coma Scale scores less than 9' (39). In a study done in Netherlands on TBI with GCS \leq 8 showed despite more on-site ALS in severely head injured patients nowadays compared to the historic cohort, there was no reduction in mortality (40). In a recent study Sanghavi P et al found Patients with out-of-hospital cardiac arrest who received BLS had higher survival at hospital discharge and at 90 days compared with those who received ALS and were less likely to experience poor neurological functioning (41).

5.9. Spine Clearance

The biggest worry for an EMS team is how to prevent a secondary spinal cord damage in a traumatic spine injury or in an unconscious patient. There is always the worry about clinical clearance the protocol has been to assume a spinal cord injury in a patient who is unconscious and to protect the spine in a paralysed patient or to protect the spine in a conscious patient complaining of pain in the back. In a prospective study on GCS 14 and > cases were evaluated clinically by EMTs for C – Spine injury.34% c-spines were clinically cleared by EMS. There were no known missed injuries in this patient group. 6% patients who were not clinically cleared by EMS were diagnosed with c-spine injury. EMS personnel in the prehospital setting may reliably and effectively perform clinical clearance of the c-spine. Further prospective study for prehospital c-spine clinical clearance is warranted (42).

Traumatic spinal cord injury (SCI) often occurs in patients with concurrent traumatic injuries in other body systems. These patients with polytrauma pose unique challenges to clinicians. Bowel and bladder disorders are common following SCI, significantly reduce quality of life, and constitute a focus of targeted therapies. Systematic management approaches to minimize sources of secondary injury are discussed, and areas requiring further research, implementation, and validation are identified (43).

Cervical collars are routinely applied in trauma patients with suspected cervical spine injury. However, cervical collar application was reported in penetrating trauma to be associated with unadjusted increased risk of mortality in two concealment of neck injuries in one study and increased scene time in another study. While, in blunt trauma, one study indicated that immobilisation might be associated with worsened neurological outcome (44).

One paper has criticised everything that is done in spinal injuries –“The emergency care of patients who may have spinal injuries has become highly ritualised. There is little scientific support for many of the recommended interventions and there is evidence that at least some methods now used in the field and emergency department are harmful. Specific treatments that are irrational and which can be safely discarded include the use of backboards for transportation, cervical collar use except in specific injury types, immobilisation of ambulatory

patients on backboards, prolonged attempts to stabilise the spine during extrication, mechanical immobilisation of uncooperative or seizing patients and forceful in line stabilisation during airway management (45).”

In Patients with neurological deficit it is far better that they reach definitive care centres early on. Patients who took greater than 24h to reach a SCIU were 2.5 times more likely to develop a secondary complication.(46)

5.10. Ambulances - Transportation of the injured patient

Ambulances have become synonymous with patient transport vehicles. They are designated as per their usage and the technology available within like ALS ambulances, BLS ambulances. In high income countries over 90% of patients are transported by ambulances. Where as in low-income countries like; India and Africa over 90% patients are transported taxis, private cars and police vehicles.

Interestingly patients with severe trauma transported by private vehicles were found to have better survival than those transported via EMS system. Persons without access to telephone also often use private transport to transfer trauma patients to a trauma centre. Of the 4 per cent patients transported in private vehicles 50 per cent did not have access to telephone. Among the others, fears of delay and under estimation of the severity of trauma were the other causes (47). In Philadelphia 61 per cent of Police Chiefs indicated that police officers would occasionally ‘scoop and run’ with a critically ill child rather than wait for the emergency medical services to arrive(48). In a study done in Delhi it was found that ambulances transported only 4 per cent of patients. Of the injured 51 per cent were transported to the hospital by taxis. This is comparable with urban ambulance transfer times in high income countries(49). In a meta analysis of ambulance transportation times from US it was found that the average duration in minutes for urban, suburban, and rural ground ambulances for the total prehospital interval were 30.96, 30.97, and 43.17 minutes (50).

5.10.1. Equipment in an Ambulance

The ambulance vehicle may be any simple vehicle with a stretcher or it could be custom built and fitted with sophisticated equipment for monitoring and providing advanced cardiac life support. Other equipment like suction machines and immobilization devices for limb or spinal immobilization boards, cervical immobilization collars, IV cannulas, Oxygen cylinders, Bag valve ventilators also form part of ambulance equipment. With improvements in technology defibrillators, mechanical ventilators, and Mechanical CPR machines are also available on some ambulances. However, there is no data to suggest that use of equipment alter the outcome of trauma.

All ambulances must also have patient extrication tools to extricate patients trapped in crashed vehicles especially those involved in high energy crashes.

5.10.2. Speed of Ambulances

Early transportation of the trauma patient within first hour of trauma is highlighted to emphasis the need for early definitive care and the term widely used is transportation in the ‘Golden Hour’. However, reported that the Golden Hour concept was not based on data or evidence. Dr Cowley used the term as part of a presidential address rhetoric to the American College of Surgeons (51). The platinum half hour concept is an extrapolation of this to further highlight the importance of reducing time to definitive treatment. But how far can we stretch the ‘Golden hour’ concept. In a study on TBI it was found that a survival benefit exists in patients arriving earlier to hospital after severe head injury but the benefit may extend beyond the golden hour. There was evidence of improved functional outcomes in patients arriving within 60 min of injury time (52).

Transportation time for the injured during world war was estimated to be 12 – 18 hours while mortality was estimated to be 8%, during world war II it was 6 – 12 hours and the estimated mortality was 4.5%, during Korean war it was 2-4 hours and 2.5% and during Vietnam war it was one and a half hours and mortality was estimated to be 2%. However, during this period not just travel times but the entire medical system changed from a sepsis, antibiotics, and anesthesia overall surgery became much safer.

Though it is important for the injured patient to reach a definitive care facility at the earliest in urban situations with short transportation times excessive speeding cannot improve transportation times. This speeding may in fact contribute to risk of injury to patients, other motorists and pedestrian on the road. Ambulance crashes for the time period of May 1, 2007 to April 30, 2009. Of the 466 crashes examined, 358 resulted in injuries and 99 persons were killed (53). The incidence of fatal ambulance crashes during emergency use is reportedly higher than during non-emergency use. These are particularly higher for lights and siren travel (54). Kahn and colleagues found that most crashes occurred at intersections and rear compartment occupants were more likely to be injured than those in the front (55). Hunt and colleagues have shown that ambulances with flashing lights and sirens do not significantly reduce patient transportation time. The study used ambulances with lights and

sirens and a control ambulance without any of this, it revealed the mean time saved to be 43.5 seconds in 50 trips (56) In another study the mean time saved was 2.9 min in urban areas and 8.9 min in rural areas (57). Use of sirens also significantly disturbs the patients being carried in it. The noise of sirens and traffic also disturb recording of blood pressures of patients in moving ambulances (58).

Ambulance transport is associated with predictable and likely preventable occupant hazards. Intersection crashes have high injury and fatality risk. Crash testing demonstrates that the ambulance transport environment includes predictable and preventable occupant risks. Failure to use current methods of occupant protection for each occupant or to secure equipment effectively can result in catastrophic outcomes to all occupants (59). In another study the mean time saved was 2.9 min in urban areas and 8.9 min in rural areas (60).

Research needs to be conducted on the type of patients that need to be rapidly transported. While some reports recommend neurotrauma and penetrating injuries this area need further evaluation.

5.10.3. Air Ambulances

Air ambulances have been promoted with a view to reduce transportation times and hence reduce mortality. Air ambulances are costly, and their health benefits are small (61)The study found that there was no improvement in response times and the time on scene was longer for helicopter-attended patients. Logistic regression analysis in helicopter transported trauma patients have shown that transportation by helicopter does not affect the estimated odds of survival (62).

Another study showed that a large majority of trauma patients transported by both helicopter and ground ambulance has low injury severity measures. Outcomes were not uniformly better among patients transported by helicopter. Increased mortality, 18 per cent compared to 13 per cent for ground transported patients for helicopter transportation of victims in urban area (63).

Air transport is also fraught with risks of crashes and fatalities. Helicopters Survival to hospital discharge was 3.5% (severely disabled) in the HEMS group and 0% in the ground-BLS . No significant benefit on long-term outcome was found, but more cases might be needed in future studies because of the inevitably low number of survivors (64).

Fatalities after helicopter EMS crashes are associated especially with post crash fire (65). Some counties have seen a 'distressing number of air ambulance crashes'(66) Helicopter services may have a role in remote inaccessible areas in the sea, desert or mountains. However, routine use of air ambulances in the urban setting is not cost effective.

5.10.4. Ambulance Personnel

The number and training of ambulance personnel varies from place to place. Some have only drivers trained in emergency care while others have emergency care paramedics. In some parts of the world there are physician-manned ambulances. Trained medics and paramedics are posted in the emergency medical service ambulance to ensure that the trauma patients receive optimal care from the site of injury. Physician-manned on scene care was found to cause a significant increase in scene time and total pre-hospital time. These delays are associated with an increase in the risk for death in patients with severe injuries(61). Physicians on the scene tend to try to provide more care in the field than well trained paramedics, therefore, the time to definitive care of the haemorrhage may be delayed (67).

Instead of paramedics physicians also have been recommended to improve outcome but except in special situations this is not feasible logistically or practically on a wider scale. Some papers claim benefit with certain caveats. There appears to be an association between prehospital management by doctors and improved survival in major trauma. Further high-quality evidence is needed to confirm these findings. Level of evidence: Systematic review, level III (68).

With the information available it seems that in an urban setting all that is required is a comfortable vehicle with sufficient space to carry the injured safely to a hospital. Role of medication Analgesics for trauma patients and cardiac drugs for non-trauma patients are the most commonly used medications (69). Drugs were administered in 8.5 per cent of urban emergency patients and 7 per cent of rural emergency patients either at site or during transportation (70). So far, there is no reported evidence that pre-hospital medications are either beneficial or cannot be delayed until the arrival at the emergency room.

The dilemma in the field situation is whether to 'scoop and run' or to 'Stay and play'. Looking at the literature that is available and in an urban situation where travel times are expected to be within the 'Golden Hour' a

'scoop and run' policy seems reliable. However in a rural situation and where delays to definitive care are expected then a balance between "scoop and run" and "stay and play" is probably the best approach for trauma patients. The chosen approach should be made according to the mechanism of injury (blunt versus penetrating trauma), distance to the trauma centre (urban versus rural) and the available resources (71).

5.11. Emergency room care

Once the patient arrives in the Casualty the transition has to be smooth. Full system evaluation is mandatory to ensure that there are no missed injuries. Primary survey has to be a head to toe complete survey. This is also part of the ATLS protocol. Primary care procedures are instituted immediately and following stabilization of the patient a secondary survey is then executed. This is a detailed evaluation which is often supplemented with the investigation reports that are available and a more definitive treatment plan is made for the patient. At this point a decision is made to transfer the patient to the Intensive care or to the operating room or if he can be sent the wards or sent home after preliminary management. This Triaging also needs experience and expertise. More so in a multiply injured patient or a polytraumatised patient. In a multiply injured patient multiple parts of the same system is affected whereas in a polytrauma patient more than one system is affected. For example, a head injury with fractures of both femurs, or a patient with ruptured liver and spinal cord injury and head injury. In multiply injured patients there is a possibility of the dominant system injury may mask some of the other system injuries and there is a higher possibility of missed injuries. To avoid these protocols have been evolved. To ensure that patient's evaluation is complete checklists have been instituted by WHO. The Trauma Care Check list formed by WHO is recommended to reduce missed injuries and ensure quality of care.⁶ This is a 15 point check list implemented after the primary survey and secondary survey has been done and before the patient leaves the casualty.

5.12. Missed Injuries

Missed injuries occurring at any time during the care process can contribute to poorer mortality and morbidity. In on prospective study researchers found an incidence of 25.5% missed injuries (72). Various reasons can be attributed to this Among them the hemodynamic instability (Systolic blood pressure less than 90 mmHg), the tachycardia and the low Revised Trauma Score, Altered level of consciousness (GCS of twelve or lower)all supposedly contributed(72). These are common in trauma patients One study showed higher rates of severe missed injuries mainly in abdomen and pelvis. Circulatory instability and low RTS were assigned as significant factors predicting of this obviousness. Various solutions are proposed to prevent missed during the first assessment in prehospital care (72).

The WHO introduced the Trauma care Checklist after trials in 11 centres around the world with a view to improve quality of care for the emergency trauma patient. Implementation of the WHO Trauma Care Checklist was associated with substantial improvements in patient care process measures among a cohort of patients in diverse settings (73).

5.13. Trauma Systems vs Trauma centres

In the seventies when EMS was still evolving trauma surgeons soon realized the importance of having multispecialty hospitals where all problems of the patient can be dealt with under one roof. So trauma centres became popular. However soon it was realized that trauma patients may have other medical problems and co morbidities and there may be the need for a cardiologist or an endocrinologist or perhaps even an obstetrician for associated problems relating to those. Many a trauma centres had to close down in the 80s and 90s because of this. What was then realized was the need for a trauma team within a multi-specialty hospital. This ensured complete care of the patient and also injury care. In high income countries networks of hospitals that are designated to receive severely injured patients have been created. These systems can be either exclusive, in which all patients are referred only to a small number of specifically designated centres that meet strict criteria, or inclusive, in which patients may be referred to any hospital of a particular area according to capacity, which is observed in France (74).

Despite the presence of seemingly sufficient resources and the evidence-based benefits of trauma systems, only nine of the 23 high income countries in a review have a well-defined and documented national trauma system. Although 90% of all lethal traumatic injuries occur in middle and Low Income countries, according to literature which the study is limited to, only few of these countries a hold formal trauma system or trauma registry (1). To date, studies assessing trauma system efficacy rely on hospital deaths as the primary indicator of effectiveness. Future research should use more sophisticated study designs (Class II) and expand available outcome measures

⁶ <https://www.who.int/emergencycare/publications/trauma-care-checklist.pdf?ua=1>

to assess the entire continuum of care, including prehospital, rehabilitation outcomes, and long-term quality of life (75).

Even in high income countries much is needed in quality improvement as is evident from this review in Netherlands “However serious concerns remain: shortage of intensive care beds, the impossibility to use the helicopter service at night, the shortage in the number of mobile medical teams at night and the slowness in executions of agreements between contracting parties. Many of the remaining problems are a matter of money” (76).

The Prehospital phase should be a part of the hospital based emergency care system. Unless this is so, ownership and seamless transfers of patients will not happen. In China “The prehospital emergency service is an integral and important part of the Emergency Medical Service System. In China, emergency service centres (stations) have been set up at the levels of province, prefecture and county (77).

By developing multidisciplinary plans of care that focus on patient and family outcomes and not arbitrary points in time, hospitals can provide quality care to trauma patients that is both appropriate and cost effective. In fact, this type of plan for SCIs can be expanded on and used across the health care continuum from prehospital to community reintegration (78). Quality of care of the surgical patient is key to reduce complications. The WHO introduced the safe surgical checklist to reduce complications among surgical patients. Researchers found rate of death was 1.5% before the checklist was introduced and declined to 0.8% afterward ($P=0.003$). Inpatient complications occurred in 11.0% of patients at baseline and in 7.0% after introduction of the checklist ($P<0.001$) (79). In addition, these, basic science research can help us recognise early signs of deterioration, Multi-organ failure, development of irreversible shock and several other parameters. These fall into a distinct area of research beyond what has been discussed here.

Long term studies are essential to understand the long term and social implications of trauma. This is rarely done as such studies are very expensive and difficult to do. In a 5-year follow-up study of a group of 461 consecutive trauma patients treated in an Intensive Care Unit from 1980 to 1983, the entry criteria (initial survival and severe injury: ISS greater than or equal to 18) were fulfilled by 233 patients with a mean ISS of 29.3 and mean age of 35.6 years (80). Full details of medical sequelae, aftercare, missed injuries, occupation, insurance, social integration, economics, legal aspects, and traffic involvement were covered. Final was gathered from 95.6% of the 233 cases. Eighteen percent of the patients died in the hospital, 5.6% died later, and 76.5% were eventually seen. Only 4.4% were lost to follow-up. Outcome was judged using the Glasgow Outcome Scale (GOS), which was compared with a GOS value given prospectively at the time of hospital discharge. Eighty-nine percent of the survivors were healthy or slightly disabled (GOS 5 and 4), 9% were severely disabled, and only 2% were in a persistent vegetative state. Outcome after 5 years was better than tentatively proposed at the time of hospital discharge. Ninety-one patients with severe head injuries (AIS 4-5) were additionally tested using the Mini Mental State Instrument. This test revealed normal mental functions in 77% and dementia, mostly of a minor degree, in 23% of the head-injured patients. Almost all the early deaths and two thirds of the late deaths were related to severe head injury. Seventy-nine percent of the survivors were working after 5 years. During the post-trauma period, patients experienced reduced social well-being and also changed professional and recreational activities. There appears to be extensive room for improvement in the post-hospital recovery phase (80).

Such long-term studies are unusual but only these are able to capture the full impact of a continuum of care including the importance of rehabilitation services and community programmes for the care of the injured.

6. RESEARCH

While today’s emergency and trauma care system offers significantly more medical capability than was available in years past, it continues to suffer from severe fragmentation, an absence of coordination, and lack of accountability (81). We are in a situation where something as basic as starting of an intravenous fluid in a traumatized patient is labelled as controversial. Despite evidence from multiple researchers it has taken 20 years for this to translate to protocols. While this may be a good safety mechanism to prevent protocols to be driven ‘shooting from the hip’ approaches it could also delay implementation of genuine interventions or removal of harmful interventions.

There is a need to evaluate Evidence Gap Maps (EGMs) in the area of emergency trauma care and then factual meta-analysis needs to be done to separate what really works from what is perhaps useful. The future may find that even some of our very basic parameters of measurement of end points of resuscitation may have changed completely. A recent report found a substantial number of Systematic Reviews in acute management of

moderate to severe TBI lack currency, completeness and quality. They have identified both potential evidence gaps and also substantial research waste (82). One of the dilemmas of pre-hospital care has been ‘are we doing too little for a damage which seems too much?’ Our emotional response seems correctly to be to do whatever possible to save as many lives as possible. There is a need, however, to avoid deification of technology and to homogenize responses in a problem which is essentially heterogeneous. To make scientific conclusions we must have well-controlled prospective randomized studies.

There exists a strong general feeling that randomizing pre hospital care is unethical (83). Since component-based research doesn’t fit well into the uncontrolled, multi-tasking environment of EMS, we need to begin to develop models specifically for systems research (84). However, there are natural control populations in place in the world where a total contrast of no pre-hospital care exists along with places where high-tech pre-hospital care is practiced. Advantage could be taken of such situations, normalize them for different injuries to have a controlled study. One such study, done in Canada, where researchers compared two cities with two different types of EMS systems. “Two distinct Emergency Medical Services (EMS) systems exist in Atlantic Canada. Nova Scotia operates an Advanced Emergency Medical System (AEMS) and New Brunswick operates a Basic Emergency Medical System (BEMS). Overall survival to hospital was the same between advanced and basic Canadian EMS systems (85).” Until more such carefully designed studies are carried out we will continue to grope for answers and components of pre-hospital care will remain controversial.

Policy, ethical and legal barriers to research in this field also need to be overcome. Article 5 of EU Directive 2001/20/EC required consent before enrolment in a research study to ensure the autonomy of potentially incapacitated research subjects. However, obtaining such consent is often impossible in emergency situations. Several EU Member States addressed this problem by permitting deferred consent. International ethical guidelines supporting deferred consent were also cited by Good Clinical Practice Directive 2005/28/EC(86).

In summary, a review of literature and the physiological processes involved suggests that in urban areas with transportation times of less than one hour and no delay in extrication scoop-and run seems to be the best policy. But this alone will not improve the survival status of the injured, this need to be alongside major improvements with trauma teams in place with excellent intensive care and operative facilities with a backup of rehabilitation services to get the patient back as a productive member of the community. However, serious research is required in this field which has largely been driven by emotions and empiricisms rather than hard evidence.

