# A *SAFE SYSTEMS* APPROACH TO VULNERABLE ROAD USER SAFETY ISSUES IN GHANA

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## ABSTRACT

Approximately, 90% of global road traffic deaths occur in low-and middle-income countries (LMICs), and vulnerable road users (VRUs) constitute 54%, even though these countries have about 60% of the world's vehicle population. VRUs are particularly prone to injuries and fatalities because they are not protected by any external vehicular body and their vulnerability is higher in mixed traffic conditions. There have been efforts by many countries across the globe to reduce road traffic deaths and injuries, but progress varies significantly between different regions and countries. In Ghana, VRUs account for a high proportion of crashes, with pedestrians and motorcyclists making up about 60% of total crashes every year. Motorcycle-related road safety has become topical due to the recent rapid rise in commercial motorcycle activities attributed to the problem of urban traffic congestion and the general lack of reliable and affordable public transport in rural areas. Additionally, uncontrolled interaction between human and high-speed vehicular activities in and around settlement areas throughout Ghana has resulted in numerous pedestrian deaths and injuries. The phenomenon has been attributed to the land-use and right-of-way planning practices as well as lack of safe crossing facilities for VRUs, comprising pedestrians, bicyclists, and motorcyclists (both two- and three-wheelers).

This dissertation is the result of three distinct, but interrelated research efforts addressing VRU safety issues in Ghana. Ghana, like many other countries in sub-Sahara Africa (SSA), is a rapidly developing nation with a rising middle-income population that is driving the urbanization and motorization processes. Nonetheless, a vast majority of the population rely on walking and

motorcycles for their daily travel needs. Pedestrians and motorcyclists, both drivers and pillions, make up a significant proportion of VRU fatalities in the country. This dissertation seeks to throw more light on the VRU safety concerns in the country by a) understanding how local transport professionals perceive pedestrian and motorcycle safety issues and the adoption of the *Safe Systems* approach as a countermeasure tool to address them, and b) conducting data-driven analyses to identify factors contributing to these crashes so that potential countermeasures can be developed based on local conditions and input from local road safety professionals.

The dissertation consists of three major areas related to VRU safety in the country. The first part of the study assessed opinions of local transport professionals on the complex safety issues relating to VRUs using the S*afe Systems* approach to explore how local context could guide the implementation of countermeasures. The *Safe Systems* approach takes a holistic view of road safety, and this framework is based on the basic premise that humans are prone to errors, mistakes, and mishaps and that as a result are vulnerable to crashes and must therefore be protected systemically. The *Safe Systems* approach addresses: behavioral issues that may result in crashes (speeding, driving under the influence, aggressive or distracted driving, etc.) under its safer people pillar; issues related to vehicle design and condition under safer vehicles; emphasis on infrastructure designed and constructed to prevent or reduce the severity of crashes through the safer roads pillar; and finally the promulgation of policies that promote safer speeds, especially where vehicular traffic is mixed with VRUs.

The study used a Multi-Criteria Decision-Making tool, the Analytic Hierarchy Process (AHP), to develop a framework based on knowledge and opinions gleaned from a survey of local road safety professionals to prioritize countermeasures for VRUs (i.e., pedestrians and motorcyclists) using a S*afe Systems* approach. This initial work provided a reference frame for two subsequent data-driven analyses of motorcycle and pedestrian crashes throughout the country. The motorcycle crash study emphasized the differences among crashes that occur in rural versus urban areas. The pedestrian study focused explicitly on crashes that occurred on inter-urban highways in Ghana.

It is anticipated that the findings of the dissertation research will provide a basis for the development of targeted and appropriate countermeasures to reduce the number of VRU deaths and injuries in Ghana. The recommendation for a localized *Safe Systems* approach and a data-driven strategy to address VRU safety issues is expected to result in improved overall road safety in the country, and other countries with similar characteristics in the region. The proposed *Safe Systems* framework developed, and its results can be used by transport professionals to prioritize localized efforts to improve the safety of VRUs.

# DEDICATION

I would like to dedicate this dissertation work to my parents, my family, my cherished friends, and all people who have supported me to fulfill my academic career dream.