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Whose City? Securing the Rights of Pedestrians in Urban India

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Abstract

Despite a variety of statutes and policies to regulate transport infrastructure and means of transport, the safety and rights of non-motorized road users remain hazy in India because the motorized user remains the central object of statutory concern. Although pedestrians and cyclists have indirect protection via provisions of the criminal law, there is no direct statutory protection. In the absence of legislative and executive action, the Indian Judiciary has often stepped in to fill the gap, using the sometimes blunt tool of Public Interest Litigation to address various traffic regulations, road safety, and vehicular pollution. We review current policies, statutes and jurisprudence related to pedestrian safety – and by extension cyclist safety – in India. Comparative analysis is done with relevant legislation and policies from countries where pedestrian compliant guidelines have been mandated. This work can provide the basis to draft appropriate legislation and policies enabling development and implementation of pedestrian priority designs and traffic management strategies.

Keywords: Pedestrian rights, law, jurisprudence, safety.

1. INTRODUCTION

Road traffic crashes resulted in the deaths of about 1.3 million people in the world in 2014 (1), of which about 150,000 occurred in India (2). The number of serious injuries on Indian roads in the same year is estimated to be more than 2,000,000 (2). About 33% of those who die in road accidents in India are pedestrians, about 6% are bicycle riders, and about 34% are motorized two-wheeler riders (2). Pedestrians in urban areas in India are even more vulnerable – the proportion of pedestrians dying in road traffic incidents is estimated to be between 45% and 60% in megacities such as Mumbai and Delhi, and between 25% and 45% in smaller (less than 1 million population) cities and towns.

According to a survey conducted by the Central Road Research Institute, nearly 90% of pedestrians in India feel unsafe on the roads (3). The Indian Law Commission states (4): ‘Is it due to lack of apt provisions in our law that travel through Indian roads is a tryst with Death? This crucial question has been engaging the attention of the Law Commission of India for quite some time.’ (p.88)

It is accepted that the pedestrian is a vulnerable road user (5, 6), and the number of people in India who commute by walking outnumber those who use vehicles (7, 8, 9, 10). But the environment in which the pedestrian walks in India is extremely unfriendly. Most areas of cities in India do not have proper sidewalks. When present, sidewalks are too narrow, too high, uneven, and strewn with obstructions; forcing pedestrians to walk on the carriageway rather than the sidewalk.

There is no legislation in India directly concerned with pedestrian safety (4). This paper explores the issues concerning pedestrian safety with the objective of providing a basis to draft appropriate legislation and policies enabling development and implementation of pedestrian priority designs and traffic management strategies. We do this by first reviewing the current policies, statutes and jurisprudence related to pedestrian safety in India, followed by a comparative analysis of relevant legislation and policies from countries where pedestrian compliant guidelines have been mandated.

The paper is broadly organized into three parts. First, we critically evaluate the existing legislation and policies in India regarding roadways from the perspective of the pedestrian with the aim of assessing the effectiveness of these documents and the safeguards present. Next we look at the United Nation Conventions and Resolutions along with the legislation present in other countries. In this part we also look at the best practices obtaining in other countries vis-à-vis safety and accessibility for pedestrians and non-motorized traffic, and do a comparative analysis of the legislations and regulations enumerating the rights of the pedestrian, present in other countries. Third, we analyze the response of the Indian Judiciary with reference to the rights of the pedestrian.

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2. EXISTING LEGAL AND POLICY FRAMEWORK

2.1 Legislation and rules

Between the Indian Penal Code (IPC), 1860 (11), the Motor Vehicle Act (MVA), 1988 (12), and the National Urban Transport Policy, 2014 (13), India has a variety of laws and policies which concern themselves with traffic management and road safety, but the rights of pedestrians remain hazy. This is primarily because most existing laws and rules cater to the motorized road user (14). For instance, the Indian Penal Code punishes acts of rash or negligent driving (§ 279), causing of death due to negligence (§ 304), either endangering life or personal safety of others (§ 336), causing hurt (§ 337), and causing grievous hurt (§ 338). The MVA, the Central Motor Vehicle Rules (CMVR) (15), and the Rules of the Road Regulations (16) aim at regulating motorized traffic, but the statutory violations enumerated by the MVA only address motor vehicles.

The MVA does not completely disregard the pedestrian; clauses (h) and (i), § 138, of the MVA recognize the interests of the pedestrian by empowering state governments to make rules prohibiting motor vehicles from using sidewalks, causing injury or annoyance to the public, damage to property, or obstructing traffic.

Apart from the MVA and the IPC, it falls on municipal corporations to safeguard pedestrians. Except for a handful of the megacities such as Delhi and Mumbai, which have their own Municipal Corporation Acts (MCAs), each state in India has a Municipal Corporation Act drafted and passed into law by its legislature, which is then applicable to all towns and cities within the state's political boundaries, with local amendments as needed. Unfortunately, only a small handful of MCAs provide any degree of protection to pedestrians, and even that is done by making it a duty of the municipal government to keep obstructions off of footpaths / sidewalks and public streets during street repairs or other similar work. For instance, the Maharashtra Municipal Corporations Act applicable to Mumbai (17, 18, 19) states that at the time of any kind of 'street repair,' adequate arrangements in the form of posts and fences must be made to ensure the safety of pedestrians. Similarly, the Bangalore Development Authority Act, 1976 (20), makes the Authority responsible for the 'maintenance, keeping in repair, lighting and cleansing of the streets formed by the Authority' [till such streets are vested in the Bangalore Municipal Corporation].

The only national statutory provision in which the term "pedestrian" is found is the Rules of the Road Regulation, 1989 (16). Under these rules, certain obligations are imposed on the driver of a motorized vehicle with respect to the pedestrian; they include:

- a) The duty of the driver to slow down when approaching a pedestrian crossing (Rule 8)
- b) Not to drive on the footpath or the cycle lane (Rule 11)
- c) No driver shall park a motor vehicle near a traffic light or on a pedestrian crossing or a footpath (Rule 15)

The most important aspect of the Rules of the Road (16) with reference to road safety is that the regulations actually recognize a pedestrian's right to use the road. Regulation 11 states:

'Pedestrians have the right of way at uncontrolled pedestrian crossing. When any road is provided with footpath or cycle tracks specially for other traffic, except with permission of a police officer in uniform, a driver shall not drive on such footpath or track.'

It bears repeating that these Rules of the Road contain the only statutory provisions which explicitly address pedestrian safety.

Certain provisions of the Persons with Disabilities (Equal Opportunities, Protection of Rights and Full Participation) Act, 1995 (21), where enforced, also enhance the safety of all pedestrians. These provisions require:

- Auditory traffic signals, engravings on the surface of zebra crossings and on the edges of railway platforms to assist visually impaired persons
- Slopes in pavements [sidewalks/footpaths] for easy access of wheel – chair users
- Appropriate symbols of disability
- Warning signals at appropriate places

The statutory provisions mentioned above recognize the interests of the pedestrian in a fragmented manner. Moreover, most of these provisions are not implemented (14).

2.2 Policies

Apart from legislation, there are national and state policies which regulate roadways in India, but none of the current policies clearly spell out the rights of a pedestrian. This, however, does not mean that the existing policies have no relevance for pedestrian safety. For instance, the National Urban Transport Policy of 2006 (22) states that the planning of a city should be with respect to the people. While this policy does suggest the creation of segregated lanes and better sidewalks/footpaths, it does not mandate such facilities. The National Urban Transport Policy was updated in 2014 (13). Although this updated policy document devotes substantial space to walkability, most of that is in the context of access to public transport. This updated policy document only mentions pedestrian safety once (§10.4), and suggests segregating pedestrians from other road traffic as a solution.

The Jawaharlal Nehru National Urban Renewal Mission (JNNURM), a national scheme with a self-explanatory name, also does not provide any guidelines or criteria for pedestrian safety, although the City Development Plans submitted by cities competing for funds under JNNURM do sometimes include provisions for the pedestrian (14). But even when funds are allocated, implementation is poor due to jurisdictional issues. For instance, in most mid-size to large cities in India, the responsibility for streets is divided between the Public Works Department (PWD) and the Municipal Corporation, while some arterial streets may be within the jurisdiction of the National Highway Authority of India (NHAI). Each of these bodies has different road standards and priorities, making any coordinated effort to enhance pedestrian safety a near impossibility.

The construction of sidewalks in India is governed by guidelines from the Indian Roads Congress (IRC). Substantial sections of these guidelines are outdated (some have stayed effectively unchanged since the days of the horse-drawn buggy), and even where updated, they are not mandatory in law. The Urban and Regional Development Plans Formulation and Implementation (URDPFI) Guidelines (23) from the Indian Ministry of Urban Development also lay down certain guidelines with respect to sidewalks / footpaths, but again, these are not mandatory, and do not address safety concerns with respect to conflicts with motorized vehicles.

3. EFFORTS BY THE UNITED NATIONS, SPECIALIZED AGENCIES AND OTHER COUNTRIES

The Geneva Convention on Road Traffic, 1949 (24), was one of the earliest attempts made by the United Nations in the field of Road Traffic. This Convention has been signed and ratified by India. The Convention refers to the pedestrian in just two articles, nos. 7 and 11, and sees pedestrians more as a nuisance to be tolerated than as a legitimate road user. The Geneva Convention was replaced by the Vienna Convention on Road Traffic (VCRT) and the Vienna Convention of Road Signals and Sounds (VCRSS) (25). India has not ratified the VCRT or VCRSS. The aim of the VCRT was to create uniform road traffic laws to aid international transportation and ensure road safety, but it too was primarily aimed at safeguarding the rights of a motorized road user rather than the pedestrian. For instance, the VCRT provides a pedestrian with the right to walk on the carriageway in the absence of a sidewalk/footpath or on the satisfaction of certain other conditions (Article 20, §§ 2-3), instead of making it mandatory for the contracting parties to construct sidewalks or dedicate certain portions of the carriageway only to the pedestrian. Article 20, §§ 6 (c)-(d) of the VCRT state that the pedestrian while crossing the road must make sure he does not impede the road traffic. Other than the VCRT, the General Assembly has passed several resolutions on road safety (GA Res. 57/303, 58/289). These resolutions recognize the need to take steps to make the roads safe for everyone. There is increased support in the General Assembly to include road safety as part of the Millennium Development Goals. The World Report on Road Traffic Injury Prevention (26) provides a basic framework for countries to make roads safer. The report makes several recommendations, some of them with reference to the pedestrian:

- incorporating as a long-term goal, safety features into land-use and transport planning – such as the provision of shorter and safer pedestrian and bicycle routes and convenient, safe and affordable public transport – and road design, including controlled crossings for pedestrians, rumble strips and street lighting
- requiring that motor vehicles be designed for crashworthiness to protect the occupants, with efforts to expand this concept to the design of the fronts of motor vehicles, so as to protect pedestrians and cyclists
- managing existing road infrastructure to promote safety, through the provision of safer routes for pedestrians and cyclists, traffic-calming measures, low-cost remedial measures and crash-protective roadsides
- Construction of Central refuges: areas in the middle of the carriageway, where pedestrians can stop and wait until the road is clear before crossing

4. POLICIES IN THE EUROPEAN UNION

The European Union (EU) has undertaken several steps to recognize and enforce the rights of the pedestrian. One of the most significant being the recognition by the EU of the rights of the pedestrian in the form of a

charter, the European Charter of Pedestrians' Rights (27), adopted by the European Parliament in 1988. This charter acknowledges the right of a pedestrian to be able to live in a healthy environment and be provided with various necessary amenities. In 2009, the EU adopted the Pedestrian Protection Regulation (EC) 78/2009 (28). The regulation aims to protect pedestrians involved in a collision with a vehicle. It requires manufacturers to fit Brake Assist Systems into their vehicles to reduce the stopping distance and lower the speed of impact. It also requires them to make energy absorbing bonnets and front bumpers.

5. POLICIES IN THE UNITED STATES OF AMERICA

The United States Department of Transportation (USDOT) is the primary federal agency which aims at protecting the rights of the pedestrian. The National Highway Traffic Safety Administration (NHTSA) is the central body regulating road traffic. The NHTSA is aided by the Federal Highway Administration (FHWA) which is responsible for the safety and technological advancement of American Roads.

The FHWA also conducts research in several areas related to road safety. In 2002, the FHWA initiated the Pedestrian and Bicycle Safety Research Program. The Bicycle & Pedestrian Program of the Federal Highway Administration's Office of Human and Natural Environment promotes bicycle and pedestrian transportation use, safety, and accessibility (29).

Each State has a Bicycle and Pedestrian Coordinator in its State Department of Transportation to promote and facilitate the increased use of non-motorized transportation, including developing facilities for the use of pedestrians and bicyclists and public educational, promotional, and safety programs for using such facilities.

The FHWA Bicycle & Pedestrian Program issues guidance and is responsible for ensuring that requirements in legislation are understood and met by the States and other implementing agencies (29) One of the most important facts of this program was the fact that it recognized the pedestrian as a legitimate road user (30).

In the United States, the pedestrian is included at the design stage itself (30). Furthermore, unlike in India, the height of the curb is restricted to 152 mm (6 inches) as an essential element of good design.

The American judiciary has also recognized the rights of a pedestrian to an extent. For example:

- In *Twinn v. Noble* (31), the Supreme Court of Pennsylvania held that a pedestrian having committed himself to crossing a roadway has the right of way against an approaching automobile
- Where there are signal lights, multiple courts have held that if the pedestrian begins to cross while protected by a favorable signal, he has the right of way until he reaches the opposite side (32, 33, 34)
- In *Griffith v. Slaybaugh* (35), the Court of Appeals of the District of Columbia held that the pedestrian on having started across the intersection while protected by the signal light, had the right of way until she reached the opposite side of the street and that the defendant was negligent in proceeding while his view was obstructed

Considering the federal nature of United States, each state has its own pedestrian policies.

6. UNITED KINGDOM

The United Kingdom has a number of laws related to roads: the Road Traffic Regulation Act, 1984 (36), Road Traffic Act, 1988 (37), and the Road Traffic Offenders Act, 1988 (38), being the most prominent. It is important to note that legislation in the United Kingdom have been amended as needed to ensure that they are in tune with changing societal priorities. For instance, the Traffic Management Act of 2004 (39) includes the pedestrian within the ambit of the definition of traffic. Some of its provisions are:

- The power given to the Traffic Authority to facilitate a passage on the road or an adjacent road for the pedestrian (§ 1(c))
- No traffic regulation order shall be made with respect to a road, which has the effect of preventing at any time access to the pedestrian to any premises situated on or adjacent to the road, or to any other premises accessible for pedestrians, or (as the case may be) for vehicles of that class, from, and only from, the road (§§ 3(1)(a) & 14(4))
- Power given to local traffic authority to establish pedestrian crossings within their jurisdictions (§ 23). In this manner the Act caters for flexible decision making.

The Quiet Lanes and Home Zones (England) Regulation, 2006 (40), further cements the right of the pedestrian. The regulation is a guide which helps a traffic authority while designating a specific area as Quiet Lane or a Home Zone. The regulation defines Quiet Lane as:

‘... minor rural roads or networks of minor rural roads appropriate for shared use by walkers, cyclists, horse riders and other vehicles. The aim of Quiet Lanes is to maintain the character of minor rural roads by seeking to contain rising traffic growth that is widespread in rural areas. There are three key elements to a Quiet Lanes scheme: community involvement to encourage a change in user behaviour; area-wide direction signing to discourage through traffic; and Quiet Lane entry and exit signs to remind drivers that they are entering or leaving a Quiet Lane, a place where they may expect people to be using the whole of the road space for a range of activities.’

- Similarly, a Home Zone aims to:

‘...improve the quality of life in residential roads by making them places for people, instead of just being thoroughfares for vehicles. The key elements to a Home Zone are: community involvement to encourage a change in user behaviour; and for the road to be designed in such a way as to allow it to be used for a range of activities and to encourage very slow vehicle speeds (usually involving sensitively designed traffic calming).’

Thus, both Quiet Lane and Home Zones discourage the presence of motorized traffic. It safeguards the people and their interest, rather than the vehicles. These areas are meant for people to enjoy and undertake the permitted activities in a safe environment.

In 2004, London released an action plan to make London a more walkable city by 2015 (41). The plan includes six objectives:

- Improving co-ordination & inclusiveness in the Walking Plan development
- Promoting walking
- Improving street conditions
- Improving development proposals and interchanges
- Improving safety and security

The Plan then goes on to highlight the necessary actions which have to be taken to achieve each objective along with a rough time estimate. Therefore, the pedestrian is not only recognized as a legitimate road user but his interests are also catered for.

7. THE INDIAN JUDICIARY AND THE PEDESTRIAN

In the face of legislative and executive inaction, the Judiciary in India has stepped in to fill the gap. The courts have been quite active in the areas of traffic regulation, safety and pollution control. The important judgments may be divided into three groups: Pedestrians and Hawkers; Pedestrian injury or fatality and compensation; and Guidelines.

7.1 Pedestrians and hawkers

There are a number of judgments which attempt to balance the rights of pedestrians and street vendors. The two landmark judgments in this regard are *Olga Tellis v. Bombay Municipal Corporation and Anr* (42), and *Sodan Singh v. NDMC* (43).

In *Olga Tellis*, the Court observed that:

‘...pedestrians deserve consideration in the matter of their physical safety, which cannot be sacrificed in order to accommodate persons who use public properties for a private purpose, in an unauthorized manner.’

‘The main reason for laying out pavements [sidewalks/footpaths] is to ensure that the pedestrians are able to go about their daily affairs with a reasonable measure of safety and security. That facility, which has matured into a right of the pedestrians, cannot be set at naught by allowing encroachments to be made on the pavements [sidewalks/footpaths].’

Along very similar lines, in *Sodan Singh*, the Court ruled that:

‘...there cannot be a fundamental right vested in a citizen to occupy any place on the pavement [sidewalk/footpath] where he can engage in trading business... If the circumstances are appropriate and a small trader can do some business for the personal gain on the pavement [sidewalk/footpath] to the advantage of the general public and without any discomfort or annoyance to others, there can be no objection. Hawkers cannot be permitted to squat on every road. Factors like the width of the road, security etc. has to be considered.’

Although both judgments are open to criticism for failing to recognize the right of a street vendor to earn a living, or the fact that the primary obstruction on sidewalks/ footpaths in India is not caused by vendors, but by parked cars, utility vaults, uneven or broken surfaces, among other things, the rulings in these cases do try to achieve some balance between the pedestrian and the hawker, and very clearly recognize the right of a pedestrian to use sidewalks without unreasonable obstructions.

7.2 Pedestrian injury or fatality and compensation

Here we look at a few judgments which lay out the general principle followed by courts in India when a pedestrian is injured by a motor vehicle. In a judgment delivered in 1986, *Madhya Pradesh State Road Transport Corp. v. Kanti Devi and Two Ors.* (44), the High Court of Madhya Pradesh mentions the duties of a motorist with respect to the pedestrian. The Court states:

‘... it is the duty of the driver to keep a proper look out for pedestrian [sic] and other users of the road. It is his duty, whenever he feels expedient, to give warning to the pedestrian and other road users by mechanical or electric horn.’

Note that the duty of the driver to take notice of the pedestrian and avoid an accident is diluted by making it a judgment call on the part of the driver. This was mitigated to a certain extent the following year by the Supreme Court of India in *Gujarat State Transportation Corporation, Ahmedabad v. Ramanbhai Prabhatbhai and Anr.* (45). This case created a right to compensation for pedestrians:

‘Where a pedestrian without negligence on his part is injured or killed by a motorist whether negligently or not, he or his legal representatives as the case may be should be entitled to recover damages if the principle of social justice should have any meaning at all.’

This judgment still holds as governing precedent in India and has been followed by several High Courts across the country (46).

In multiple judgments, the Supreme Court has also emphasized the need for the creation of no fault liability in certain accident claims (47). The legislature passed a no-fault liability amendment to the MVA in 1989.

In *Prabhakaran v. State of Kerala* (48), the Supreme Court acknowledged the fact that road accidents are a leading cause of accidental death in India. The Court in the said judgment discussed in detail the General Assembly Resolution and its recommendations along with the economic impact of road accidents. In another similar judgment in 2009 (49), the justices noted that it is the ‘duty of every court to award proper sentence having regard to the nature of the offence and the manner in which it was executed or committed.’