## LIST OF ABBREVIATION AND SYMBOLS

| | |
|---|---|
| AIC | Akaike's Information Criterion |
| AHP | Analytic Hierarchy Process |
| ATI | Alabama Transportation Institute |
| BRRI | Building and Road Research Institute |
| CSIR | Council for Scientific and Industrial Research |
| DVLA | Driver and Vehicle License Authority |
| GDP | Gross Domestic Product |
| LC-MNL | Latent class multinomial logit |
| LL | Log-likelihood |
| ML | Maximum likelihood |
| MMNL | Mixed Multinomial logit |
| MTTD | Motor Traffic and Transport Department |
| NMT | Non-motorized transport |
| NRSA | National Road Safety Authority |
| NRSC | National Road Safety Commission |
| SDG | Sustainable Development Goal |
| SSA | Sub-Sahara Africa |
| UN | United Nations |
| VRUs | Vulnerable road users |

| | |
|---|---|
| WHO | World Health Organization |
| ROW | Right of way |
| $\varphi$ | Vector of parameters of chosen density |
| $\beta$ | Coefficients to be determined |
| $\theta g$ | Set of group parameters |
| $c$ | Number of latent classes |
| $G$ | Possible number of groups in latent class analysis |
| $\pi g$ | Mixture proportions in latent class analysis |
| $f$ | Probability density function |
| $\alpha c$ | Latent class specific parameters |
| $\eta$ | Log-odds $P$ Probability |
| $X$ | Explanatory variable |
| $\gamma$ | Higher level regression coefficient |
| $Zn$ | Vector of latent class probabilities |
| $Z$ | Sub-regional explanatory variable |

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# CHAPTER 1 INTRODUCTION AND MOTIVATION

The World Health Organization (WHO, 2018) established that road traffic injuries are a leading cause of death, killing some 1.35 million annually. Approximately, 90% of these fatalities occur in low- and middle-income countries. The risk of traffic injury is disproportionally borne by pedestrians, cyclists, and motorcyclists, who constitute the most vulnerable road users (VRUs). Research shows that about 54% of all road traffic crashes are among pedestrians, cyclists, and motorcyclists (WHO 2018). There have been efforts by many countries across the globe to reduce road traffic deaths and injuries, but progress varies significantly between different regions and countries. Like many other countries, several national strategic road safety measures have been implemented to reduce road crashes in Ghana. These include a Five-Year Strategy I in 2001, followed by another Five-Year Strategy II in 2006 which provided the then National Road Safety Commission (NRSC) and now National Road Safety Authority (NRSA) with an action plan for its strategic activities. Additionally, a ten-year road safety strategy covering the period 2011-2020 was prepared after the evaluation of the first and second strategies and informed by the United Nations (UN) Global Plan for the Decade of Action for road safety 2011-2020. Despite the implementation of all the above strategies to improve road safety, road traffic crashes continue to increase throughout the country and these crashes cost the nation some 1.6% of the Gross Domestic Product (GDP). The road user class with the highest share of fatalities continues to be pedestrians (36.7%), followed by motorcycle users (28.0%) and then bus occupants (14.4%) according to the 2019 crash data. Figure 1.1 shows the trend of road user classes (pedestrian, motorcycle, bicycle, and bus occupants) fatalities over ten years (2011-2020) in Ghana. The fatalities among pedestrians and motorcycle users have remained high over the years compared to the other road users but little or no attention is given to reducing their fatalities. Perhaps, this may be because VRUs issues were underestimated, and now need to be addressed with a sense of urgency as VRUs cannot be dissociated from overall mobility systems in the country. The efforts to reduce VRU fatalities in Ghana have not yielded the desired results to date. To influence the policy objectives, it is necessary to have insight into the contributing factors associated with VRU crashes and injuries. To increase the level of safety among VRUs, there is the need for innovative policy guidelines and countermeasures in addressing the problem, hence the introduction of the *Safe* S*ystems* approach.

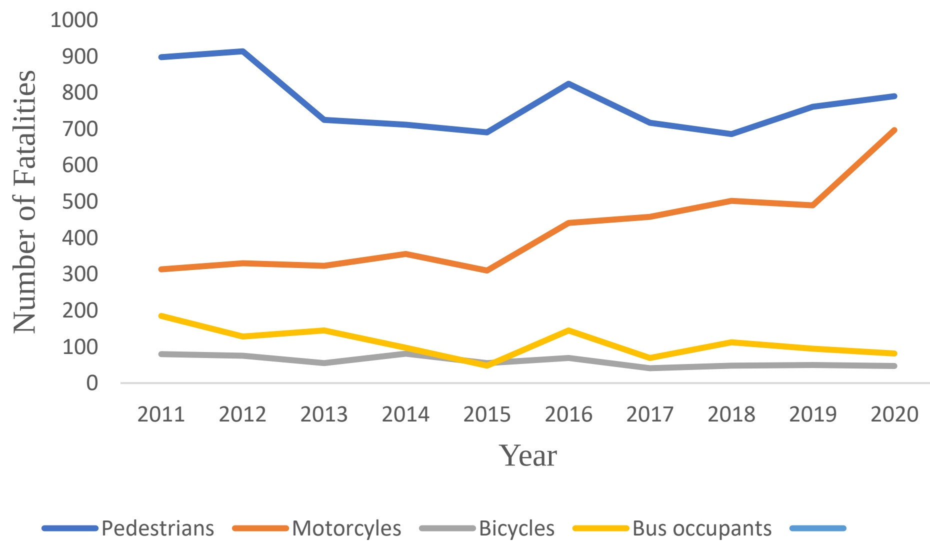


Figure 1.1 Fatality of road user class by year

This dissertation, therefore, seeks to identify VRU safety concerns, specifically those attributable to pedestrians and motorcyclists, in the country by identifying the contributing factors as part of efforts to develop localized countermeasures. Studying the effect of road user behavior and characteristics is instrumental to precisely measuring and evaluating how each of the investigated variables changes in the local environment to develop appropriate countermeasures for implementation.

To achieve this objective, the first aspect of the study aimed at assessing the level of knowledge of transport professionals in Ghana on the complex safety issues relating to vulnerable road users using the *Safe Systems* approach. The *Safe Systems* approach takes a holistic view of road safety that is based on the basic premise that humans are prone to errors, mistakes, and mishaps and that as a result are vulnerable to crashes and must therefore be protected systemically. The *Safe Systems* approach addresses: behavioral issues that may result in crashes (speeding, driving under the influence, aggressive or distracted driving, etc.) under its safer people pillar; issues related to vehicle design and condition under safer vehicles; emphasis on infrastructure designed and constructed to prevent or reduce the severity of crashes through the safer roads pillar; and finally the promulgation of policies that promote safer speeds, especially where vehicular traffic is mixed with VRUs. There is a need to build a transport system where safety is paramount for all road user types by using *Safe Systems* approach. This approach recognizes that the transport system must work to reduce the net injury risk to vulnerable road users. Human beings by nature cannot physically, cognitively, or psychologically always cope with the complex demands of socio-technical systems (Dekker, 2002), and as a result, there is the need to understand the human capabilities concerning the system and how to adapt to the properties of the system. The human body has limited tolerance to violent force (e.g., experiencing a road crash) and when this tolerance is exceeded, a fatal or serious injury is likely to occur. Crashes involving VRUs will continue to occur, given that humans make mistakes when using (as well as designing, constructing, managing) the road system, and the challenge for any *Safe System* in an event of a crash, is to ensure that no fatalities will occur.  This challenge can be addressed by managing the road infrastructure, vehicle, and speeds to reduce crash energies to levels that can be tolerated by the VRU bodies. The design of the road transport system should guide the VRUs to safe behaviors and mitigate the consequences of common human errors – for example, the fact that a driver makes a mistake (e.g., being distracted) and runs off the road should not necessarily lead to injuries or deaths. The capabilities and limitations of VRUs must be taken into consideration when designing the road transport system.

The second part of the dissertation investigates and compares factors that are associated with motorcycle crash injury outcomes in rural and urban areas of the country. Motorcycle-related traffic safety concerns have become topical because of the recent rapid rise in commercial motorcycle activities that have been attributed to the problem of urban traffic congestion and the general lack of reliable and affordable public transport in rural areas. In this study, motorcycle-involved crash data was collected and analyzed to understand the significant factors that are associated with motorcycle crash injury outcomes in rural and urban areas of the country. The mixed multinomial logit modeling technique was adopted to account for the effects of unobserved heterogeneity in the crash data.