7.3 Guidelines

The Supreme Court has been active in the field of road safety. The guidelines given by the Court in the case of *M C Mehta v. Union of India* (50) are an indicator of the same. In the said judgment, the Court observed that the control and regulation of traffic in National Capital Region (NCR) and National Capital Territory (NCT), Delhi, is a matter of paramount public safety and, therefore, within the ambit of Article 21 of the Constitution. Hence, the Court under Article 32 of the Constitution, read together with Article 142, gave specific directions, which included the following:

- a) No heavy and medium transport vehicles and light goods vehicles being four wheelers would be permitted to operate on the roads of the NCR and NCT, Delhi, unless they are fitted with suitable speed control devices to ensure that they do not exceed the speed limit of 40 KMPH.
- b) The scheme of the Act [MVA] necessarily implies an obligation to use the vehicle in a manner which does not imperil public safety. The authorities should, therefore, ensure that the transport vehicles are not permitted to overtake any other four-wheel motorized vehicle.
- c) Transport vehicles not permitted to overtake any four wheel motorized vehicle
- d) Separate bus lanes and bus bays to be demarcated on the roads

- e) School buses to be driven by person having a minimum of 10 yr experience.
- f) All hoardings hazardous to the movement of traffic were to be removed.

It is important to note that the court issued directions to ensure the safety of all road users, including pedestrians. The direction with respect to hoardings was also made applicable to sidewalks, thus explicitly recognizing the right of the pedestrian to have access to sidewalks free of any obstruction. The direction with respect to the hoardings was challenged in the High Court of Delhi in *Outdoors Communication v. PWD and Municipal Corporation of Delhi* (51). In this case, a contract had been granted to the Petitioner by the Municipal Corporation of Delhi to display hoardings on the roadside. This contract was challenged by the Public Works Department (PWD) as being against public policy. The Court in this case held the contract to be illegal on the ground that it was against public policy. While coming to this conclusion the court observed:

‘The pavement [sidewalk/footpath] by its very definition is meant for the use of pedestrians. The pedestrian is as much a user of the road or the circulation system of the city as a bus, a truck or a luxurious car... Pedestrians include the healthy citizens and also the unhealthy. It includes physically handicapped people and may also include the visually impaired.’

The Court voiced its concern for the pedestrian when a driver is distracted by an advertisement on the road side. Furthermore, the court rightly observed that the advertisements are often obstructions in the path of the pedestrian.

This trend of judicial activism seems to be on the wane. In 2008, the Supreme Court refused to issue guidelines to improve the licensing requirements, road infrastructure, etc., in a PIL filed by *Common Cause* (52). The Court stated that issuing guidelines on such an issue might lead to judicial legislation which would lead to a violation of separation of powers.

In *Dr. P. Nalla Thampy Thera v. Union of India* (53), a writ petition was filed in the Supreme Court with respect to the safety and security provided by the railways. The Court, while granting the petition, stated:

‘... every citizen of this country ... is entitled to demand that the State shall provide adequate facilities and create and maintain an environment in which the right to move freely and carry on any business or profession would both be practical and feasible. It is of paramount importance that the services should be prompt, efficient and dignified. The quality of the service should improve. Travel comforts should be ensured.’

Even though the above mentioned case dealt with the railways, the Court’s statement may be read as requiring the State to provide adequate facilities to citizens to make their movement feasible and practicable on roads as well as rails. In other words, the Court imposes a duty on the State to ensure that the pedestrian has a right to move freely on the roads. The Andhra Pradesh High Court went a step further while making an observation about traffic congestion in Hyderabad (54). The court noted that the right to the citizen to move freely, whether riding in/on a vehicle or on foot, was being trampled by the presence of buffaloes on the road. Furthermore, the court did not restrict this observation to the right to movement of the vehicle but also included the pedestrian

8. CONCLUSION

The rights of pedestrians in India are weak. Even though legislation and policies recognize certain rights of pedestrians, the framework is fragmented. Where specific provisions for pedestrian safety do exist, they are rarely implemented.

Judicial activism has filled some of the gaps in many areas related to road safety, but the effect of court provided guidelines or directions is not the same as laws and associated rules passed by legislative authority to ensure pedestrian safety.

Pedestrians are a plurality of road users in urban India, and also constitute a high percentage of road traffic fatalities. Pedestrian safety must be pivotal to the Government of India’s Smart City mission, and the statutory framework must also prioritize pedestrian safety and access.

NOTE

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Unsafe Riding Behaviors of Shared-Bicycle Riders in Urban China: A Retrospective Survey

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1 INTRODUCTION

New-generation dock-less, internet- and smartphone-based, low-cost shared bicycles have skyrocketed in popularity in China. Since their introduction in early 2016, the proportion of kilometers travelled by cycling in China rose from 5.5% to 11.6%.¹ Shared bicycles offer several benefits, including increased physical activity for citizens, alleviation of air pollution and traffic jams in busy urban centers, and opportunities for economic development.² However, shared bicycles also create risks. Researchers in other countries report significant risks to riders from lack of helmet use,^{3, 4, 5, 6} red-light running behavior,⁷ cycling against the traffic flow,⁸ and distracted riding.^{9, 10} The domestic popular media in China also reports risks to shared-bicycle riders from multiple factors, including traveling in motor vehicle and/or pedestrian lanes, carrying passengers on bicycles,¹¹ and lack of helmet use.¹²

More broadly, the global road injury incidence for cyclists has been increasing recently, reaching a rate of 156 per 100,000 persons in 2017 according to the estimates from the Global Burden of Disease (GBD) 2017 update.¹³ In China, about 8.5% of road traffic deaths and 19.1% of prevalent cases for road injuries occurred among cyclists in 2017.¹³ However, quantitative research evidence concerning the extent of unsafe riding behaviors, including among shared bicycle riders, lacks for China.

This study was designed, therefore, to quantify the extent of shared bicycle riding risks in urban China through epidemiological strategies. We used internet-based survey strategies to gather data from a large sample of shared-bicycle users in urban areas throughout China.

2 METHODS AND MATERIALS

2.1 Study recruitment

Because almost all shared bicycles in urban China are based on smartphone applications,¹⁴ we used an iterative sampling process to recruit study participants through WeChat, the most popular smartphone-based social media program in China. Non-probability sampling is preferred over random sampling to recruit a study sample when a random sample that is representative of the population is unlikely to be obtained,¹⁵ as is the case for social media-based sampling. To recruit our sample, initial survey invitations were sent to a convenience sample of colleagues, family members, classmates, and friends who had WeChat contact with members of the research group. Many of these individuals chose to participate, and then were asked to send the information about the survey to people included in their own WeChat contact list. This “snowball” recruitment process was iterated for a month, at which point the sample size was deemed sufficient and data collection was halted.

We recruited a total of 1960 respondents. Among them, riders aged 25 years and younger accounted for 54% of the sample, followed by age groups 26-35 years old (32% of sample) and ≥ 36 years old (14%). Males comprised 36%, 47% and 56% of the sample in the age groups of 25 years and younger, 26-35 years old, and ≥ 36 years old, respectively. 39% of respondents reported having received postgraduate education or higher (769 participants; 41% male and 59% female), 50% reported having an undergraduate education (970 participants; 42% male and 58% female), and the remainder of the sample reported an education less than an undergraduate degree (221 participants, 11% of the sample; 48% male and 52% female).

2.2 Ethical Statement

Informed consent was provided by all participants online and all data were collected anonymously. The research plan was approved by the Medical Ethics Committee of Central South University (No. XYGW-2017-39).

2.3 Outcome measures

We assessed eight self-reported unsafe shared bicycle riding behaviors: (1) not wearing helmets, (2) running red lights, (3) cycling against the traffic flow, (4) riding in a motor vehicle lane where bicycles are prohibited, (5) riding in a pedestrian lane where bicycles are prohibited, (6) carrying passengers on a shared bicycle with only

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one seat, (7) using a cell phone while riding a shared bicycle, and (8) eating while riding a shared bicycle. The eight risky behaviors were identified through a series of steps involving a thorough review of existing scientific literature and popular media sources, multi-round group discussions among the research team, and pilot testing. In each case, respondents answered the frequency with which they engaged in the risky behavior on a 4-point scale (always, often, sometimes, or never).

Of the eight risky behaviors, only two are prohibited by national law – running red lights¹⁶ and riding in a motor vehicle lane or pedestrian lane¹⁷. A third, cycling against the traffic flow, is prohibited for motor vehicles but not bicycles.¹⁶

2.4 Independent variables

Participants reported basic demographic information (sex, age, level of education), the type of city where they lived and rode shared bicycles, and shared bicycle travel-related information (typical purpose of shared bicycle travel, number of shared bicycle riding hours a week, and riding time for average shared bicycle rides).

2.5 Data collection

The WeChat-based online survey was active for one month, from September 7, 2017 to October 6, 2017. We estimated a priori that a one-month survey period would be sufficient to obtain a moderate or large sample size, and our estimation proved true after the month had passed. Minimal sample size was not calculated due to lack of information concerning relevant parameters.

2.6 Statistical Analysis

Data analysis proceeded in several steps. First, tables and percent bar charts were created to present the frequency of each of the eight unsafe riding behaviors that participants self-reported. We combined responses of “often” and “always” to ease interpretation of the tabled results. Second, Chi-square tests were conducted to examine differences in the proportion of riders often/always having unsafe behaviors based on demographic and travel-related variables. Third, we used multivariate binary logistic regression to examine associations between the eight unsafe behaviors and demographic and travel-related variables. The adjusted odds ratio (AOR) was calculated to quantify the associations. SPSS (Statistical Product and Service Solutions) statistical software version 22.0 (IBM Corp, Armonk, NY, US) was used to perform all statistical analyses. P values < 0.05 were considered statistically significant.¹⁵

3 RESULTS

3.1 Characteristics of the study sample

In total, 1960 persons participated in the survey (Table 1). The mean age of participants was 27.63 years, with a standard deviation (SD) of 9.50 years. Of them, persons aged ≤25 years old, 26-35 years old, and ≥36 years old accounted for 54%, 32%, and 14% of participants, respectively. Males constituted 43% of participants. 50% and 39% of respondents respectively reported having received undergraduate education and having postgraduate education or higher. The majority of respondents came from provincial capitals (56%) and central municipalities (23%). Geographically, the participants came primarily from Hunan Province (29.5%), Guangdong Province (11.7%), Beijing city (8.4%) and Tianjin city (7.3%), with the remainder spread across China.

The most common reasons to ride shared bicycles were commuting to work/school (55%), entertainment (28%), and physical exercise (9%). Ninety-four percent of respondents reported riding 5 hours or less per week. A little over half of participants reported their typical use of shared bicycles on weekdays (56%), with the remainder (44%) reporting they typically used the shared bicycles on weekends/holidays (44%). Rush hours (both morning and evening rush hours) were the most common time for people to ride shared bicycles (56%).

As shown in Table 1, the proportions of self-reported unsafe riding behaviors were significantly associated with several demographic and travel-related factors. Univariate analyses showed that (a) the proportion of behavior A (not wearing helmets while riding a shared bicycle) was significantly related to sex, age group, level of education, type of urban area of bicycle use, reason for travel and type of typical riding days; (b) the occurrence of behavior C (cycling against the traffic flow) was significantly associated with sex, riding hours per week and typical riding time; (c) the proportion of behavior D (riding in a motor vehicle lane) was associated with province/city of bicycle use; (d) the proportion of behavior E (riding in a pedestrian lane) was significantly associated with type of urban area of bicycle use; (e) the proportion of behavior F (carrying passengers while riding) significantly correlated with type of level of education, type of urban area of bicycle use, riding hours per week, and type of typical riding days; (f) the proportion of behavior G (using a cell phone while riding) was significantly related to sex, age group, province/city of bicycle use and reason for travel; and (g) the proportion of behavior H (eating while riding) was significantly associated with sex (Table 1).

Table 1. Proportion of sharing-bicycle riders who reported always or often having unsafe riding behaviors in the past month

Variable	Number (%)	Proportion of riders reporting unsafe riding behaviors							
		A	B	C	D	E	F	G	H
Total	1960 (100)	97.6	1.9	3.4	6.1	24.9	1.1	5.4	2.1
Sex									
Male	833 (43)	96.3	2.4	4.8	7.2	26.7	1.3	8.3	3.8
Female	1127 (58)	98.6*	1.6	2.4*	5.2	23.7	1.0	3.3*	0.9*
Age group									
≤25 years	1056 (54)	99.1	1.7	3.0	6.9	24.5	0.9	6.1	2.2
26-35 years	623 (32)	97.3*	1.8	3.7	5.1	24.6	1.6	5.8	2.1
≥36 years	281 (14)	92.9*	3.2	4.3	5.0	27.4	0.7	2.1*	2.1
Level of education									
Postgraduate or higher	769 (39)	99.0	2.2	3.4	5.2	23.5	0.5	5.1	1.6
Undergraduate	970 (50)	98.5*	1.6	3.2	6.4	26.1	1.0*	5.7	2.3
All others	221 (11)	89.1*	2.3	4.5	7.7	24.9	3.6*	5.4	3.6
Type of urban area of bicycle use									
Central municipality	450 (23)	98.4	1.6	3.8	4.9	18.0	2.2	6.4	2.0
Provincial capital	1092 (56)	98.6	1.6	2.8	6.1	26.0*	0.5*	4.9	1.6
Deputy provincial city	90 (5)	96.7	2.2	4.4	6.7	38.9*	0.0	6.7	3.3
All others	328 (17)	93.3*	3.4	4.6	7.3	27.1*	1.8	5.5	3.7
Province/City of bicycle use									
Hunan	579 (30)	97.4	1.7	2.6	8.5	25.9	1.2	3.5	1.7
Guangdong	230 (12)	97.8	0.9	3.9	7.0	33.9	0.0	5.7	2.6
Beijing	164 (8)	98.8	2.4	6.1	3.7	18.3	1.2	6.7	2.4
Tianjin	144 (7)	100.0	0.7	2.1	6.2	16.7	0.7	9.7*	2.1
All others	843 (43)	97.0	2.5	3.6	4.6*	24.6	1.4	5.7	2.3
Reason for travel									
Commuting to work/school	1070 (55)	98.7	2.1	4.2	6.6	23.9	1.0	6.6	2.1
Entertainment	544 (28)	98.2	1.8	2.2	4.8	26.1	1.5	5.0	2.6
Physical exercise	180 (9)	90.0*	2.8	3.9	6.7	28.3	1.7	3.3	2.8
Others	166 (9)	97.0	0.6	1.8	6.0	24.1	0.0	1.2*	0.6
Riding hours per week									
<1 hour	240 (12)	99.2	0.8	2.9	5.0	24.6	0.0	4.2	0.8
1-2 hours	732 (37)	98.9	1.9	3.7	5.6	25.1	1.0	4.9	1.9
3-5 hours	877 (45)	96.5	1.8	2.6	6.0	24.7	1.3	5.9	2.3
>5 hours	111 (6)	94.6	5.4	9.0*	11.7	26.1	3.6*	7.2	5.4
Type of typical riding days									
Weekday	1105 (56)	98.6	2.1	4.1	7.0	23.3	0.6	6.2	2.2
Weekend or holiday	855 (44)	96.3*	1.8	2.6	4.9	27.0	1.8*	4.3	2.1
Typical riding time									
Morning rush hours	399 (20)	96.2	2.0	6.0	6.8	24.1	0.8	5.3	1.5
Evening rush hours	698 (36)	98.1	2.6	2.7*	5.9	25.4	1.1	5.7	3.2
Other times	863 (44)	97.8	1.4	2.8*	5.9	25.0	1.3	5.2	1.6

Note: Post hoc multiple comparisons were performed between the first category and the rest of the categories for each variable respectively, based on Chi-square tests.

*: $p < 0.05$.

Abbreviations of eight unsafe behaviors: A. Not wearing helmets; B. Running red lights; C. Cycling against the traffic flow; D. Riding in a motor vehicle lane; E. Riding in a pedestrian lane; F. Carrying passengers; G. Using a cell phone while riding; H. Eating while riding.

3.2 Proportion of unsafe riding behaviors

The frequency with which participants reported unsafe shared bicycle riding behaviors in the past month differed greatly across the behaviors (Figure 1). The most common unsafe riding behavior self-reported as often or always occurring in the past month was not wearing helmets (97.6% often/always reported doing this; 95% CI: 96.9-98.3%), followed by riding in a pedestrian lane (24.9%, 95% CI: 23.0-26.9%), riding in a motor vehicle lane (6.1%, 95% CI: 5.0-7.1%), using a cell phone while riding (5.4%, 95% CI: 4.4-6.4%), cycling against the traffic flow (3.4%, 95% CI: 2.6-4.2%), eating while riding (2.1%, 95% CI: 1.5-2.8%), running red lights (1.9%, 95% CI: 1.3-2.5%), and carrying passengers (1.1%, 95% CI: 0.7-1.6%).

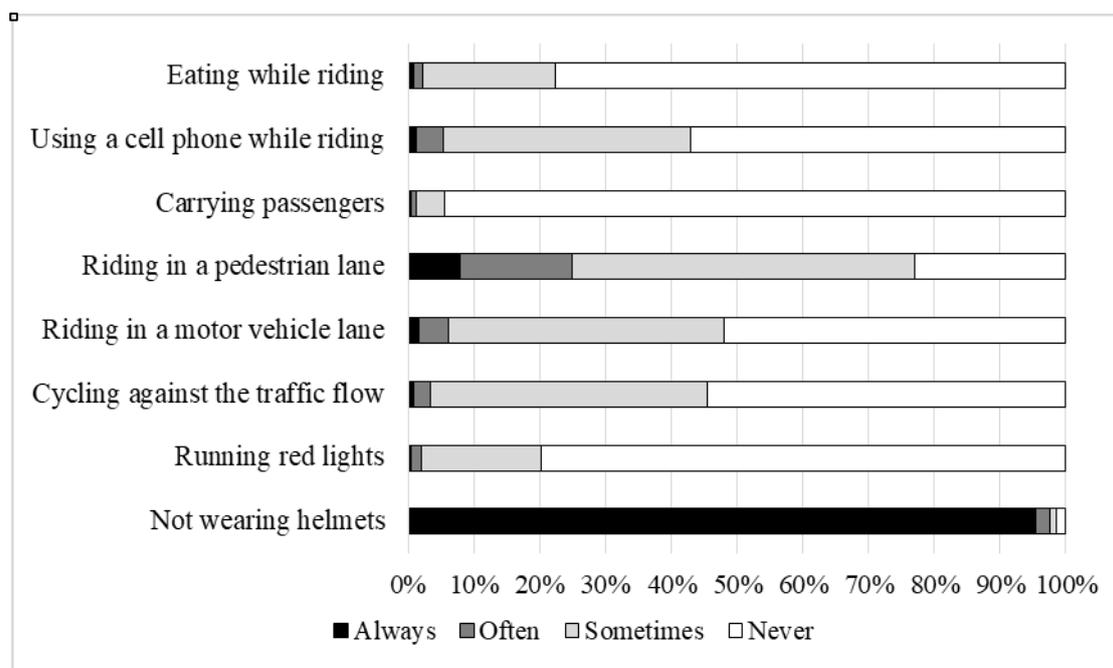


Figure 1. Self-reported unsafe riding behaviors among 1960 shared-bicycle riders in the prior month in China.

3.3 Associations between unsafe riding behaviors and demographic and travel-related variables

The differences in the proportions of participants reporting unsafe riding behaviors were generally insignificant across the demographic and travel-related variables we examined, with a few exceptions outlined below (Table 2). Specifically, multivariate logistic regression showed that (a) after adjusting for other variables, females were more likely than males to not wear helmets (AOR=2.28) and less likely to cycle against the traffic flow (AOR=0.54), use a cell phone while riding (AOR=0.34), and eat while riding (AOR=0.23); (b) riders aged ≥ 36 years were less likely to use a cell phone while riding compared to those aged 25 years or younger (AOR=0.28); (c) compared to riders with postgraduate education or higher, those with undergraduate education had a higher likelihood of carrying passengers (AOR=8.52) but lower likelihood of not wearing helmets (AOR=0.21); (d) compared to riders from central municipalities, those from the other three types of urban areas had a higher proportion of riding in a pedestrian lane (AOR=1.59, 2.82, and 1.61), and those from provincial capitals had a lower proportion of carrying passengers (AOR=0.19); (e) the proportion of individuals not wearing helmets was lower among those who rode shared bicycles for physical exercise than those for commuting to work/school (AOR=0.33); (f) shared-bicycle users who rode for more than 5 hours a week were more likely to carry passengers than those who rode less than 1 hour (AOR=4.72); and (g) participants who typically rode on weekends or holidays had a lower proportion of not wearing helmets (AOR=0.35) but a higher proportion of carrying passengers (AOR=3.93) than those who typically rode on weekdays (Table 2).