For a data-driven and evidence-based approach to finding appropriate countermeasures for pedestrian safety, this third area of the study investigated the factors associated with pedestrian injury outcomes of inter-urban highway crashes. Historical pedestrian crash data were obtained and analyzed to also understand what factors influence injury severity on highways that pass through settlement areas in the country.  Programs such as education, enforcement, and effective emergency response will remain essential to argue the *Safe Systems* approach effort to reduce VRU deaths and injuries. Initiatives related to safer roads and roadsides, vehicles, and speed zones, as well as behavioral approaches, are key areas of priority for the targeted activity to prevent fatal vulnerable road user crashes in the future. Transport policymakers and road authorities who are responsible for road safety strategies and policies at national and local levels need to provide safe road infrastructure that integrates protection for vulnerable road users.

# CHAPTER 2 VULNERABLE ROAD USERS THROUGH SAFE SYSTEMS LENSES? PERSPECTIVES FROM TRANSPORT PROFESSIONALS IN GHANA ON PEDESTRIANS AND MOTORCYCLISTS

## 2.1 ABSTRACT

The problem of road traffic crashes is more acute in low- and middle-income countries, especially in sub-Saharan Africa (SSA), which exhibits the worst regional death rates per population in the world. The provision of a safe transport system to address this problem is crucial to the socioeconomic development of every nation, especially those in SSA, and relates to the overall improvement of public health, economic development, etc. This study aimed to assess the level of knowledge of transport professionals in Ghana relating to the complex safety issues of vulnerable road users (VRUs) within the context of the *Safe Systems* approach and to explore how the local context could guide its implementation. The study used an online survey to collect relevant information from transport professionals on their understanding of the *Safe Systems* approach and used the Analytic Hierarchy Process (AHP) to prioritize countermeasures for two types of VRUs, pedestrians, and motorcyclists. The findings from the study revealed that for pedestrians, transport professionals were more concerned with behavioral issues (i.e., safe people) followed by safe roads, then safe speeds, and lastly safe vehicles. Whereas for motorcyclists, safe people were rated first, safe roads, safe vehicles, and then safe speeds.

**Keywords:** Pedestrian; Motorcycle; Safe People; Safe Road; Safe Vehicle; Safe Speed.

## 2.2 INTRODUCTION

Road traffic crashes are a major global problem. The problem is more acute in low- and middle-income countries (LMICs), especially in sub-Saharan Africa, which has one of the worst road death rates (26.6 per 100,000 population) in the world (WHO, 2018). The provision of a safe transport system to address this problem is crucial to the socio-economic development of every nation, especially those in SSA, and relates to the overall improvement of public health, economic development, etc. (e.g., Gudmundsson et al., 1996; Jones and Walsh, 2013; Porter, 2014). Concerning transport decisions, the lack of consensus might cause traffic problems and negative economic impacts. Accordingly, there is an urgent need for governments to find solutions to reduce this menace on our roads but regrettably, the movement of people and goods across the globe has resulted in many injuries and fatalities especially vulnerable road users (VRUs) through road crashes. This study asks how well the prevailing understanding and application of the S*afe Systems* approach serves the needs of VRUs. The *Safe Systems* approach, which recognizes that the system must work to reduce the net injury risk to VRUs to an acceptable level, is based on four preventative pillars: safer roads, safer speeds, safer vehicles, and safer people (Harris, 2015).

Ghana has had its share of road safety problems of VRUs at risk when using the road facilities with the rapid expansion of its road network and increased growth rate of motorized vehicles. Solving these problems require transport professionals with in-depth knowledge and requisite training to recommend the appropriate countermeasures. This study aimed to assess the level of knowledge of transport professionals on the complex safety issues relating to VRUs using the *Safe Systems* approach in Ghana and to explore how local context could guide its implementation. This paper presents the results of an internet-based survey used to solicit information from transport professionals. The survey was intended to collect and synthesize insight into related themes and issues identified in recent studies and relevant research literature. The survey was specifically aimed at capturing priorities and opinions regarding potential research and policy needs relative to the understanding and use of the *Safe Systems* approach in addressing VRU safety in Ghana and, hopefully by extension elsewhere in SSA.

A stakeholder-driven framework is proposed because resources for researching and addressing VRU safety issues are relatively scarce in LMICs. Also, most road traffic safety research is often funded by international agencies/partners and (ideally) emphasizes objectivity and accountability in local decision-making processes. The proposed framework and its results can be used by transport professionals to prioritize decisions to allocate road safety and other transportation funds based on an approach grounded in the *Safe Systems* perspectives. The following sections present a literature review conducted to develop the context for the development of specific research questions. The methodology to develop and administer the internet survey is then described and followed by a detailed analysis and interpretation of the results.

## 2.3 BACKGROUND

Ghana, with a current population of 30.8 million inhabitants according to the 2021 census has issues with the importation and registration of used motorized vehicles into the country in addition to inadequate public transport, inadequate facilities for non-motorized transport, and road traffic crashes. For example, the number of registered motorcycles have increased over 1140% from 1995 to 2020 according to data from the Driver and Vehicle Licensing Authority. There has also been a substantial increase in all vehicular traffic resulting in crippling traffic congestion, especially in cities. As such, many travelers are forced or prefer to patronize the services of motorcycles taxis, locally referred to as *okadas*, to meet their transport needs. But these motorcycles have many safety concerns as the riders do not abide by the traffic rules resulting in deaths and injuries. The mass importation of these motorcycles from Asian countries into Ghana is not sufficiently regulated and monitored and individual vehicles are not vigorously inspected for defects by the port authorities, thus resulting in many of them being on the roads of Ghana despite not being roadworthy. Again, there are no special training schools for motorcycles for citizenry hence road traffic safety knowledge among these classes of road users is low which is detrimental to their safety when using the road and has resulted in many deaths and injuries. Pedestrians also make up a significantly high proportion of traffic fatality and injury casualties. Lack of pedestrian crossing facilities in the predominantly mixed traffic conditions in the country, construction of high-speed inter-urban highways through settlement areas, inadequate road safety education, low law enforcement, and general investment in road safety have been cited as some of the leading reasons for the high rate of pedestrian fatalities. Therefore, comparing motorcyclist and pedestrian deaths and injuries require an effective safety policy to address these issues by the authorities.

Over the past decade, there has been a focus on *Safe Systems* approach solutions in addressing road traffic crash issues in our road environments. This has been necessitated by the observation that in the previous few years, there has been a decreasing trend in the fatalities and serious injuries of car users; however, the fatalities and serious injuries of VRUs have continued to increase. This challenging and complex subject requires new efforts, new methods, and innovation in research, policymaking, and implementation. Belin et al., (2012) discussed the concept of Vision Zero in traffic safety policy, which was based on a *Safe Systems* approach. The thrust of Vision Zero policy was based on the principle that "The design and structure of the road transport system should be adapted to the physical pre-requisites of human beings for withstanding road accidents." Vision Zero as a promising road traffic safety policy has been strengthened by official statistics in Sweden showing that the number of road deaths was halved and that the number of deaths among car users decreased by 60% between 2000 and 2010 (Kristianssen et al., 2018). Indeed, the tenets of the Vision Zero concept are grounded in the *Safe Systems* framework. The success of the Vision Zero policy, therefore, gives impetus to the global adoption and implementation of the *Safe Systems* approach to improving VRU safety in particular, and overall highway safety in general.

## 2.4 METHODOLOGY

The current study utilized data from an online survey of transport professionals developed by the Building and Road Research Institute (BRRI). The dissemination of the survey questionnaire was done through email and a WhatsApp group comprising some 96 African transport professionals, most of whom are from West Africa. Emails were sent out to local Ghanaian transport professionals listed as BRRI contacts.

Ultimately, 78 professionals responded to the BRRI survey. Among the respondents, 75% indicated they represented a government agency and/or academia (applicants were allowed to check multiple industry types). The remaining respondents provided representation from the Ghanaian National Road Safety Council, law enforcement, private consultancies (both local and international) as well as from NGOs and multilateral development agencies. Figure 2.1 shows the distribution of years of professional experiences represented by survey respondents.