4 DISCUSSION

4.1 Primary findings

We found that 97.6% of participants in China reported they often or always failed to wear a helmet while riding shared bicycles in the past month. Additionally, 24.9% of participants admitted to riding bicycles in a pedestrian lane, 6.1% to riding bicycles in a motor vehicle lane, 5.4% to using cell phones while riding, 3.4% to cycling against the traffic flow, and a small number to taking other risks while riding shared bicycles.

Table 2. Associations of eight unsafe riding behaviors with relevant variables based on multivariate binary logistic regression models
Adjusted odds ratio (95% CI)

Variable	A	B	C	D	E	F	G	H
Female (ref=male)	2.28 (1.17, 4.43)*	0.76 (0.39, 1.47)	0.54 (0.32, 0.90)*	0.72 (0.49, 1.05)	0.90 (0.73, 1.12)	0.84 (0.35, 2.03)	0.34 (0.22, 0.51)*	0.23 (0.11, 0.47)*
26~35 years (ref= ≤ 25 years)	0.52 (0.22, 1.21)	0.87 (0.39, 1.94)	1.07 (0.60, 1.92)	0.68 (0.44, 1.07)	1.02 (0.80, 1.29)	1.86 (0.70, 4.92)	0.86 (0.55, 1.35)	0.79 (0.38, 1.66)
≥ 36 years (ref= ≤ 25 years)	0.41 (0.17, 1.00)	1.68 (0.68, 4.15)	1.07 (0.51, 2.27)	0.57 (0.30, 1.09)	1.21 (0.87, 1.67)	0.45 (0.09, 2.33)	0.28 (0.12, 0.67)*	0.65 (0.24, 1.74)
Undergraduate (ref=postgraduate or higher)	0.21 (0.09, 0.53)*	0.67 (0.22, 2.03)	1.27 (0.56, 2.89)	1.53 (0.81, 2.88)	0.91 (0.63, 1.32)	8.52 (2.26, 32.15)*	1.37 (0.67, 2.79)	1.95 (0.72, 5.29)
All others (ref=postgraduate or higher)	0.76 (0.31, 1.91)	0.68 (0.33, 1.41)	1.02 (0.58, 1.79)	1.14 (0.74, 1.76)	1.10 (0.87, 1.39)	2.38 (0.70, 8.14)	1.13 (0.72, 1.77)	1.32 (0.62, 2.80)
Provincial capital (Ref=central municipality)	1.36 (0.53, 3.54)	1.20 (0.49, 2.95)	0.77 (0.41, 1.43)	1.28 (0.77, 2.12)	1.59 (1.20, 2.11)*	0.19 (0.07, 0.54)*	0.70 (0.43, 1.13)	0.78 (0.34, 1.79)
Deputy provincial city (Ref=central municipality)	0.65 (0.15, 2.73)	1.40 (0.28, 7.04)	1.01 (0.32, 3.15)	1.29 (0.50, 3.32)	2.82 (1.72, 4.62)*	—	0.84 (0.33, 2.13)	1.27 (0.33, 4.89)
All others (Ref=central municipality)	0.55 (0.21, 1.43)	2.51 (0.90, 6.97)	1.17 (0.55, 2.51)	1.60 (0.85, 2.99)	1.61 (1.13, 2.30)*	0.39 (0.13, 1.23)	0.89 (0.46, 1.69)	1.55 (0.60, 3.98)
Entertainment (ref=commuting to work/school)	1.53 (0.55, 4.23)	0.99 (0.38, 2.57)	0.67 (0.30, 1.49)	0.87 (0.49, 1.53)	0.99 (0.73, 1.34)	0.58 (0.19, 1.76)	0.82 (0.46, 1.45)	1.28 (0.54, 3.05)
Physical exercise (ref=commuting to work/school)	0.33 (0.13, 0.81)*	0.99 (0.32, 3.11)	0.90 (0.36, 2.28)	1.16 (0.57, 2.36)	1.07 (0.72, 1.59)	0.41 (0.10, 1.66)	0.59 (0.24, 1.47)	1.10 (0.36, 3.38)
Others (ref=commuting to work/school)	0.49 (0.15, 1.60)	0.36 (0.05, 2.82)	0.51 (0.15, 1.77)	1.07 (0.52, 2.23)	0.89 (0.59, 1.35)	—	0.18 (0.04, 0.74)*	0.31 (0.04, 2.41)
1-2 hours (ref= ≤ 1 hour)	0.95 (0.19, 4.85)	1.93 (0.43, 8.66)	1.07 (0.45, 2.53)	1.11 (0.57, 2.17)	1.03 (0.73, 1.45)	—	1.00 (0.48, 2.08)	1.71 (0.38, 7.71)
3-5 hours (ref= ≤ 1 hour)	0.31 (0.07, 1.39)	2.02 (0.45, 8.97)	0.75 (0.31, 1.80)	1.20 (0.62, 2.30)	1.04 (0.74, 1.46)	1.35 (0.50, 3.61)	1.26 (0.62, 2.55)	2.20 (0.50, 9.68)
>5 hours (ref= ≤ 1 hour)	0.27 (0.05, 1.62)	5.02 (0.96, 26.19)	2.18 (0.78, 6.12)	2.18 (0.93, 5.08)	1.12 (0.66, 1.90)	4.72 (1.25, 17.88)*	1.21 (0.45, 3.24)	3.83 (0.73, 20.19)
Weekend or holiday (ref=Weekday)	0.35 (0.15, 0.79)*	0.78 (0.33, 1.83)	0.88 (0.45, 1.72)	0.68 (0.42, 1.11)	1.16 (0.89, 1.52)	3.93 (1.29, 11.97)*	0.76 (0.45, 1.29)	0.70 (0.31, 1.55)
Evening rush hour (ref=morning rush hour)	2.32 (0.95, 5.63)	1.59 (0.64, 3.94)	0.55 (0.28, 1.06)	1.02 (0.60, 1.74)	1.02 (0.75, 1.39)	1.31 (0.31, 5.57)	1.38 (0.77, 2.46)	2.56 (0.97, 6.77)
Other time (ref=morning rush hour)	2.05 (0.88, 4.77)	0.95 (0.36, 2.46)	0.60 (0.32, 1.12)	1.03 (0.61, 1.73)	1.05 (0.78, 1.42)	1.49 (0.37, 5.98)	1.31 (0.75, 2.31)	1.40 (0.51, 3.87)

With a few exceptions, the proportions of unsafe riding behaviors were generally similar across sex, age, and level of education groups, as well as across types of city, and reasons and hours of riding.

The extremely high proportion of participants who reported they did not wear helmets on shared bicycles concurs with findings elsewhere, such as in South Korea (81%),¹⁸ Paris (98%),¹⁹ and Germany (88%),²⁰ but is somewhat higher than reports in Italy (78%)²¹ and in Vancouver, Canada (about 67%).²² Helmets are widely documented to reduce serious head injuries and deaths among cyclists,^{23, 24} but are often cited by cyclists as uncomfortable, unsightly, and logistically a hassle to use.^{25, 26, 27} A 2012 study by Kraemer et al. suggested shared bicycle riders may wear helmets significantly less often than bicyclists riding their personal bikes for commuting or casual/leisure riding.

Some scholars also attribute low helmet use to the existence of a good road infrastructure (e.g. bike lane and traffic lights), creating a safer cycling environment that cyclists perceive as safer, overriding the need to wear helmets.²⁶ Mandatory helmet use laws can increase bicycle helmet use somewhat,^{28, 29,} as an example, the introduction of legislation requiring helmet use generated a substantial positive change in Canada, with the proportion of helmet use rising from 38% in 1996 to 75% in 1997.³¹ One challenge is enforcement of helmet laws, which is generally poor. There are no bicycle helmet laws in China.³²

Strikingly, quite a few participants in our study responded that they often or always rode in lanes designated for pedestrians and/or motor vehicles. Two previous studies highlighted the dangers of such behaviors for cyclists, either in a pedestrian lane or a motor vehicle lane.^{33, 34} In China, shared-bicycle users may use those lanes because specific bicycle lanes are unavailable or are impeded by parked cars or street vendors; the solution, of course, is to create the strong road infrastructure and to enforce policies to ensure the use of lanes for their designated purposes.³⁵

Matching results concerning cyclists riding their own bicycles in Groningen, the Netherlands,³⁶ we found a small portion of shared-bicycle riders reported using a cellphone while riding. Although the risks of distracted driving and distracted pedestrian behavior are well documented, few studies have addressed distracted bicycle riding.^{32, 37} One observational study by Wolfe et al. (2016) reported that nearly one third of observed bicyclists were distracted in some way, including listening to headphones or carrying cell phones in their hand while cycling. Males were more likely to ride bicycle distracted than females in that study, a result that matches our results as well as recent findings by Useche et al. (2018a). Similarly, we and others³⁸ found that teen and young adult cyclists are more likely to use a phone while cycling than middle-aged and the older adult cyclists. Legislation to prohibit distracted bicycle riding, similar to legislation in many jurisdictions worldwide to prohibit distracted motor vehicle riding, would likely be effective in China, as would campaigns to promote education and behavior change.

We also found cycling against the traffic flow, eating while riding and other unsafe riding behaviors among some surveyed riders. These findings generally replicate the results of previous observational studies,³⁹ although they differ somewhat in the frequency of occurrence.⁴⁰ Previous publications have attributed risky cycling against the traffic flow to poor road design/infrastructure, and eating while riding to low awareness of the safety risks.^{40, 41}

Although we found the frequency of unsafe shared bicycle riding was similar across most demographic groups and bicycle travel variables we studied, a few differences did emerge. As has been reported by others, we found comparatively lower helmet use among females compared to males.^{18, 20-21, 42} This mechanism behind the phenomenon is unclear and may be related to different perceptions concerning the value of using helmets between males and females. In contrast with previous researches,^{20, 43-44} we found comparatively lower helmet use among riders with higher levels of education. Such results are perplexing, conflicting with reports that riders with lower education levels may be less safety conscious compared to those with higher education levels.⁴³ Future research is recommended to replicate our results and evaluate potentially relevant variables like safety consciousness, but they may reflect the fact that our sample was not representative, with just 11% having less than an undergraduate degree.

4.2 Implications

Our findings have multiple implications. First, they highlight the need for the government of China to promote the implementation of well-designed road infrastructure that permits safe transportation by bicycle as well as other modes of transportation. Currently, very few Chinese cities have road

infrastructures designed to promote bicycling^{45, 46} despite the facts that cycling rates are sharply increasing with the advent of shared bicycles and a research indicates the presence of a road infrastructure with dedicated on-road bicycle lanes decreases crash risk by as much as 60%.⁴⁷

A second implication of our results is to consider innovations that increase helmet use by shared bicycle riders. One option is to engineer new bicycle helmets that are comfortable, low-cost, and hygienic for use with shared bicycles. These helmets might be rented with shared bicycles or carried by cyclists, but should be durable, comfortable, and have minimal impact on hairstyle when removed. A recent study⁴⁸ showed that airbag helmets have potential to reduce cyclist head injury compared to more commonly-used helmets made of expanded polystyrene (EPS) foam. Another study⁴⁹ found that increased helmet liner thickness reduces peak headform acceleration. These innovations may improve helmets, thus raising the use of helmet among riders of shared bicycles as well as private bicycles.

Finally, our results suggest future research should be conducted to consider why some behavioral differences emerged across demographic factors and riding characteristics. Such research could reveal trends or information that are valuable to generate individualized solutions to reduce unsafe riding behaviors.

4.3 Limitations of the study

This study is primarily limited by the selection of study participants. Our use of the snowball technique (non-probability sampling) yielded a large sample, but one that may have led to selection biases. Second, our use of a self-administered online survey may have created biased results in any number of ways. We may have omitted some riders who were unwilling or uncomfortable to participate in the survey, or we may have created a situation where anonymous surveys were completed dishonestly. Third, we did not collect information on participants' bicycle injury history. This would be valuable data for future research to collect, but since the base rate for cycling injuries is low, a very large sample size would be required to gather meaningful information on shared bicycle use and actual injury events.

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Road Traffic Accident Patterns in Two District of Shanghai From 2010 To 2012

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Abstract

Objective To compare the road traffic accident occurrence pattern in Songjiang District and Pudong District, and to explore the impact of data volume and research factors on the robustness of the latent class model. **Method** The data came from traffic accident records of Songjiang district and Pudong district from 2010 to 2012. Firstly, six factors including accident time, quarter, gender, age, traffic mode and accident cause are included in the latent class model, to compare the classification results in two regions when the variable categories are consistent and the data volume is inconsistent. Then, the road factors were added to the accident model in Pudong district, to compare the model classification results before and after the increase of road factors. **Result** The accident modes in Songjiang and Pudong district were both divided into four categories. In the motor vehicle accident, the proportion of motor vehicle accidents in Pudong was greater than the proportion in Songjiang. There were more truck accidents in the Songjiang area, and more passenger car accidents in the Pudong area. The urban expressway accident is another motor vehicle accident group in Pudong area; The road vulnerable user groups such as electric bicycles and pedestrians in the two regions were the second largest accident group except for motor vehicle accidents, and the composition of road vulnerable groups in Songjiang area is larger than that in Pudong area. There was a phenomenon of motorcycle driving without a license in both regions. **Conclusion** The accident modes of the two regions are classified by traffic mode, and the impact of small data volume on the stability of the model is not obvious, road factors can make accident classification results more detailed

Keywords: road traffic injury; latent class analysis; road traffic accidents patterns

1 INTRODUCTION

With the rapid development of the urban economy, the urban space has been expanding, and the intensity of travel and the way of travel have changed significantly (1). Between 2005 and 2015, Shanghai's population and traffic volume have increased significantly and the loss caused by road traffic accidents (RTA) reached 216 million yuan (2). One of the strategies to improve the level of road traffic safety is to effectively intervene in risk factors. However, due to the heterogeneity of traffic accident data, the impact of some risk factors on traffic damage may be hidden or weakened (3). The method of improving the heterogeneity of accident data is usually to select a specific type of accident (4). That is, by enhancing the homogeneity of the accident to provide ideas for exploring the mechanism of injury caused by an accident or accident. Latent class analysis is a common method of data mining, which can classify data of the same feature to reduce the heterogeneity of data. Songjiang District and Pudong New District are located in the southwest and east of Shanghai respectively. Both regions are key development areas of Shanghai, but there are differences in economic and industrial structure, population structure, transportation system, etc. The road traffic system is an important carrier of economic development. How to effectively promote traffic safety and prevent road traffic accidents in the context of rapid economic and traffic volume growth is a common problem faced by the two regions. This study uses the accident records of the traffic police system in Songjiang District and Pudong District of Shanghai to explore the occurrence pattern of urban RTA under different social and economic backgrounds, and provide research support for RTA prevention.

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2 METHOD

2.1 Data

The data of this study were derived from the traffic police accident system in Songjiang District and Pudong District of Shanghai, and the accident records from January 1, 2010 to December 31, 2012 were extracted.

2.2 Record screening criteria

To improve variables' independence for further model analysis, the accident liability item is used as a screening variable to identify a primary responsible person in each event is included in the analysis. The "primary responsible person of accident" in this study is defined as: the accident liability of a person involved in a specific accident is tagged by the traffic police system as taking "full responsibility" or "major responsibility"; If more than one person's incident liability in the same incident is classified as "equal responsibility", an accident record with a smaller random number assigned is elected. The accident record data of the primary responsible person represents the time of the accident, the external environmental factors of the accident, and the cause of the accident. After screened, there were 280 records in Songjiang District from 2010 to 2012, and a total of 2132 records in Pudong District.

2.3 Statistical methods

Latent Class Analysis (LCA) (5) mainly uses latent categorical variables to interpret the association between multiple explicit variables. The main parameters include latent category probability and conditional probability. The latent category probability represents the composition ratio of the category in the group. The conditional probability is the embodiment of the feature in the category. The greater the conditional probability of an item, the more the item can represent the main features of the category. The model evaluation indicators mainly include AIC, BIC, CAIC, etc. The selection of AIC for large sample data is more reliable, and the selection of AIC for small sample data is more suitable (6). In this study, the LCA model of Songjiang District chooses AIC as the evaluation index, Pudong District selects BIC as the evaluation index, and the smaller the AIC/BIC value, the better the model fits. After the model is determined, the individuals in the sample are classified into different potential category groups according to the posterior probability, and the number of individuals in each potential category is determined.

In this study, the chi-square test (X^2) was used to compare the accident data of Songjiang area and Pudong area, and it was completed by SPSS 24.0. The latent class analysis included the age, gender, accident time, quarter, transportation and cause of the accident. The variable construction model of the accident is constructed using the proc LCA module of SAS 9.4 (7, 8).

3 RESULTS

3.1 Descriptive statistics of crashes in two districts.

Comparison of accident characteristics data in two regions: There are 2,132 accidents in Pudong District, including 1,870 males and 262 females, with an average age of (39.35±14.01) years; 280 accidents in Songjiang District, including 249 males and 31 females, with an average age of (38.59 ± 15.49) years. There were significant statistical differences in transportation, quarters, and accident causes between the two regions. There were no significant differences in gender, age, and accident time. See Table 1 for details.

Table 1. Descriptive statistics of crashes in two district

Item	Songjiang District (%)	Pudong District (%)	X^2	<i>P</i>
gender				
male	249 (88.93)	1870 (87.71)		
female	31 (11.07)	262 (12.29)		
age			6.1	<i>P</i> =0.30
<20 years old	9 (3.21)	69 (3.24)		
20-29 years old	65 (23.21)	518 (24.3)		
30-39 years old	86 (30.71)	563 (26.41)		

Item	Songjiang District (%)	Pudong District (%)	X^2	P
40-49 years old	65 (23.21)	512 (24.02)		
50-59 years old	28 (10.00)	303 (14.21)		
≥60 years old	27 (9.64)	167 (7.83)		
time			6.97	$P=0.22$
6-9 clock	54 (19.29)	457 (21.44)		
10-13 clock	43 (15.36)	361 (16.93)		
14-17 clock	49 (17.50)	454 (21.29)		
18-21 clock	70 (25.00)	463 (21.72)		
22-01 clock	33 (11.79)	227 (10.65)		
02-05 clock	31 (11.07)	170 (7.97)		
Quarter			12.41	$P<0.01$
One*	45 (16.07)	517 (24.25)		
two	67 (23.93)	549 (25.75)		
three	90 (32.14)	587 (27.53)		
four*	78 (27.86)	479 (22.47)		
the weather			-	-
Rain and snow	-	299 (14.02)		
Yin	-	352 (16.51)		
clear	-	1481 (69.47)		
Road type			-	-
General city road	-	1250 (58.63)		
City motorway	-	620 (29.08)		
Urban expressway	-	186 (8.72)		
Other roads	-	76 (3.56)		
intersection			-	-
Bifurcation	-	557 (26.13)		
Ordinary section	-	1458 (68.39)		
Elevated section	-	117 (5.49)		
Transportation			28.52	$P<0.01$
bus*	73 (26.07)	844 (39.59)		
truck*	83 (29.64)	412 (19.32)		
motorcycle	48 (17.14)	301 (14.12)		
electric bicycle	30 (10.71)	279 (13.09)		
bicycle	20 (7.14)	130 (6.10)		
walk	26 (9.29)	166 (7.79)		
Cause of the accident			133.47	$P<0.01$
Speeding	2 (0.71)	27 (1.27)		
Drunk driving	12 (4.29)	78 (3.66)		
Retrograde	17 (6.07)	103 (4.83)		
Illegal change	5 (1.79)	64 (3.00)		

Item	Songjiang District (%)	Pudong District (%)	X^2	P
Illegal occupation	15 (5.36)	71 (3.33)		
Violation of traffic lights*	25 (8.93)	283 (13.27)		
Violation across the motorway*	42 (15.00)	70 (3.28)		
Unsafe car distance	7 (2.50)	55 (2.58)		
Not letting	36 (12.86)	229 (10.74)		
Driving without a license*	21 (7.50)	101 (4.74)		
other illegal operations while driving	85 (30.36)	539 (25.28)		
Other improper operation*	13 (4.64)	388 (18.20)		
other	-	124 (5.82)		
total	280(100.00)	2132(100.00)		

Note: * Items with statistical differences between the two regions.

3.2 Model fitting results

From Figure 1, the LCA models in the Songjiang area are divided into four categories (Fig. 1.1). When road factors are not included in the LCA model of Pudong area, it is divided into three categories (Fig. 1.2). After the road factors are included, they are divided into four categories (Fig. 1.3).

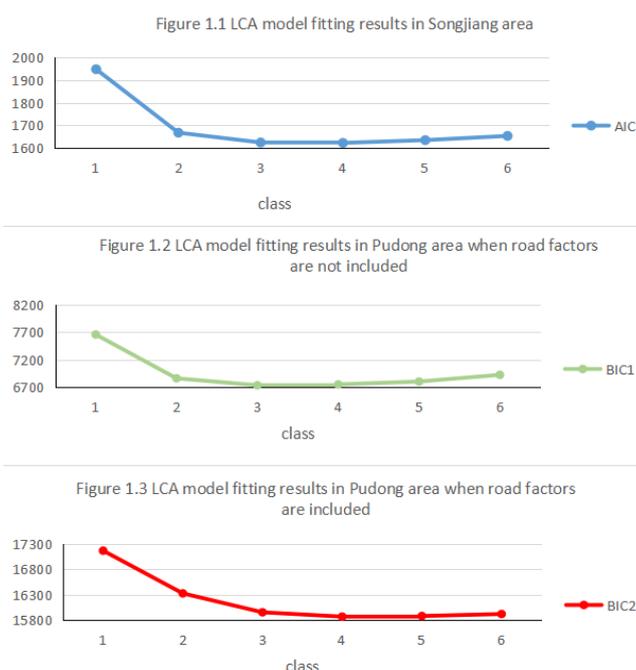


Fig 1 LCA model fitting results in Songjiang and Pudong area

3.3 Cluster Analysis

Comparison results of two regional accident models including six factors: accident time, quarter, gender, age, mode of transportation, and cause of accident: comparing the accident classification patterns of LCA models under different data volumes when the variables in the two regions are consistent, The results show that the Songjiang area is divided into four categories, and the Pudong area is divided into three categories.

The first category with the highest probability of potential categories in both regions is motor vehicles, the probability of Songjiang District is 0.4893, and the probability of Pudong District is 0.6016, suggesting that the proportion of motor vehicle accidents in Pudong District is greater than that in

Songjiang District. The accidents of this type of motor vehicles are mainly male, the age distribution is between 20-49 years old, and the probability of concentration of 30-39 years old is large. In the time distribution, there is no obvious peak period in Songjiang District. In Pudong District the probability of occurrence of early peak (6-9 o'clock) and afternoon (14-17 o'clock) is higher. The probability of truck involvement in Songjiang District is relatively high, and the probability of taking buses in Pudong District is relatively high.

The second category of Songjiang District and the third category of Pudong District are motorcycle-based accidents. The similarities between the two regions are that the motorcycle accidents are mainly men aged 20-29, and the peak of the accident is concentrated at 18-21 clock, the cause of the accident was “unlicensed driving”. The difference between the two regions is that motorcycle accidents in the Songjiang area account for a higher proportion of all accidents, second only to passengers car/truck accidents.

The third category and the fourth category in the accident classification of Songjiang District and the second category in Pudong District are road vulnerable groups, and the total probability of the two categories in Songjiang District (0.3034) is larger than that in Pudong District (0.2641). The third type accidents in Songjiang area are mainly electric bicycle accidents, and the fourth category is walking and bicycle accidents. The two categories have the highest probability of accidents in the cause of accidents, which are “violation of crossing the motor vehicle lane” . In contrast, the second category accidents in Pudong District is electric bicycles, which have the highest probability of accident traffic, followed by walking and bicycles. The main cause of the accident is “violation of traffic lights” . There are differences in the causes of accidents among vulnerable groups in the two regions.

Comparison of accident models in two regions with increased road factors: After increasing the road type and intersection type in the LCA model in Pudong area, the accidents in Pudong area are classified into 4 categories, and the newly added category 4 is the urban express road elevated section. The motor vehicle accidents, the basic characteristics of the other three types of accidents are consistent with those not included, and the probability of the latent category of the first type of passengers/trucks is reduced, suggesting that the new road factor variables in the LCA model have refined the original passenger/truck accident classification.

Table 2. latent category probability and conditional probability of two regions accident models

item	Songjiang District				Pudong District I			Pudong District 2			
	1	2	3	4	1	2	3	1	2	3	4
Latent category probability	0.4893	0.2074	0.1753	0.1281	0.6016	0.2641	0.1343	0.5232	0.246	0.1397	0.0912
male	0.9911	0.9337	0.6576	0.7453	0.9374	0.7008	0.9537	0.9253	0.6907	0.9564	0.9819
female			0.3424	0.2547		0.2992			0.3093		
20-29 years old	0.217	0.3583	0.2949		0.2601		0.34	0.2585		0.3449	0.257
30-39 years old	0.4488	0.3065			0.3514			0.3475			0.3503
40-49 years old	0.295		0.3489		0.2631	0.2141		0.2519	0.2131		0.3165
50-59 years old			0.2194			0.2121			0.2132		
≥60 years old				0.7529		0.2421			0.2528		
6-9 clock				0.273	0.2134	0.2575		0.2199	0.2637		
14-17 clock		0.2019		0.3055	0.2234			0.2416			
18-21 clock		0.3	0.5617			0.2672	0.2872		0.2645	0.2773	
22-01 clock		0.2065									
Urban expressway	-	-	-	-	-	-	-				0.8312

item	Songjiang District				Pudong District 1			Pudong District 2			
	1	2	3	4	1	2	3	1	2	3	4
Elevated section	-	-	-	-	-	-	-				0.5305
Bus	0.4016				0.6271			0.6653			0.3999
Truck	0.5984				0.3209			0.2666			0.5443
Motorcycle		0.7575					0.8893			0.8724	
Electric bicycle			0.4322			0.4155			0.4222		
Bicycle				0.3524		0.2309			0.2479		
Walk			0.2035	0.4465		0.2948			0.2959		
Violation of traffic lights			0.2513			0.2128			0.216		
Violation across the motorway			0.3128	0.7431							
Unsafe car distance	-	-	-	-	-	-	-				0.1576
Driving without a license		0.319					0.2998			0.304	
Other illegal operations while driving	0.4824	0.3258			0.3377			0.3096			0.4616

Note: The conditional probability greater than 0.2 is presented in the table. The “unsafe car distance” in the cause of the accident is the specific cause of the accident with the highest probability except “other illegal operations while driving”, so it is retained. The quarterly factors were not evident in the differences between the categories in the two regions.

Pudong area 1: LCA analysis results without road factors; Pudong area 2: LCA analysis results after road factors were included.

3.4 Correlation analysis of road types and traffic modes in Pudong district

There is a correlation between road types and transportation modes in Pudong district, and the number of columns is 0.284 ($P < 0.01$). In the urban expressway, the truck is the largest vehicle type, followed by the passenger car, representing the main features of the fourth category in the Pudong district.

Table 3. Correlation analysis of road types and traffic modes in Pudong district

Transportation modes	Passenger Cars	Trucks	Motorcycles	Electric Bicycles	Bicycles	Walk	Total	X^2	P
General city road	517	165	169	188	99	112	1250	187.237	$P < 0.01$
City motorway	239	138	111	76	28	28	620		
Urban expressway	64	89	5	8	0	20	186		
Other roads	24	20	16	7	3	6	76		
Total	844	412	301	279	130	166	2132		

Number of columns: 0.284, $P < 0.01$

4 DISCUSSION

This study uses exploratory LCA to analyze accident patterns in two regions of Shanghai. Due to the differences in data structures between the two regions, the stability of the model in both cases was compared: (1) Incorporate the same variables and compare the effects of different data volumes on the stability of the model. From the results of Table 2, it could be found that in the Songjiang District with smaller data volume, the road vulnerable groups are divided into 2 categories (class 3, Class 4), the characteristics of electric bicycles are more obvious, so the small amount of data can't significantly affect the stability of the model. (2) Compared the effects of included more variables on the stability of the model under the same data volume, compared the results of Pudong Areas 1 and 2 in Table 2, after incorporated the two types of road types and intersection types into the model, it was found that motor

vehicle accidents in Pudong were subdivided into “urban expressway accidents (category 4)”. The test found that there is a correlation between road type and traffic mode. Under the interaction between variables, the model classification results could better reflect the real situation.

Motor vehicle accidents in both regions are the largest group of accidents, which is related to the rapid growth of motor vehicles. From 2010 to 2012, Songjiang civilian vehicles increased from 89,980 vehicles to 120,274 vehicles (9). Rapidly growing motor vehicles have led to a decline in road capacity, increased traffic control pressures, and increased motor vehicle accidents. Motor vehicle accidents in Pudong district account for a larger proportion of all accidents, which is related to the greater road mileage and motor vehicle volume in Pudong. In 2011, the mileage of public road in the Pudong area reached 1936.99 km (10), and the total number of motor vehicles using public parking services in the district reached 26.276 million times (11). Studies have shown that vehicle ownership, road mileage, and transportation scale have a significant impact on traffic accidents and accident deaths (12). The results of the chi-square test in Table 1 show that there are differences in accident transportation modes between the two regions. Among them, the largest proportion of the Songjiang area is the truck, and the largest proportion of the Pudong area is the passenger car, which is related to the industrial structure of the two regions. Songjiang district was dominated by industrial manufacture, and the Pudong district was dominated by high-tech industries. The main types of road traffic caused by industrial structure are different. In addition, in the accident of motor vehicles, there are urban expressway motor vehicle accidents in Pudong area, which is related to the total length of urban expressway and expressway sections in Pudong area accounting for 24.2% of Shanghai (12).

The third and fourth categories of road traffic accident in Songjiang district are the types of road vulnerable groups. The two categories have a greater combined probability than the second category of motorcycle accidents. The road vulnerable groups are the second most common type of accidents in the two regions. According to the distribution characteristics of conditional probability, electric bicycles are the main types of non-motor vehicles in the two regions. Electric bicycles have become the primary choice for short-distance travel of most residents because of convenience and convenience, but also reflect to some extent that public transportation could not meet the travel needs of residents, and due to the increase of population and motor vehicles, ground traffic congestion will affect the efficiency of travel (13). Some surveys have shown (14) that electric vehicles/bicycles/walking + rail transit are widely available due to the remoteness of residential areas from subway stations, and the peak of travel is mainly concentrated in the peak of the day of work, which is consistent with the time distribution of the roads of vulnerable groups in the two regions. In terms of the cause of the accident, the differences between the two regions are reflected in the fact that the main cause of the accident in the Songjiang area is “violation of crossing the motorway”, followed by “violation of traffic lights”, and the Pudong area is mainly “violation of traffic lights. This feature indicates imperfect road infrastructure in the Songjiang district, such as no road isolation facilities, and no obvious traffic signs or lights at the intersections. In the Pudong area, the awareness of road users' safety norms is lacking. An observation of the illegal behavior of electric vehicles on the road in Songjiang District shows that the incidence of red light in electric vehicles is 5.9% (15). Chen Xiuqin et al(16)found that the risk factors of road traffic injuries in electric vehicles in Songjiang District are mainly low education level, non-Shanghai household registration, and violation of traffic rules. In view of the large number of migrants in Songjiang and Pudong, it is necessary to strengthen road safety knowledge education to reduce accidents.

Motorcycle accidents, as another accident group in the two regions, cannot be ignored. This study found that the cause of motorcycle accidents is mainly "unlicensed driving". Tan Wenyan et al (17)survey of residents in Jinping District of Shantou City found that 68.3% of the residents had motorized driving experience, of which 30.3% of the residents were driving without license. The reasons for unlicensed driving are related to the driver's lack of safety awareness, difficulty in motorcycle driver's license test, and complicated procedures for issuing permits (18).

Suggestions for accident prevention in the two regions: In the prevention of motor vehicle accidents, Pudong district should put more emphasis on passenger car accident prevention, and strengthen management of vehicles that do not maintain safe distance in urban expressways; Songjiang District should put more emphasis on truck accident prevention. In the prevention of road vulnerable groups, the two regions should improve the public transportation system, build necessary road safety facilities,

and strengthen the safety education of the migrant population. At the same time, the punishment for unlicensed driving of motorcycles should be strengthened.

This study used the LCA model to classify road traffic accidents in two regions of Shanghai, which reduced the heterogeneity of traffic accident data and provides a basis for developing preventive measures for people with different modes of transportation. However, due to limited factors in the model, no more detailed classification results were achieved, and more relevant factors will be considered in subsequent studies.

The age, gender, transportation, accident time, road factors, accident causes and other variables were included in the LCA model to compare the similarities and differences between the two regions. The comparison results show that (1) In the motor vehicle accident, the proportion of motor vehicle accidents in Pudong was greater than the proportion in Songjiang. There were more truck accidents in the Songjiang area, and more passenger car accidents in the Pudong area. The urban expressway accident is another motor vehicle accident group in Pudong area; (2) The road vulnerable user groups such as electric bicycles and pedestrians in the two regions were the second largest accident group except for motor vehicle accidents, and the composition of road vulnerable groups in Songjiang area is larger than that in Pudong area. (3) There was a phenomenon of motorcycle driving without a license in both regions. (4) The accident modes of the two regions are classified by traffic mode, and the impact of small data volume on the stability of the model is not obvious. (5) In the case of interactions between road types and modes of transport, the inclusion of road types makes the classification results more detailed.

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Investigation of Drivers' Preference and Choice for the Content and Format of Variable Message Signs

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Abstract

In China, only about 23% drivers were persuaded by VMS to follow route diversion. In order to capture the full benefits of VMS, the aim of this paper is therefore to identify the factors affecting VMS by examining what kinds of VMS contents, formats and their interactions are more preferable to drivers, specifically in China. A revealed preference (RP) questionnaire and stated preference (SP) survey consisting of 1,154 samples from private and taxi drivers was conducted and analyzed using discrete choice model. The results revealed that the information showed by amber-on-black on text format, white-on-blue on graph format or the suggested route diversion information showed by single line are preferred by drivers in fog weather. In addition, highly educated drivers or drivers with no occupation are more prone to the qualitative delay time on a text-graph format in fog weather. In normal weather, drivers with working trip purpose are mostly preferred to receive the information on a congested traffic condition with a reason on a text-only format. However, the congested traffic condition along with the information on the apparent causes shown by red-on-black or green-on-black on a text-only format was least preferred by drivers. Regarding current and adjacent road traffic information, drivers prefer to receive the suggested route diversion on a graph-only format in fog weather and the qualitative delay time on a text-graph format in normal weather. Irrespective to weather conditions, male drivers incline to the qualitative delay time on a text-graph format. The findings of this study could assist traffic authorities to design the most acceptable VMS for displaying traffic information for the purpose of improving road traffic efficiency and provide the theory evidence for the design of in-vehicle personalized information service system.

Keywords: variable message signs (VMS), VMS contents, VMS formats

1. INTRODUCTION

1.1 Overview

The daily physical transport of people and goods provided by current inefficient transport infrastructures, especially within city areas, is an increasingly serious problem in China. The continuous increase of vehicle-ownership, city logistics, urbanization and the growth for intercity mobility along with the insufficient infrastructure capacity at rush hours have led to the daily appearance of extended traffic gridlock and unprecedented levels of air pollution and traffic collisions in Chinese megacities. In addition to these serious consequences, public transport inadequacy, long commuting, high costs of infrastructure maintenance and a blatant lack of consideration for pedestrians and bicycles in the physical design of built environments and facilities are critical for the economic and social life of the affected metropolitan areas. This inevitably calls for a drastic and ground-breaking transform of current transport and mobility. In order to alleviate these problems, authorities have implemented both conventional and smart solutions. On the one hand, traditional solutions focus on the increase of roadway capacity by building new roads which is, however, very costly. Smart solutions, on the other hand, aim to employ a range of ITS technologies, strategies and other transport demand management measures in order to reduce passenger car use and provide better public transport services (1), car-pooling and vehicle-sharing schemes (2). With respect to technological solutions, various intelligent transport systems have been implemented in managing demand to match the capacity available. These include: intelligent traffic signals (3), ramp metering (4) and advanced traveler information system (ATIS) (5) through variable message signs (VMS). VMS, which is an infrastructure-based ATIS, has been proven to be an effective measure for alleviating traffic congestion caused by roadworks, special events, incidents and accidents affecting drivers' route diversion decisions (6,7,8). VMS panels with respect to their design, installation and operation are, however, costly and overuse and inappropriate use of their contents may result in compromising their integrity (9). Therefore, the effect of VMS on drivers' behaviors greatly depends on VMS contents and displayed formats

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(10). It is, therefore, very important for the traffic authorities to comprehend the likely preferences of motorists to different messages before designing and displaying them.

Dudek and Ullma (11) seek to address several issues relating to how the information could be displayed so as to provide understandable and effective messages. The methods to determine what kinds of VMS content and format should be displayed are divided into two approaches: (i) subjective and (ii) objective method. The former is mainly focused on identifying what kinds of VMS contents and formats satisfy drivers' requirements, while the latter mainly measures which one has the minimum distraction time when drivers receive the information. Based on the objective approach, considerable research efforts have been made to identify the optimum VMS content and format using, for example, response accuracy (12,13,14,15,16,17), response duration (13,14,15,16,17,18), gaze number (17) and response distant (17,19). However, there is a dearth of research on the subjective measure to determine whether the displayed content and format of VMS is preferable to motorists. More importantly, subjective measures are often regarded as a complementary means to objective measures. Therefore, this study aims to satisfy drivers' requirement of information based on the subjective measure with three main objectives in mind:

1. To identify more preferable VMS contents, formats and their interactions;
2. To draw policy implication on the design and display of VMS information.

2. METHOD

2.1 Survey design

As the participants were directly exposed to the VMS at the data collection points, this study used a revealed preference (RP) survey to analyze driver' preference for VMS content and format displayed on VMS panels in Xi'an city, China.. Before the survey, a preliminary introduction of the survey purpose was presented in order to ensure the validity of data and the fieldwork was carried out during weekdays in May, 2015. In this study, data were collected by means of a face-to-face on-site survey and an internet survey (a web link of the survey was sent to the drivers who could not fill the survey on site) distributed to drivers at four petrol stations which are located at the downstream sections of the VMS installations. Therefore, it can be guaranteed that all participants had driven through the VMS locations before the completed the survey. Face-to-face on-site questionnaire were distributed to a total of 520 drivers, within which 473 questionnaires were returned giving a response rate of 90.96%. A total of 212 respondents were obtained from the internet survey. Survey data with incomplete information were excluded resulting in a total of 577 respondents. Considering that every driver was asked their preference for the interaction of VMS content and format in both fog and normal weather, respectively, the overall dataset has 1,154 samples.

Table 1: Variable description

Variables	Code	Abbreviation	%
Driver's preference for the interactions of VMS contents and formats	1=Suggested route diversion information on a text-only format	Route-text	13.86
	2=Suggested route diversion information on a graph-only format	Route-graph	16.64
	3=Suggested route diversion information on a text-graph format	Route-text-graph	28.60
	4=Congested traffic condition with a reason on a text-only format	Congestion-text	6.24
	5= Qualitative delay time on a text-only format	Delay-text	13.86
	6= Qualitative delay time on a text-graph format (Reference case)	Delay-text-graph	20.97
Road information attribute	1=Current road information(Reference case)	CRI	13.86
	2=Current and alternative road information	CAR	50.26
	3=Current and adjacent road information	CJR	35.88
Color of text-only format	1= Amber-on-black(Reference case)	ABT	41.33
	2= Red-on-black	RBT	23.21
	3= Green-on-black	GBT	35.46
Color of graph-only format	1=White-on-green(Reference case)	WGG	26.32
	2=White-on-blue	WBG	36.31
	3=Amber-on-black	ABG	37.37

Variables	Code	Abbreviation	%
Color of text-graph format	1=Amber-on-black on text format and white-on-blue on graph format (Reference case)	ATWG	64.51
	2=Red-on-black on text format and white-on-blue on graph format	RTWG	14.16
	3=Green-on-black on text format and white-on-blue on graph format	GTWG	21.33
Gender	0=Female	—	25.56
	1=Male	—	74.35
Driving experience	0= More than 3 years	—	49.91
	1= Less than 3 years	—	50.09
Education level	0= Below Bachelor degree	—	42.46
	1= Above Bachelor degree	—	57.54
Occupation	0=Fix occupation	—	38.99
	1=Free occupation	—	61.01
Monthly income	0=More than 6000 RMB	—	22.36
	1=Less than 6000 RMB	—	77.64
Trip purpose	0=Non-official trip	—	64.12
	1=Official trip	—	35.88
Number of message lines/layers	1=Single lines/layers(Reference case)	—	15.08
	2=Double lines/layers	—	65.68
	3=Triple lines/layers	—	19.24
Whether weather conditions affect drivers' choice	0= No	—	38.13
	1= Yes	—	61.87

Note that the text-graph format has the two layers on graph format and various lines on text format.