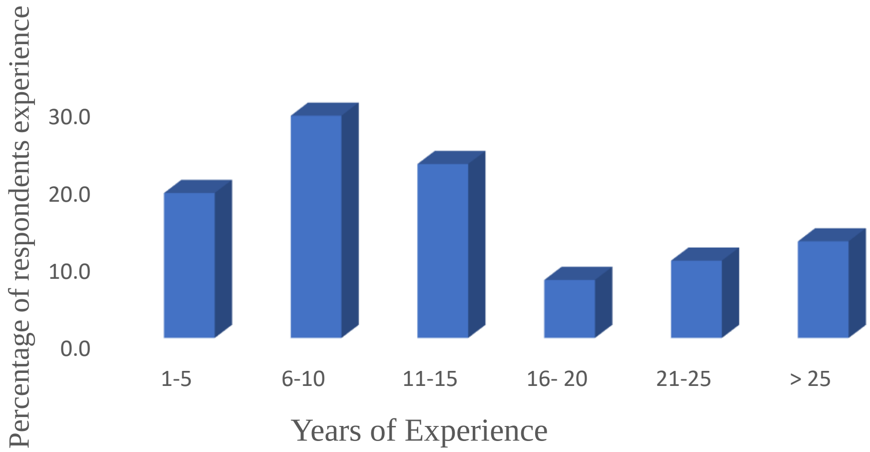


Figure 2.1 Years of professional experience among respondents

The study was divided into three subsections as set out in Figure 2.2. The first subsection aimed to create a high-level, general context for subsequent responses by gauging the extent to which respondents were aware of the *Safe Systems* approach and whether they deemed pedestrians or motorcyclists to be the VRUs of most concern. Once respondents identified which VRU was most concerning, they were then allowed the opportunity to conceptually indicate which of the four *Safe Systems* components (safe people, safe roads, safe vehicles, and safe speeds) they thought would be most effective in mitigating issues for the VRU they chose as most important (i.e., pedestrian or motorcyclist).