2.2 Statistical analysis

The RP experiment offered choices between six kinds of VMS panel information as shown in Table 1. Since the dependent variable is a nominal categorical variable, the most appropriate statistical method is a multinomial logit model. This is the most commonly employed discrete choice model in which we assume a sample of N drivers with the choice of I alternatives on a choice occasion t . The utility that a decision maker n choosing alternative i on a choice occasion t has two parts: (i) representative or observed utility (i.e. V_{nit}) and (ii) a random component (i.e. ε_{nit}) denoted as:

$$U_{nit} = V_{nit} + \varepsilon_{nit} \quad (1)$$

The observed component V_{nit} dependent on a systematic part $X_{nit}\beta_i$, where X_{nit} is a vector of relevant covariates confronting the individual n on a choice occasion t choosing alternative i , and β_i is a vector of associated importance weights and the intrinsic preference of individual n for decision i , which is captured by a fixed term, i.e., α_{ni} . Hence, the random utility is given as follows:

$$U_{nit} = \alpha_{ni} + X_{nit}\beta_i + \varepsilon_{nit} \quad (2)$$

In which the random component captures the observed factors that not covered in the observed utility. The multinomial logit (MNL) model is therefore derived by assuming that each ε_{ni} is independently and identically distributed (IID) extreme value known as Gumbel and type I extreme value distribution. The probability that a participant maker n chooses alternative i on a choice occasion t can be expressed as:

$$p(y_{nt} = i) = \text{prob}(\alpha_{ni} + X_{nit}\beta_i + \varepsilon_{nit} > \alpha_{nj} + X_{njt}\beta_j + \varepsilon_{njt}) \quad \forall j \neq i \quad (3)$$

The MNL model probabilities are obtained by the following formula:

$$p(y_{nt} = i) = \frac{\exp(\alpha_{ni} + X_{nit}\beta_i + \varepsilon_{nit})}{\sum_{j=1}^J \exp(\alpha_{nj} + X_{njt}\beta_j + \varepsilon_{njt})} \quad i = 1,2,3,\dots,I \quad (4)$$

As every participant was asked to fulfill the questionnaire about their preference for VMS panel information (fog and normal weather), unobserved individual-level corrected effects and heterogeneity should be taken into

account. However, the MNL model assumes that the random components of the utilities of different choice alternatives are IID and cannot capture the heterogeneity across participants. The mixed multinomial logit (MMNL) model offers significant advantages over the MNL model by allowing for heterogeneity across participants. The random-parameter formulations of the MMNL model is given by:

$$p(y_{nt} = i) = \int_x \frac{\exp(X_{nit}\beta_i)}{\sum_{j=1}^J \exp(X_{njt}\beta_j)} f(\beta | \theta) d\beta \quad (5)$$

where $f(\beta|\theta)$ is a density function and θ is the vector of parameters to be estimated that represents, for instance, the mean and standard deviation of contributory factors.

In contrast to the random parameter model, an alternate means to accommodate unobserved heterogeneity among participants is through the use of latent class model. The latent logit model accommodates unobserved heterogeneity among study participants without any assumption as to the form of this underlying heterogeneity. Instead, the latent class logit model assumes individuals are implicitly sorted into a series Q classes, with the classification unknown (i.e., unobserved) for a particular individual. It is assumed that parameters have identical effects within these class, but different effects between classes. The prior probability for class q and individual n follows the form of a logit model:

$$P(class = q) = \frac{\exp(Z_n\theta_q)}{\sum_{q=1}^Q \exp(Z_n\theta_q)} \quad q = 1, 2, 3, \dots, Q, \theta_Q = 0 \quad (6)$$

where Z_n denotes a set of individual characteristics that are associated with a class membership. θ_q is corresponding parameter for q class. To ensure that the model is identifiable, the Q^{th} parameter vector is arbitrarily normalized to zero (39, 40).

Within the class, choice probabilities are assumed to be generated by the multinomial logit model:

$$P(y_{nt} = i | class = q) = \frac{\exp(X_{nit}\beta_q + a_{ni})}{\sum_{j=1}^J \exp(X_{njt}\beta_q + a_{nj})} \quad (7)$$

where β_q is class specific parameter vector.

The likelihood for individual n is the expectation over all classed of the class-specific contributions:

$$P(y_{nt} = i) = \sum_{q=1}^Q \frac{\exp(Z_n\theta_q)}{\sum_{q=1}^Q \exp(Z_n\theta_q)} \cdot \frac{\exp(X_{nit}\beta_q + a_{ni})}{\sum_{j=1}^J \exp(X_{njt}\beta_q + a_{nj})} \quad (8)$$

3. RESULT

3.1 Preference for VMS

Table 2 and Figure 1 present the final modeling results and the marginal effects of the model, respectively. As illustrated in Table 2, there are many distributions that are supposed to use for the random parameters in MMNL model, such as normal, lognormal distribution, skewed normal, truncated normal, uniform, triangular, censored (left), censored (right) etc. However, only when the distribution is supposed to the censored (right), the results has the significant random parameters (i.e., amber-on-black (ABG) and red-on-black on text format and white-on-blue on graph format (RTWG)). Additionally, the standard deviation of RTWG is not listed because it is zero. Compared with MNL and MMNL model, the two-class latent class logit model has a significantly improved goodness-of-fit because it has the lower AIC as well as the higher log-likelihood and likelihood ratio. In addition, the latent class logit models more than two classes could not be estimated because of the convergence problem. With respect to the color of the text-only format, 70% of the motorists (Class 1) are much more likely to prefer RBT (in comparison to amber-on-black, ABT) for the ‘route-text’, ‘congestion-text’ and ‘delay-text’ alternatives. The finding is, however, opposite for Class 2 motorists. More specifically, Red-on-Black (RBT) color has a positive impact on drivers’ preference for a text-only format in Class 1 but a negative impact in Class 2, which indicates that a 70% of the drivers prefer the VMS information to be displayed by RBT and the rest 30% of the divers prefer the VMS information with ABT on a text-only format. This confirms inherent taste heterogeneity among the motorists as expected. Additionally, as to the overall sample, drivers are most likely preferred the congested traffic condition with the reason information (i.e. congestion-text) and least likely to the qualitative delay time information (i.e. delay-text) shown by RBT on a text-only format. It is inconsistent with the previous studies conducted by Yang et al. (11), Lai (14, 15), who found that drivers showed strong preference for amber over red colored message on a text-only format. One possible explanation is

the compatible relationship of VMS content and format. The previous studies aim at exploring the effect of VMS format but ignoring the effect of VMS content on drivers' choice, so they simply assume that the RBT decreases the probability of a text-only format preferred by drivers by adding all off them (i.e., $-5.49\%+2.77\%+0.77\%=-1.95\%$). The negative coefficient of RTWG in Class 1 and the positive coefficient value of RTWG in Class 2 indicate that 70% of the drivers prefer the VMS information to be showed by amber-on-black on a text format and white-on-blue on a graph format (ATWG) whereas the rest 30% of the drivers prefer the VMS information showed by RTWG on a text-graph format (i.e. route-text-graph alternative and delay-text-graph). Nevertheless, RTWG was found to increase drivers' preference for a text-graph format. One explanation of this finding is that the coefficient effect of small group (Class 2) on drivers' preference for the color of a text-graph format is much larger than the big group (Class 1), supporting most drivers' choice. Owing to all drivers' choice affected by weather conditions, the effect of weather condition on their choice cannot be explicitly illustrated. The detail explanation about how weather conditions affect drivers' choice is presented in following section.

The variable - double lines shows a significantly negative value for the suggested route diversion information on a text-only format (route-text) and the suggested route diversion information on a text-graph format (route-text-graph) in Class 1 and the congested traffic condition with a reason on a text-only format (congestion-text) in Class 2. This means that drivers prefer the information showed by single line to double lines, which confirms a previous finding (13). However, Lai (15) pointed out that messages with double lines generally lead to a faster reading and preferred by participants. A possible explanation is the compatible relationship of lines and message contents of VMS. Differing from displaying one kind of message VMS content in this paper, the message in the Lai's experiment included two different parts message, therefore two doubles lines message correspond to the different part message. In addition, drivers are more inclined to the suggested route diversion information on a graph-only format (route-graph) showed by two layers. There is a clear downward trend for the probability of drivers' preference for the suggested route diversion information as drivers' driving experience have more than 3 years. It is consistent with previous studies (12, 26, 33) which concluded that inexperienced drivers found VMS guidance information more useful and faced fewer problems while using VMS. Free occupation increases the probability of route-text-graph and qualitative delay time on a text-graph format (delay-text-graph) as well as decreases the probability of route-text, route-graph and congestion-text preferred by drivers in all samples. Evidence from the marginal effect means that drivers with free occupation are inclined to the suggested route diversion and qualitative delay time shown on a text-graph format. It is supported by the questionnaire data which demonstrated that the proportion of route-text-graph preferred by drivers with free occupation is largest (32.10%), followed by delay-text-graph (23.30%). Compared with delay-text-graph, drivers with official trip purpose prefer the congestion-text most, followed by qualitative delay time on a text-only format (delay-text), route-graph. It was consistent with Sharples et al. (22) who found that the specific reasons of traffic congestion instead simple congestion were easier to make drivers trust it. However, this is inconsistent with the previous study (20) which found that drivers preferred the guidance information to qualitative information. This may be explained by the previous studies which synthesize delay-text-graph and delay-text to a whole (2.27%-6.45%=-4.18%).

Table 2: Estimation result for various model (p-value in the parentheses)

Variable	MNL	MMNL	Latent class logit model		
			Class 1	Class 2	
Color of text-only format (Red-on-black, RBT)	—	—	0.59 (0.01)	-1.58(0.00)	
Color of graph-only format (Amber-on-black, ABG) (Mean)	—	0.55(0.03)	—	—	
Color of graph-only format (Amber-on-black, ABT) (Standard deviation)	—	2.47(0.00)	—	—	
Color of text-graph format (RTWG)	—	0.32 (0.05)	-0.57(0.01)	2.23(0.01)	
Whether weather conditions affect drivers' choice (Yes)	—	—	-0.31(0.01)	0.80(0.03)	
Suggested route diversion information on a text-only format (route-text)	Number of message lines (Double lines)	-0.56(0.02)	—	-0.70 (0.02)	
	Gender (Male)	-0.48(0.04)	-0.49(0.03)	—	
	Education level (Above Bachelor degree)	-0.80 (0.01)	-0.84(0.00)	—	—
	Driving experience (More than 3 years)	—	—	-1.25(0.01)	—
	Occupation (Free occupation)	-0.61(0.01)	-0.70(0.01)	-0.73(0.02)	—
	Constant	0.78(0.01)	0.67(0.01)	1.21(0.01)	-9.42(0.97)
Suggested route	Number of message lines (Double layers)	0.44(0.05)	—	1.10 (0.01)	—

	Variable	MNL	MMNL	Latent class logit model	
				Class 1	Class 2
diversion information on a graph-only format (route-graph)	Driving experience (More than 3 years)	-0.57(0.01)	—	-1.92(0.04)	—
	Occupation (Free occupation)	-0.46(0.03)	-0.41(0.05)	-0.71(0.03)	—
	Trip purpose (Official trip)	—	—	-0.88(0.04)	4.82(0.00)
	Constant	-0.19(0.52)	0.18(0.51)	0.51(0.36)	-3.26(0.03)
Suggested route diversion information on a text-graph format (route-text and graph)	Number of message lines (Double lines)	—	—	-0.64(0.02)	—
	Gender (Male)	0.58(0.01)	0.54(0.01)	—	—
	Education level(Above Bachelor degree)	—	-0.37(0.03)	—	—
	Driving experience (More than 3 years)	-0.66(0.00)	—	-1.78(0.00)	—
Congested traffic condition with a reason on a text-only format (congestion-text)	Occupation (Free occupation)	—	—	0.62(0.04)	—
	Constant	0.24(0.35)	0.09(0.68)	1.46(0.01)	14.28(1.00)
	Weather conditions affect (Yes)	0.88(0.00)	-0.44(0.03)	—	—
	Number of message lines (Double lines)	—	—	—	-1.57(0.05)
Qualitative delay time on a text-only format (delay-text)	Driving experience (More than 3 years)	-0.81(0.00)	—	—	—
	Occupation (Free occupation)	-0.60(0.01)	-0.63(0.03)	-1.39(0.00)	—
	Trip purpose(Official trip)	—	—	0.87(0.04)	—
	Constant	0.05(0.86)	0.29(0.29)	-0.82(0.27)	1.32(0.09)
Class probabilities	Driving experience (More than 3 years)	-1.38(0.00)	—	—	—
	Trip purpose (Official trip)	—	—	—	3.44(0.01)
	Constant	-0.90(0.02)	-1.05(0.04)	12.01(0.99)	-0.10(0.91)
	Class probabilities	—	—	0.70(0.00)	0.30(0.00)
Number of parameters		6	6	7	
Constant-only likelihood		-1965.9082	-1965.9082	-1965.9082	
Final log-likelihood		-1889.1788	-1921.5735	-1859.2561	
AIC		3848.4	3901.9	3832.5	
Likelihood ratio test vs MNL model		—		$\chi^2 = 59.8 > 3.84$	

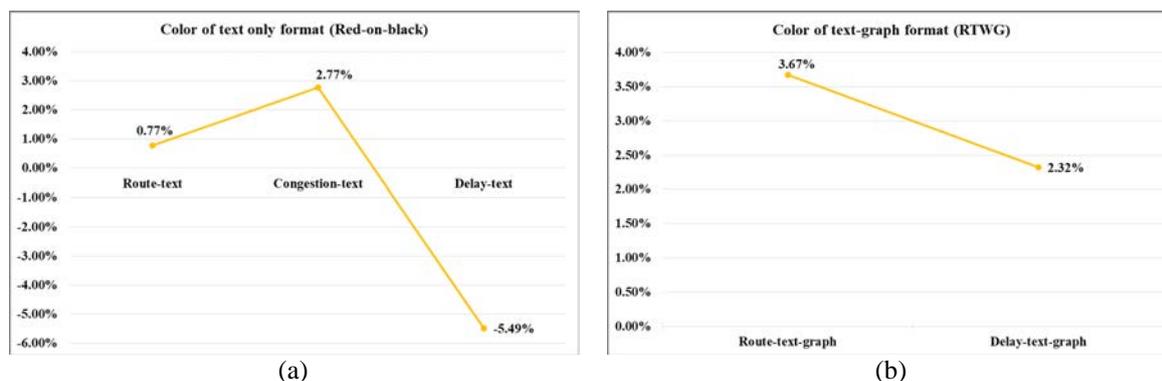


Figure 1: Marginal effect for predictor variables by model formulation

4. DISCUSSION

4.1 Policy implications

Findings from the modelling exercises have important implication for the design and display of roadside VMS information and for the design of personalized in-vehicle advanced driver assistance systems (P-ADAS). Most notably, the color of text message, weather conditions and the number of message lines/layers have found to be very important factors in designing VMS panels and displaying mandatory and advisory information. Firstly, the appropriate compatibility of the VMS information and the color of the text message need be considered in order to make a VMS acceptable and reliable to motorists. . Secondly, the text message showed by single line and the suggested route diversion information showed by two layers on a graph-only format are preferred by drivers. This means that any effective VMS format must be equipped with the suitable number of message lines/layers to

instantly deliver the appropriate information to drivers in a short period of time. As the finding that driver characteristics can significantly influence drivers' preference for VMS content, the in-vehicle P-ADAS can therefore provide the personalized information for drivers by identifying drivers' individual characteristics. For instance, the in-vehicle system is supposed to provide the qualitative delay time information for the drivers when the system identifies the drivers who have free occupation, or the drivers who have more than 3 years driving experience. In addition, the system should first provide the congested traffic condition with a reason for the delay information for them when drivers inform the in-vehicle system about their trip purpose.

4.2 Conclusions

This paper aims to facilitate the design and display of desirable VMS panels by examining what kinds of VMS content, format and their interactions are more preferable to drivers. The results showed that the congested traffic condition with a reason information are preferred by drivers when the information is showed by RBT (red-on-black) on a text-only format or by drivers when they have a specific trip purpose (e.g., working trips). Drivers with free occupation prefer suggested route diversion and qualitative delay time information on a text-graph format. However, RTWG (red-on-black on a text format and white-on-blue on a graph format) shown on a text-graph format are less preferred by most drivers. Regarding suggested route diversion information, drivers are more likely inclined to graph-only showed by two layers and text format showed by a single line. Nevertheless, drivers with more than 3 years driving experience are less prone to suggested route diversion information. The research has potential to improve the efficiency of variable message signs based on the available resources and design personalized in-vehicle advanced driver assistance systems. Further works shall combine the subjective and objective measures to optimize the VMS.

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Driving Anger Among Professional and Non-Professional Drivers In China

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Abstract

Driving anger, as the most common emotion in the driving environment, has been associated with traffic crashes and injuries. This study aimed to investigate the types of situations that cause Chinese drivers to become angry. The translated 33-item Driving Anger Scale was used to investigate driver anger amongst 3200 drivers from China, including both professional and non-professional drivers. Confirmatory factor analysis showed that the fit of the original six-factor model (discourtesy, traffic obstructions, hostile gestures, slow driving, illegal driving and police presence) was satisfactory, after removing two items and allowing five error pairs to covary. The result of confirmatory factor analysis and reliability analysis indicated that the six factor DAS fit well with the data of Chinese driver sample, verifying that the overall reliability of the six factors was acceptable. Driving anger among Chinese drivers was lower than that of some western countries. Compared with older and experienced drivers, younger and new drivers were more likely to be angry. As for gender, there was no difference in total driving anger between males and females. Additionally, the higher the driver's anger level was, the more likely they were to participate in a car accident. Above all, driving anger among Chinese drivers has a strong correlation with drivers' characteristics and traffic collisions. Targeted measures according to drivers' characteristics, especially for young and new drivers, need to be developed to prevent road traffic injuries caused by driving anger in future studies.

Keywords: Road traffic injuries, driving anger, confirmatory factor analysis

1. OBJECTIVE

Road traffic injuries have become a substantial public health issue in China, with an increasing number of traffic fatalities year after year. Aggressive driving is a risk factor for increasing drivers' chances of involvement in a motor vehicle collision and the likelihood of a serious collision. Driving anger, as the most common emotion in the driving environment, has been associated with aggressive driving. Previous studies found that driving anger can interfere with the driver's ability to focus, perceive, and process information and ability to drive safely, thereby increasing risky driving behaviors that can increase the risk of crashes, such as driving faster and with less focus. At present, research on characteristics influencing driving anger in China is rare. Most of the previous research samples were professional drivers with a small sample size. Therefore, the previous research has the limitation of insufficient population representation. This study investigated driving anger in a large sample of Chinese motor vehicle drivers, including both professional and non-professional drivers. This research aimed to validate the use of the 33-item Driving Anger Scale (DAS) in a Chinese sample of drivers and to explore the relationship between the DAS and demographic characteristics using variables such as age and gender.

2. METHODS

A cross-sectional study was conducted to interview 3,200 drivers in southern China. The content of the questionnaire included three parts. The first part included basic demographic characteristics of the car driver, the type of car, and the number of years of obtaining a driver's license, the actual number of years of driving, the state of health, personal habits, living conditions and driving behavior. Part 2 was about the driving anger scale which envisages situations that may be encountered. The translated 33-item Driving Anger Scale (DAS) was used to measure driving anger. The DAS contains 33 items in six dimensions: discourtesy; hostile gestures; slow driving; obstructed traffic; illegal driving; and police presence. Participants were instructed to imagine each situation actually happened to them and then assess anger on the 5-point Likert scale (1 = not at all, 5 = very much). The third part was about the

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driver's road violations and car traffic accidents in the most recent year. Data were collected by face-to-face interviews between June 2016 and September 2016.

Data were entered using Epidata 3.02 and analyzed with SPSS 11.0. Confirmatory factor analysis (CFA) was performed to evaluate the model fit on 33 items of DAS using the maximum likelihood (ML) method in AMOS 20.0. The goodness-of-fit was evaluated with the following indices: adjusted comparative fit index (CFI), incremental fit index (IFI), and the Root Mean Square Error of Approximation (RMSEA) as well as its 90% Confidence Interval (C.I. 90%). For CFI and IFI, values greater than 0.90 demonstrate a good fit. For RMSEA, values less than 0.06 indicate a good fit. In the preliminary analysis, the mean and standard deviation of the descriptive variables were first analyzed, then the means and standard deviations of each item of the DAS and each subscale were explored, and Cronbach's alpha was calculated. Pearson's correlation coefficients were explored to examine the relationships between the driving anger subscales and total anger with the demographic factors (age, annual income, driving years, daily mileage, and daily driving time). Differences in driving anger between different countries were assessed by using an independent sample t-test using summary data. Additionally, Independent t-tests were also used to investigate gender differences and differences in overall anger scores between participants who had been involved in a crash.

3. RESULTS

Our face-to-face survey received a total of 3,101 valid questionnaires with a total response rate of 96.9%. Reasons for non-response included incomplete questionnaires and absence from the survey. Participants in this survey ranged in age from 21 to 72 years (Mean = 38.82, SD = 8.82). They had an average of 8 years driving experience, ranging from 1 to 40 years. Confirmatory factor analysis showed that the fit of the original six-factor model (discourtesy, traffic obstructions, hostile gestures, slow driving, illegal driving and police presence) was satisfactory, after removing two items and allowing five error pairs to covary. The model showed satisfactory fit: GFI = 0.90, IFI = 0.90, RMSEA = 0.06, 90% C.I. = 0.061-0.064. The discourtesy had the highest score among the six factors, with an average subscale score of 2.14 (SD = 0.88). The least angering situation was "Police officer pulls you over" (M = 1.19; SD = 0.60) and this belonged to police presence subscale, which had the lowest average subscale score (M = 1.27; SD = 0.53) of the six factors. Age, driving years, daily mileage and daily driving time were negatively correlated with total driving anger ($p < 0.05$). Age was also negatively correlated with four of the six anger subscales ($p < 0.05$). Driving anger of females was higher than males in discourtesy, traffic obstruction and hostile gestures ($p < 0.05$), while male participants reported significantly more anger provoked by police presence ($p < 0.05$). There was no difference in total anger between males and females ($p > 0.05$). Police presence scores from the Chinese drivers were similar to the United Kingdom sample ($p > 0.05$). Other than this, the subscale means from the Chinese drivers were statistically lower than those from British, New Zealand, Spanish, French, and Turkish drivers ($p < 0.01$). Drivers who suffered from traffic accidents scored higher in the three dimensions of discourtesy, traffic obstructions, and hostile gestures, than in those who did not ($p < 0.05$).

4. CONCLUSION

The Chinese version of the six-factor DAS has good reliability and validity, indicating that the DAS can be an available measure of driving anger in China. Driving anger among Chinese drivers was lower than that of some western countries. Compared with older and experienced drivers, younger and new drivers were more likely to be angry. The higher the driver's anger level was, the more likely they were to have had a traffic collision. Above all, driving anger among Chinese drivers has a strong correlation with drivers' characteristics and traffic collisions. Targeted measures according to drivers' characteristics, especially for young and new drivers, need to be developed to prevent road traffic injuries caused by driving anger in future studies.

Effective Police Enforcement: What Works

Dinesh Mohan^{1a} and Rahul Goel^b

Abstract

Enforcement of traffic rules and regulations forms an important component of strategies to reduce deaths and injuries due to road traffic crashes. As with many other issues concerning road safety policy, it is not always clear whether common sense approaches in police enforcement actually reduce injuries and fatalities on the road. It is therefore important to assess whether a given enforcement measure, though seemingly beneficial in its intent, actually results in any reduction of delinquent behaviour of drivers and number of crashes. In this article we assess the evidence base of effectiveness of on-road enforcement measures by conducting a review of systematic reviews on this topic. In this review we focussed only on the objective police programmes or strategies and excluded the reviews which assessed the effectiveness of a traffic enforcement law. We answer the following questions in this review: (a) What is the theoretical basis of different enforcement measures? (b) What are the different road safety enforcement measures for which evidence is available in systematic reviews and how current is this evidence? (c) What are the different limitations or drawbacks of different studies as reported by the systematic reviews and what are their implications on results? (d) What are the different factors which limit the generalisations of available evidence across different settings or across different types of modes? Our review suggests that: (i) Legislation and enforcement is effective when violations are visible and easy to detect. (ii) Strict punishment not as effective as subjective perception of being caught violating a law. (iii) There is an absence of studies that could provide guidelines on police enforcement for low and middle-income countries on the following issues: a. Influence of road and infrastructure design on traffic violations and the difficulties of enforcement when designs are not adequate for the kind and volume of road users present; b. critical/minimum levels of enforcement necessary for different traffic violations; c. enforcement methods that would be cost effective in situations with high proportion of motorcycles and other vulnerable road users.

Keywords: Penalties, traffic safety, enforcement, police

1. INTRODUCTION

Road traffic injury (RTI) reduction depends on interventions in institutional arrangements, road and environment design, vehicle safety features, post-crash care and ensuring safer road user behaviour by better policing systems. Regulation of traffic by police enforcement can be an effective strategy to reduce the public health burden resulting from traffic injuries (1-3). As with many traffic safety interventions, the outcomes are not always as expected, and a weak theoretical foundation in traffic safety research makes it difficult to predict the effectiveness of different enforcement measures. For example, an increase in fixed penalties for speeding or jail terms for drinking and driving offences have not been found to be very effective deterrent measures in some studies (4-9). Given the large variation in road designs and types of traffic mix, a given intervention is likely to have varying effects across different settings. Traffic enforcement measures can be costly, lead to additional workload for enforcement agencies and may involve additional costs in publicising these measures through various platforms. It is therefore important to assess whether a given enforcement measure, though seemingly beneficial in its intent, actually results in any reduction of delinquent behaviour of drivers and number of crashes.

1.1. Theoretical framework for enforcement measures

Elvik (10) discusses a simple theoretical model that was developed by Evans (11) which can be used to understand the finding of a road safety evaluation study (Figure 1). The basic understanding according to this model is that there are two causal chains which connect a road safety measure to its final outcome—engineering and behavioural. In the context of traffic enforcement, we are concerned with the causal chain through the behavioural effect. There are, therefore, two main theoretical strands based on which we can explain the effectiveness of traffic enforcement. First is the theory which explains why drivers correct their behaviour when

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Figure 1. Theoretical model of road safety (Adapted from Reference 2).

an enforcement measure is implemented. Second is the theoretical basis which explains why that particular change in behaviour would lead to higher safety. For example, an enforcement measure targeting over-speeding would likely result in reducing the proportion of drivers driving above a certain speed limit. This is the behavioural effect of the enforcement. The final outcome i.e. number of crashes and accidents would then be dependent on the relationship between speed distribution and crashes.

The underlying theory which explains the effectiveness of different enforcement measures is called the 'deterrence theory', where deterrence is 'the omissions or curtailment of a crime from the fear of legal punishment' (12). According to this theory the fear of punishment encourages potential offenders to comply with the law. The enforcement measure works not only by apprehending the offenders, which is often a very small proportion of all road users and in fact a small proportion of all offenders, but also by discouraging 'potential' offenders because of the perceived certainty getting caught (5, 6, 13-15).

"The principal opportunity for criminal law to be effective in reducing drunk driving is paradoxically, not by affecting the apprehended law violators, who stand within its power. Rather, it lies in affecting unapprehended individuals who are sensitive to the threat that, should they behave illegally, they will be punished (15)"

There are two types of deterrence, specific and general. Specific deterrence primarily focusses on punishing apprehended offenders and assumes that they will be deterred from repeating their offence in the future to avoid punishment. On the other hand, general deterrence focuses on the population in general and assumes that the threat of punishment will deter people from violating the law in the first place. The greater the perception of risk of punishment, the greater the likelihood that general deterrence will be effective. For an enforcement policy to be effective, it needs to ensure both types of deterrence are at work, so that a sanction not only impacts the individual who is being punished but also others who do not directly experience the sanction. The understanding of theoretical aspects that explain the effectiveness of enforcement measures is important to develop hypotheses for future application of these measures in different settings.

2. OBJECTIVES

In this paper we assess the evidence base of effectiveness of on-road enforcement measures by conducting a review of systematic reviews on this topic. In this review we focussed only on the objective police programmes or strategies and excluded the reviews which assessed the effectiveness of a traffic enforcement law. This is because in different settings across the world a law may translate to actual implementation on the road by varying degrees in terms of how soon it is implemented as well as its spatial coverage. In some countries, while a law may exist, but its implementation may be limited because police may think of it as less of a priority or because there is lack of capacity to implement it (3, 16). We will use this review to answer the following questions:

- 1) What are the different road safety enforcement measures for which evidence is available in systematic reviews and how current is this evidence?
- 2) What are the different limitations or drawbacks of different studies as reported by the systematic reviews and what are their implications on results?
- 3) What are the different factors which limit the generalisations of available evidence across different settings or across different types of modes?
- 4) What is the theoretical basis of different enforcement measures?

3. SUMMARY OF SYSTEMATIC REVIEWS

To find relevant studies, we used three main sources with a database of systematic reviews of road traffic injuries. These are The Handbook of Road Safety Measures (17), Cochrane Injuries Review Group (<https://injuries.cochrane.org/our-evidence>) and Community Preventive Services Task Force (<https://www.thecommunityguide.org/content/task-force-findings-motor-vehicle-injury>). We also searched for the systematic reviews using the ancestry approach. We have not included any reviews published before 1990. Among the traffic enforcement measures, we found reviews covering four offences: speeding, red-light running, alcohol-impaired driving, and seat belt use. In some cases, we found multiple reviews for the same enforcement measure. For example, the review of red-light cameras by Aeron-Thomas and Hess (18) has been updated by Perkins, Steinbach (19). The speed camera review by Wilson, Willis (20) published in 2006 (Cochrane Collaboration) was updated by Wilson, Willis (21) in 2010, and a study to update and expand the Cochrane systematic review, to provide a comprehensive account of the range of automatic speed enforcement strategies employed worldwide has been initiated by Steinbach, Perkins (22). For effectiveness of speed cameras, we have also included a later contemporary review by Høyve (23) as it added value in terms of discussing some other facets that are missing from Steinbach's review.

3.1. Speed control

One of the earliest reviews of the effectiveness of speed cameras was done by Pilkington and Kinra (24) in 2005. The authors did not conduct a meta-analysis given the differing nature of the studies included. The review found that all the studies reported reduction in various crash outcomes (collisions, injuries and deaths). However, the authors noted that the level of evidence was relatively poor, and most studies lacked adequate comparison groups. The other two meta-analysis of speed enforcement were conducted more recently and includes all types of speed camera measures.

The most common speed enforcement methods are point-based where vehicle speeds are detected at fixed locations on the road. With point-based speed enforcement methods, the drivers get familiar with locations of cameras and modify their behaviour only in the immediate vicinity of speed enforcement. Hence, innovative approaches were needed to make speed enforcement more effective. Average speed enforcement method was developed as an alternative to point-based method. This is also referred to as 'average speed section control', 'point to point', 'time over distance' cameras or section control or trajectory control (21, 24). This type of enforcement involves the installation of a series of cameras at multiple locations along a road section. The average speed of a vehicle over a section of a road is calculated by capturing its license plate number at more than one camera locations. In case this speed exceeds the posted speed limit, the vehicle information is communicated to a central unit. Almost all current installations throughout the world involve some degree of human verification to assess the validity of detected infringements. In such a system there are stopping sites for manual enforcement.

A meta-analysis of speed cameras and average enforcement method was conducted by Høyve (23). The study reported following:

- Speed cameras resulted in reduction of all crashes (20%) and larger reduction of fatal crashes (51%), though the latter may be affected by regression-to-the-mean.
- Section control resulted in larger reduction in all crashes (30%) compared to speed cameras, and reduction in KSI crashes (56%) was even greater than reduction of all crashes by section control and reduction of fatal crashes by speed cameras
- The effect of speed cameras reduce as the distance from the camera increases.
- The authors also compared the reduction in the number of crashes as estimated by the two of the reviewed studies to the estimate from the power model of speed as reported by (17). Both the studies found crash reduction to be greater than what would be expected from the reduction in speed alone as predicted by the power model.
- The implementation of speed cameras may be accompanied by crash migration when drivers tend to slow down close to the cameras and then driver faster than they would have otherwise away from the cameras. The review found no evidence that this phenomenon, known as kangaroo driving, resulted in adverse safety effects.

Another review of speed cameras was done by the Cochrane group (22). This review includes mobile and fixed cameras, including the average enforcement methods. Unlike fixed cameras, mobile cameras are operated from parked motor vehicles, and therefore can be moved from one place to another. The study concluded the following:

- There was no difference of effect between the covert and overt cameras or between the urban and rural areas.
- There is a strong evidence suggesting that the implementation of speed cameras is associated with reduction in speed and crash outcomes.
- There was a reduction in percentage of vehicles exceeding the speed limit (50% to 64%)
- The effects do not account for the differences in the posted speed limit though percentage reduction is likely to be a function of the speed limit
- There is evidence of some halo effect i.e. the greater reduction in speed and crash outcomes in the vicinity of the cameras.
- No study provided empirical information on the effects of camera programmes on speeding and crash outcomes in the wider areas within which speed cameras are implemented, in order to assess whether general deterrence theory might be supported.
- No studies reported on the sizes of fines or penalties issued to offenders. By linking the size of fine with the specific road and camera where the driver had offended, it would be possible to assess whether larger fines and penalties are more effective. It is possible that 'persuasive' letters to offenders once caught speeding are equally effective a deterrent as being caught and brought to justice.

A review of the effectiveness of average speed enforcement methods was reported by Soole, Watson (25) in 2003. The review concluded the following:

- In general, drivers show higher level of acceptance of average speed enforcement. The traditional camera-based measures using instantaneous speed are criticised on the grounds that drivers need to speed at certain points due to unforeseen reasons.
- The limited evidence suggests that average speed enforcement method may be more effective than instantaneous speed enforcement methods.
- Studies have found the implementation of this method is associated with the reduction in average and 85th percentile speeds, the proportion of speeding vehicles and speed variability. The approach has been specifically effective in reducing excessive speeding behaviour.
- In addition to reduction in speed, studies have also found considerable reduction in fatal and serious injury crash rates.
- There is lack of distance 'halo' effect resulting from average speed enforcement implementation. This means that reduction in speed and crash rates have not been found outside the area of enforcement. Therefore, this enforcement method should be used as complementary to the existing fixed and mobile speed enforcement methods.
- Studies suffered from multiple drawbacks because of which the evidence needs to be carefully interpreted. None of the studies used the control/comparison site. Other drawbacks include lack of driving exposure data and studies not accounting for regression-to-the-mean effect.

There is a strong theoretical understanding based on which effectiveness of average speed enforcement method can be explained. Reduction in excessive speeding behaviour has considerable implications for road safety given the exponential relationship between vehicle speed and crash risk (26-28).

3.2. Red-light cameras

Red-light running results mostly in side-collision crashes which are more severe than other type of intersection crashes. In case there is a dedicated signal for the left-turning vehicles (in right-hand traffic), red-light running also results in head-on collisions. The implementation of red-light cameras (RLCs) is also associated with an increase in rear-end crashes resulting from drivers' tendency to apply break abruptly in order to avoid the fine. Since both the head-on and right angle crashes have higher severity than rear-end crashes, even if the number of crashes are cancelled out, the severity level of crashes is still likely to reduce with the implementation of RLCs. A review by Høyve (29) summarises the empirical evidence of the effects of RLCs on intersection crashes.

- The present study found a non-significant decrease of all injury crashes by 13% and a non-significant increase of all crashes by 6%.
- Right-angle collisions were found to decrease by 13% (not statistically significant) and rear-end collisions were found to increase by 39% (statistically significant).
- For right-angle injury collisions a far larger decrease was found (-33%, statistically significant) and for rear-end injury collisions a smaller increase was found (+19%, statistically significant).

- The results seem to be affected to some degree by publication bias and the effects may therefore be less favourable than indicated. The direction of the effects does however not change when controlled for publication bias.
- The effects for crashes with unspecified severity are likely to be still more favourable when RLC-warning signs are not set up at each RLC-intersection, possibly because of drivers getting a habit of respecting red lights and expecting other drivers braking. If this assumption is correct, one may also expect RLC to become more favourable over time.

A systematic review of the effectiveness of red-light cameras by Perkins, Steinbach (19) concluded the following:

- RLCs can be effective in reducing red-light violations and some types of traffic crashes, particularly right-angle crashes, right-angle injury crashes, and total injury crashes.
- RLCs also appear to be linked to an increase in rear-end crashes which is likely a result of drivers abruptly braking to prevent the offense.
- The presence or absence of warning signs did not appear to have an impact on RLC effectiveness.
- While a number of studies reported that spillover (or diffusion of benefits) occurred, the magnitude of this effect is not established.
- Studies are limited to four countries: USA, Canada, Singapore and Australia. The authors caution the use of this evidence in the UK since the intersections in the USA and Australia are much larger in size than the UK hence drivers may have greater feeling of openness and more likely to jump the light. Further, the speed limits across the settings are different which may also influence the likelihood of red light running.
- This review did not include studies which evaluated the effectiveness of red light cameras used both for red-light running as well as enforcing speed limit during the green.
- Due to the rarity of death or severe injury events, most studies use a combined measure of crashes and do not differentiate between the severity levels of crashes.

In some cases, additional time is given to yellow times and successful RLC programmes may include many on-site modifications such as red-light visibility, addition of warning signs, and amelioration of intersections geometry. This is clearly a case where engineering and enforcement measures are highly interrelated or at least the relationship between the two can be established (30).

3.3. Police patrol for alcohol-impaired driving

Control of drivers under the influence of alcohol has a strong empirical justification. A meta-analysis demonstrates that there is no evidence of a threshold effect for alcohol. Alcohol gradually affects driving skills. There is no sudden transition from unimpaired to impaired occurring at a particular BAC level. A review from the US (31) indicates that crash risk grows exponentially with increasing blood alcohol concentration (BrAC). The study shows that at low levels of alcohol (e.g., 0.03 BrAC) the risk of crashing is increased by 20 percent, at moderate alcohol levels (0.05 BrAC) risk increases to double that of sober drivers, and at a higher level (0.10 BrAC) the risk increases to five and a half times. At a BrAC of 0.15, the risk is 12 times, and by BrACs of 0.20+ the risk is over 23 times higher. Another meta-analysis concludes that “most skills which are relevant for the safe operation of a vehicle are clearly impaired by BACs of 0.05%, with motor functions being more affected than cognitive functions and complex tasks more than simple tasks. Generally, the results provided no evidence of a threshold effect for alcohol. There was no driving-related performance category for which a sudden transition from unimpaired to impaired occurred at a particular BAC level” (32)

A systematic review by Goss, Van Bramer (33) of effectiveness of increased police patrols for preventing alcohol-impaired driving (including studies evaluating increased police patrols, either alone or combined with other interventions) targeting alcohol-impaired motor vehicle drivers concludes that:

- The 32 eligible studies included one randomized controlled trial, eight controlled before-after studies, 14 controlled interrupted time series (ITS) studies, six ITS studies, and three studies with both ITS and controlled before-after analyses. Most interventions targeted only alcohol-impaired driving (69%) and included additional interventions such as media campaigns or special training for police officers (91%).
- Only two studies reported sufficient information to assess study quality completely. Two-thirds of studies were scored ‘not adequate’ on at least one feature. Five of six studies evaluating traffic fatalities reported reductions with the intervention, but differences were statistically significant in only one

study. Effects of intervention on traffic injuries were inconsistent in the six studies evaluating this outcome, and no results were statistically significant.

- All four controlled studies evaluating fatal crashes reported reductions with the intervention, which were statistically significant in one study. All 12 controlled studies assessing injury crashes reported greater reductions with the intervention, though effects were minimal or not significant in several studies. ITS studies showed less consistent effects on fatal crashes (three studies) and injury crashes (four studies), and effect estimates were typically imprecise. Thirteen of 20 studies showed reductions in total crashes and about two-thirds of these were statistically significant.
- Therefore, the available evidence does not firmly establish that increased police patrols reduce the adverse consequences of alcohol-impaired driving. Good quality controlled studies with adequate sample size are needed to evaluate increased patrols. Also needed are studies assessing the cost-effectiveness of this intervention.

Evidence shows that an increase in the perceived risk of arrest appears to deter alcohol-impaired driving more effectively than increasing the severity of penalty after arrest and police patrol intervention increase the presence of police and the perception of being caught (33).

3.4. DUI (Driving under the Influence) checkpoints

These checkpoints refer to police operations where one or more police cars are standing beside the road and where police officers pull out drivers in order to check whether or not he or she has an illegal blood alcohol level (BAC). At these checkpoints, also known as sobriety checkpoints, drivers can be stopped even if they do not give any indication of driving under the influence of alcohol, and therefore, by correcting their driving behaviour close to these checkpoints does not necessarily prevent the drivers from being stopped. Erke, Goldenbeld (34) conducted a meta-analysis of the effectiveness of DUI-checkpoints. The review concludes:

- Crashes involving alcohol (or proxy measures of such crashes) are reduced at least by 17% and all types of crashes are reduced by 10-15%. Proxy measures of alcohol-related crashes include night-time or weekend night crashes.
- The largest reductions were found during the first 6 months of the DUI-checkpoint implementation, which may be confounded because the intensity of implementation may be much higher for short-term programmes.
- DUI-checkpoints in Australia result in the highest reduction in crashes indicating the Australian methods of booze buses and intensive publicity are highly effective. A similar approach when implemented in New Zealand also found large reductions, thus strengthening the evidence of their effectiveness.

A practical implication from this meta-analysis is that highly visible checkpoints where many drivers are pulled out and tested, following the Australian example, are likely to be most effective.

3.5. Seat belts

Dinh-Zarr, Sleet (35) conducted a systematic review of the effectiveness of primary seat belt laws in the United States which included five evaluations of the effect of primary laws on observed seat belt use. These studies examined belt use in 12 states and the District of Columbia that enacted primary laws during the 14-year period from 1984 to 1997 and a couple of years later Shults, Elder (36) re-examined the studies included in the systematic review to explore whether the benefits of a primary law differ based on: (1) the baseline seat belt use rate; or (2) whether or not the primary law replaces a secondary law. This review includes studies from 1980 to 2000 and is restricted to the studies from US. This review also estimates the effect of seat belt enforcement where the law is graduated from secondary to primary. A primary seat-belt law implies that a driver can be stopped by enforcement officers solely for not wearing a belt. On the other hand, within a secondary seat-belt law the driver can be fined for seat belt only after the driver has been stopped for another offence. The authors hypothesised that a primary law has a greater effect on drivers' perceived risk of detection and punishment, and public in general may also perceive seat belt law as important. These factors may result in making a primary law more effective than a secondary law. The study concluded the following:

- All the studies evaluating primary vs secondary law found primary seat belt law to be more effective than secondary law. The studies which reported fatalities as outcome, found median decrease of 8% higher among primary law states than secondary law states, though statistical significance of this estimate was not reported.

- Enforcement enhancement programs are associated with an increase in seat belt use (median 16 percentage points) and decrease in injuries.
- Based on the studies which carried out a follow-up of the enforcement enhancement programmes after they had concluded, there is evidence that the seat-belt use somewhat declined after the programs are ended.

Elvik, Vaa (17) have reported meta-analysis of seat belt enforcement with no restriction to country and conclude the following:

- The results show the enforcement increases seat belt use by 21% during the enforcement period and by 15% afterwards.
- The covertness of the enforcement improves the effectiveness of seat-belt use. Greater effects have been found when checkpoints are not announced compared to when they are. This may be possible if the drivers think that they will fasten the seatbelts close to a checkpoint, and therefore, general compliance may be lower.
- The change in seat-belt usage rate is higher when the baseline rate is lower. A scatterplot of increase in usage rate versus the baseline usage rate shows a negative relationship between the two.

4. EFFECT OF INTENSITY OF ENFORCEMENT AND PENALTIES ON DETERRENCE

Though a great amount of research has been done on the mechanisms and processes of deterrence over the past four decades, the exact situations under which sanctions (or the threat of sanctions) are likely to influence or change a person's behaviour are still not known in certainty. The difficulty associated with determining casual relationships arises partly from the problem of eliminating competing explanations. Some of these include effect environmental design changes on road user behaviour, changes in modal shares on the road and secular changes in people's behaviour over time. Another problem is that police enforcement levels and intensities can change over short periods of time due to economic and political changes and so it is difficult to do long term studies in many locations. Because there are no systematic reviews of the effect of penalties on deterrence in this section we discuss the results of studies that are available.

4.1. Intensity of enforcement

In 2002 Koornstra et al (37) published a report where they attempt to find a relationship between intensity of police enforcement and level of traffic law violation as an approach to get more insight about which enforcement level is needed in order to change road user behaviour and fatality risks. The results are shown in Figure 2 illustrated by belt wearing data on enforcement and violation levels in Sweden, the United Kingdom, and the Netherlands at that time. The authors cautioned that this curve needs to be validated with research results because of the complexity of that research when it comes to differentiating police

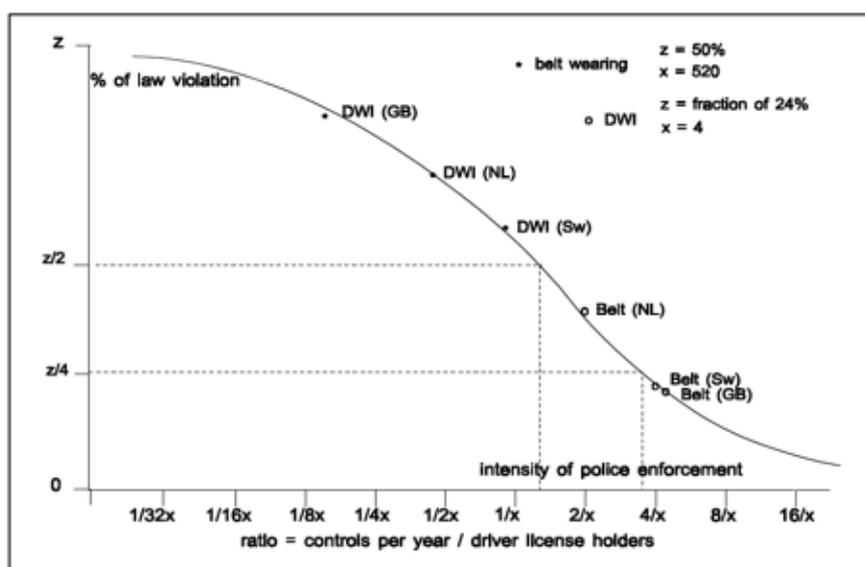


Figure 2. Relationship between enforcement intensity and law violation levels (Source: Reference 20).

GB-United Kingdom, Sw-Sweden, NL-Netherlands, DWI-driving while intoxicated

Table 1. Overview of all information regarding the alcohol related BAC limits, road toll and enforcement measures in selected European countries, data 2007-2010. Adapted from Reference 37.

Country	Legal blood alcohol limit g/L	Police tests per 1,000 inhabitants	Share of alcohol related road fatalities, percent		Share alcohol offenders (above legal limit) %	Share respondents who had atleast once a week 5 or more drinks %
			Expert estimates	Official statistics		
Poland	0.2	47	13	7	9.5	19
Portugal	0.5	63	35	6	5.9	28
Austria	0.5	87	18	6	5.8	36
Spain	0.5	112	NA	31	1.8	34
Hungary	0	130	8	31	3.1	24
France	0.5	190	29	31	3.3	20
Sweden	0.2	287	25	16	0.8	13
Finland	0.5	385	24	29	1.3	22

enforcement efforts (combined with publicity) and the complexity of data-collection. To the best of our knowledge no serious efforts have been made to determine such curves for speed control, seat belt use, helmet use, DUI control and other violations for different modal shares in different countries of the world. What the curve does show is that percent law violation decreases as enforcement intensity increases and that enforcement levels have to be different for different types of violations. For example, the curve shows that in Sweden the enforcement levels needed for control of DWI and for enforcing seat belt use so that violations were limited to about 12 per cent, there had to be 250 checks per 1,000 driver license holders for DWI and 8 for seat belt use.

Table 1 shows information regarding the alcohol related BAC limits, road fatalities and enforcement measures in selected European countries (38). This report commissioned by the DG for Mobility and Transport, European Commission, concluded that 20 to 28% of all road fatalities in the EU in 2012 could be attributed to drink-driving. This is a significant decrease from the 1980s when many countries reported share of alcohol related fatalities to be in the range 30 to 45% (39). The data also show that in some countries expert estimates of the share of alcohol related alcohol fatalities can be higher than the official statistics. Moreover, the definition of 'impaired' is different for each country. It ranges from 0.2g/l in Sweden to 0.5g/l in many countries and so a comparison of countries based on numbers of deaths from drink driving crashes is not really possible. There is general agreement that there was a significant reduction in the period 1980-2010 which can be attributed to stronger laws, vigorous enforcement, and changes in social norms which all contributed to the progress that has been made though not much change has been observed over the last decade.

However, what is not clear is the level of enforcement that ensures a significant reduction in fatalities attributed to drinking and driving. Table 1 shows the that the enforcement levels range from 100 to over 300 tests per 1,000 inhabitants per year. This means that in megacities like Delhi, Shanghai, Beijing or Mexico (populations in excess of 15 million persons), about 5,000 to 15,000 drivers would have to checked every day for effective control of drinking and driving in these cities. At present, we do not have reliable studies available to inform us about the minimum level of enforcement that needs to be put in place in a cost-effective manner in low and middle-income countries.

4.2. Effect of penalties

In a review of deterrence based measures on road user behaviour Davey and Freeman (40) state:

- In order for the 'fear of punishment' to be effective, individuals must believe that the likelihood of apprehension for breaking the law is relatively high.
- A considerable body of early research demonstrated a weak negative relationship between perceived severity of sanctions and a range of illegal behaviours. That is, as perceptual severity increases, the likelihood of an individual committing that offence decreases; *however, an opposing body of research demonstrates that perceptions regarding the severity of penalties do not have the salient deterrent impact that was once assumed* (emphasis added). In fact, some researchers have reported a counter-intuitive relationship, with crime rates actually increasing with increases in the severity of the penalty. Nevertheless, it may be suggested that the greatest deterrent impact in regards to severity of sanctions will be found among those who have never committed an offence, rather than habitual offenders.
- It is recognised that for road safety, the swiftness of impending penalties is an important aspect for achieving deterrence. However, despite the link between the speed of the response and learned

behaviour, the effects of the celerity of legal sanctions is by far the least studied of the three major deterrent mechanisms.

- In regards to general deterrence, a considerable body of evidence suggests that the threat of apprehension and subsequent legal sanctions, especially when supported by well-publicised media campaigns, can produce a deterrent effect, even if short, on offending behaviour.
- In order to create and maintain a deterrent effect, policing operations should be highly visible, sustained and widespread. This ensures that all motorists, whether newly licensed or experienced, perceive a constant high risk of apprehension. If drivers do not regularly observe policing operations, they may become undeterred which may be then reinforced by successfully engaging in offending behaviours that remain undetected, e.g., punishment avoidance.
- Any deterrence-based method employed in isolation does not offer a panacea for the problem of road accidents and fatalities.
- Our current understanding of the mechanisms of deterrence is based heavily on studies that have focused on younger populations. In fact, the bulk of published deterrence-based studies are from a small number of highly industrialised countries (e.g., United States, Canada, Australia, etc), and thus deterrent forces are likely to fluctuate with the surrounding environment.

The above summary highlights the fact that we do not have enough systematic reviews that assess the effectiveness of general deterrence policies on road safety that may have universal applicability. For the present, we have to rely on the studies that seem to point in a similar direction. A brief summary from different countries is given below.

4.2.1. Fixed penalties – fines

Norway

“For speeding in general, no effect of increasing fixed penalties can be found. For speeding close to speed camera sites, there is a weak tendency for the violation rate to go down. This tendency is not statistically significant at conventional levels. For seat belt wearing, wearing rates are found to increase as fixed penalties have increased. In recent years, however, enforcement of the seat belt law has stepped up, making it impossible to separate the effect of enforcement from that of fixed penalties” (4).

The Netherlands

“Many studies have demonstrated that the combination of enforcement and penalties prevent the violation of traffic regulations and increase road safety. However, the most common type of penalty at the present time, a fine, has been found to have little effect... When road users consider the subjective probability of detection to be sufficiently likely, they will avoid violating a regulation... The combination of enforcement and penalty is generally preventative when road users avoid traffic violations on the basis of the expected negative consequences. In other words, road users adapt their behaviour without having already been punished. In particular, frequently conducted and very visible traffic checks, which are unpredictable in terms of time and place and are combined with public information campaigns, bring about the general prevention of traffic violations. Many studies have demonstrated that combining enforcement and penalties prevents violations and increases road safety. Of course, the penalty must match the seriousness of the violation and must be substantial enough to influence behaviour, but particularly the frequency, visibility, and unpredictability of inspections are responsible for the general prevention of traffic violations. Making penalties heavier, as an isolated measure, has been found to have little extra effect. Research into the specific preventative effect of penalties shows that the effect of the currently most common type of penalty, a fine, is negligible when expressed in time. The effects are also negligible in terms of recidivism.” (5)

Australia

“What we do know from the available evidence, however, is that the certainty of detection, apprehension and conviction does matter and in fact may matter more than punishment severity in deterring potential offenders. Informal sanctions from family, peers and colleagues who learn about the offence, and the resulting feelings of shame and embarrassment, are also anticipated costs associated with apprehension and conviction for an offence. Policies that can successfully increase the perceived certainty of detection and prosecution for drink-driving offences are therefore likely to have a greater impact on offending and, subsequently, road accident rates than those advocating harsher penalties.” (6)

“It is suggested that substantial increases in fines and licence disqualifications would have limited potential in deterring recidivist offenders. The present analysis, failed to find any evidence for a significant relationship between fine amount and the likelihood that an offender will return to court for a new driving offence. Nor was

there any evidence from our analyses to suggest that longer licence disqualification periods reduced the likelihood of an offender reappearing before the courts.” (41)

USA

“Speeding citations and their legal consequences are the most common enforcement tools to identify and control speeders, yet little is known about the effectiveness of a speeding citation. There was no significant effect of receiving legal consequences on the risk of receiving a subsequent speeding citation (adjusted RR 0.98, 95% CI 0.83-1.16)... Increasing drivers' perception that they are at risk of being caught speeding and awareness of the consequences from receiving points may improve the effectiveness of speeding law enforcement.” (8)

“We examined effects of state statutory changes in DUI fine or jail penalties for first time offenders from 1976 to 2002. Results: Twenty-six states implemented mandatory minimum fine policies and 18 states implemented mandatory minimum jail penalties. Estimated effects varied widely from state to state. Using variance weighted meta-analysis methods to aggregate results across states, mandatory fine policies are associated with an average reduction in fatal crash involvement by drivers with BAC \geq 0.08 g/dl of 8% (averaging 13 per state per year). Mandatory minimum jail policies are associated with a decline in single-vehicle nighttime fatal crash involvement of 6% (averaging 5 per state per year), and a decline in low-BAC cases of 9% (averaging 3 per state per year). No significant effects were observed for the other outcome measures. Conclusions: The overall pattern of results suggests a possible effect of mandatory fine policies in some states, but little effect of mandatory jail policies.” (9)

“Driving under the influence (DUI) is a significant public health problem... The results showed support for the swiftness and certainty of punishment, there was no support for the severity of punishment. That is, the relationship between the amount of the fine and DUI relapse was not significant. However, deterrence theory would expect certainty and severity of punishment to show a multiplicative relationship, meaning that severity would have its strongest effects when certainty of punishment was high. This interaction was not tested in either study; therefore, firm conclusions regarding the influence of fines cannot be drawn at this time.” (42)

New Zealand

“The question arises whether it is fair and appropriate to have flat-rate penalties (irrespective of prior records) for more and more offences, particularly in the cases of first offenders who can receive no concession and those who continue to re-offend and incur no additional penalty... There must be principled means for adjusting the amount of a fine to take account of both the offender's culpability and his or her resources and there must be efficient and reliable systems of collection and enforcement to ensure that most fines that are imposed will be paid in full and on time... Large fines are often difficult to collect and prove costly to enforce... as with infringements (although to a lesser extent) they may get to be perceived as a method of raising additional public revenue rather than as appropriate penalties for offences.” (7)

4.3. Summary of the evidence on deterrence

- Legislation and enforcement is effective when violations are visible and easy to detect.
- Stricter punishment not as effective as subjective perception of being caught.
- Severe punishment and laws sometimes reduce enforcement by police officials and conviction rates in courts
- There is little evidence that severe penalties reduce violations in traffic, including jail sentences given in isolation.
- Announcement of severe punishments can have a deterrent effect over a short period and the beneficial effect disappears over time.
- All violations that are not considered serious in terms of threat to life or wilful negligent acts endangering the community (serious injury or death), and those that do not require court judgement should have fixed penalties. Penalties for such offences should be in proportion to the ability of the defaulter to pay.
- There is an absence of studies that could provide guidelines on police enforcement for low and middle-income countries on the following issues:
 - Influence of road and infrastructure design on traffic violations and the need of enforcement or effectiveness of enforcement.
 - Critical/minimum levels of enforcement necessary for different traffic violations.

5. CONCLUSIONS

There is a need to translate the results from car-based studies to settings where motorcycles and cyclists share the road space with cars. In such a context, what car-based studies refer to as property-damage only crashes may translate to higher severity crashes if the parties involved are cars/buses/trucks and vulnerable road users. This is the same for intersection crashes resulting from red-light running. The side crashes are often lead to high-severity crashes in case of cars. These will result in even higher severity injury crashes if between a four-wheeled vehicle hitting a motorcycle. It is possible that some of the enforcement measures which proved to be successful in car-based societies may lead to higher reduction in severity of crashes if not the number of crashes in contexts where vehicular mix consists of cars and a high proportion of vulnerable road users.

The reviews included focussed on answering multiple questions. The outcomes include both the compliance rate for the law that is being enforced as well as the crash rates. The first outcome indicates how effective enforcement measure has been to reduce the delinquent behaviour of the drivers that was being targets. The second outcome which includes various metrics of crashes indicates whether enforcement measure translates to reducing the crashes which is not always a given. For instance, red-light camera enforcement results in overall increase in the number of crashes because increase in rear-end crashes may offset the decrease in side and head-on crashes resulting from red-light running.

The reviews have not discussed the injuries classified by the road user types. This means that there is a potential for a revised review of the same studies to understand the effect of the enforcement measures on road users outside the cars such as pedestrians, cyclists and motorcycle riders.

In summary:

- Legislation and enforcement is effective when violations are visible and easy to detect.
- Stricter punishment not as effective as subjective perception of being caught.
- Severe punishment and laws sometimes reduce enforcement by police officials and conviction rates in courts
- There is little evidence that severe penalties reduce violations in traffic, including jail sentences given in isolation.
- Announcement of severe punishments can have a deterrent effect over a short period and the beneficial effect disappears over time.
- All violations that are not considered serious in terms of threat to life or wilful negligent acts endangering the community (serious injury or death), and those that do not require court judgement should have fixed penalties. Penalties for such offences should be in proportion to the ability of the defaulter to pay.
- There is an absence of studies that could provide guidelines on police enforcement for low and middle-income countries on the following issues:
 - Influence of road and infrastructure design on traffic violations and the difficulties of enforcement when designs are not adequate for the kind and volume of road users present.
 - Critical/minimum levels of enforcement necessary for different traffic violations.
 - Enforcement methods that would be cost effective in situations with high proportion of motorcycles and other vulnerable road users.

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