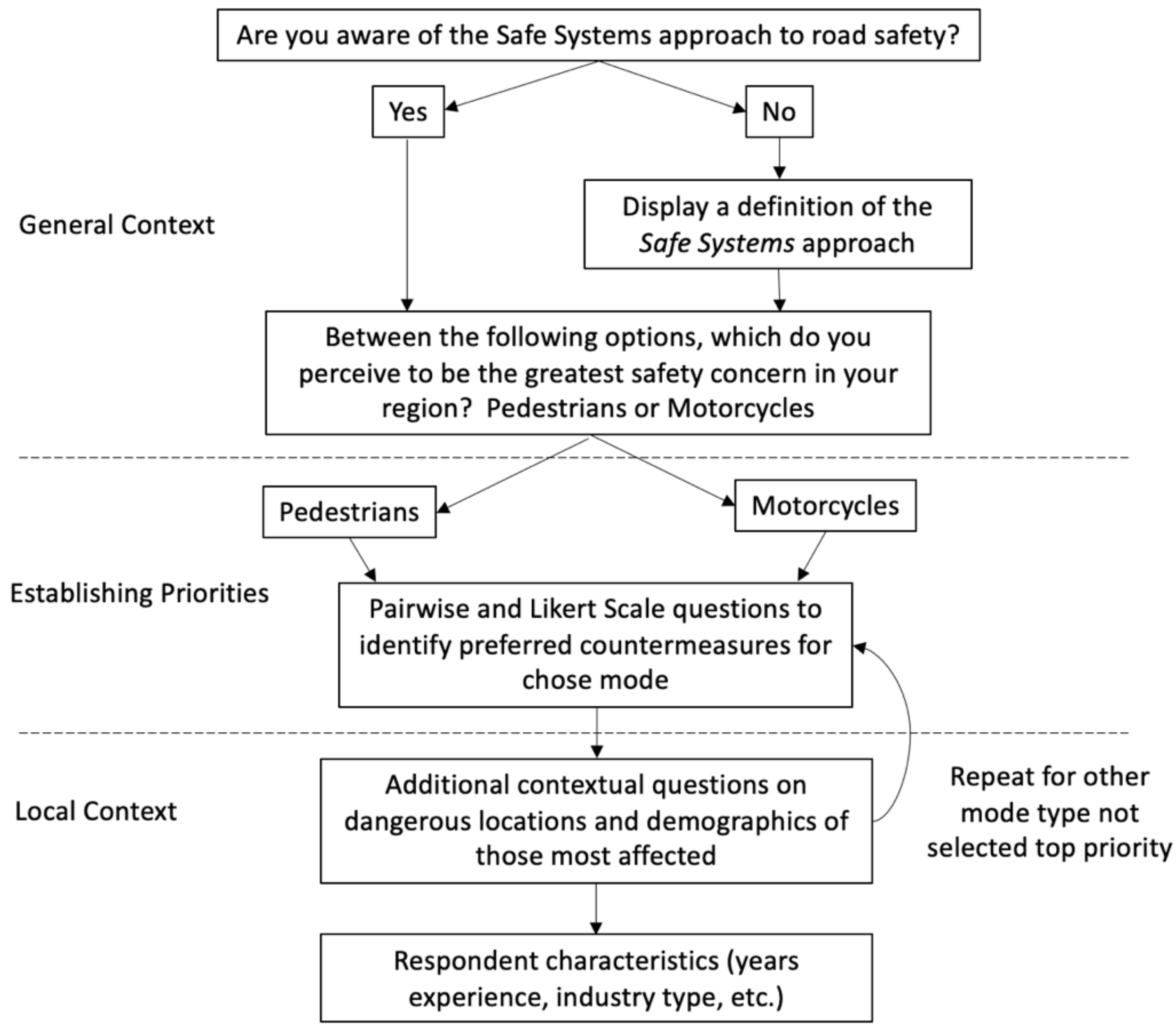


Figure 2.2 Transport professional opinion survey sections and flow.

### *2.4.1 Establishing Priorities*

The AHP is a multiple criteria decision-making tool designed by Saaty (1980). The AHP was selected for this study because of its suitability in prioritizing input from stakeholders based on subjective judgments of qualitative information (Lee, 2000; Jones et al., 2014; Kim and Lee, 2015).

The AHP, as set out by Saaty (2006), typically uses a 9-point scale – in other words, there are nine pairwise rankings among the choices. To make the survey as straightforward as possible for the practitioner respondents, the number of pairwise choices was reduced to five as indicated in the sample questions shown in Figure 2.3. Note that respondents were shown a set of pairwise comparison questions for pedestrians and motorcycles separately to allow respondents provide mode-specific responses – the format of the questions was the same and the term "pedestrian/motorcycle" is used in Figure 3 to avoid duplicating the figure or entire questions. Such a simplification is consistent with Miller (1956) who indicated that the human capacity for processing information is 7 ± 2 different items and it was assumed that any reduction in relative sensitivity of the pairwise comparisons was offset by improved responses, and perhaps the consistency of answers given the subjectivity and closely related ideas connoted by the four *Safe Systems* pillars.

Between road user behavior (safe people) and properly designed/ maintained vehicles (safe vehicles) which do you consider to be most important to reducing the occurrence and severity of pedestrian/motorcycle crashes?

- *Safe people are much more important*
- *Safe people are somewhat more important*
- *They are the same*
- *Safe vehicles are somewhat more important*
- *Safe vehicles are much more important*

Between road user behavior (safe people) and properly designed/maintained infrastructure (safe roads) which do you consider to be most important to reducing the occurrence and severity of pedestrian/motorcycle crashes?

- *Safe people are much more important*
- *Safe people are somewhat more important*
- *They are the same*
- *Safe roads are somewhat more important*
- *Safe roads are much more important*

Between road user behavior (safe people) and properly determined/enforced speed limits (safe speeds)

Figure 2.3 Pairwise comparison questions for *Safe Systems* approach to safety

A general review of relevant road safety literature allowed for the identification of specific countermeasures. A total of 14 general countermeasures were identified for pedestrian safety issues and 13 for motorcycles.  Specific merits of these were discussed with colleagues and compared against different evidence from the literature to ensure that they were as applicable as possible to the Ghanaian context. The individual countermeasures were then organized with respect to their relevance to each of the four *Safe Systems* pillars (safer people, safer roads, safer, vehicles, and safer speeds).

These two pieces of information, the high-level pairwise comparisons, and the countermeasure-specific Likert rankings were then used as part of an AHP-based process to identify which countermeasures (and groups thereof) were deemed to be most effective, and therefore ostensibly appropriate, within the context of Ghanaian road safety practice.  In this case, countermeasures that were deemed not effective were scored as a “1” and those deemed very effective as “5”. Figures 2.4 and 2.5 show the AHP framework for the pedestrian and motorcycle-focused questions, respectively.

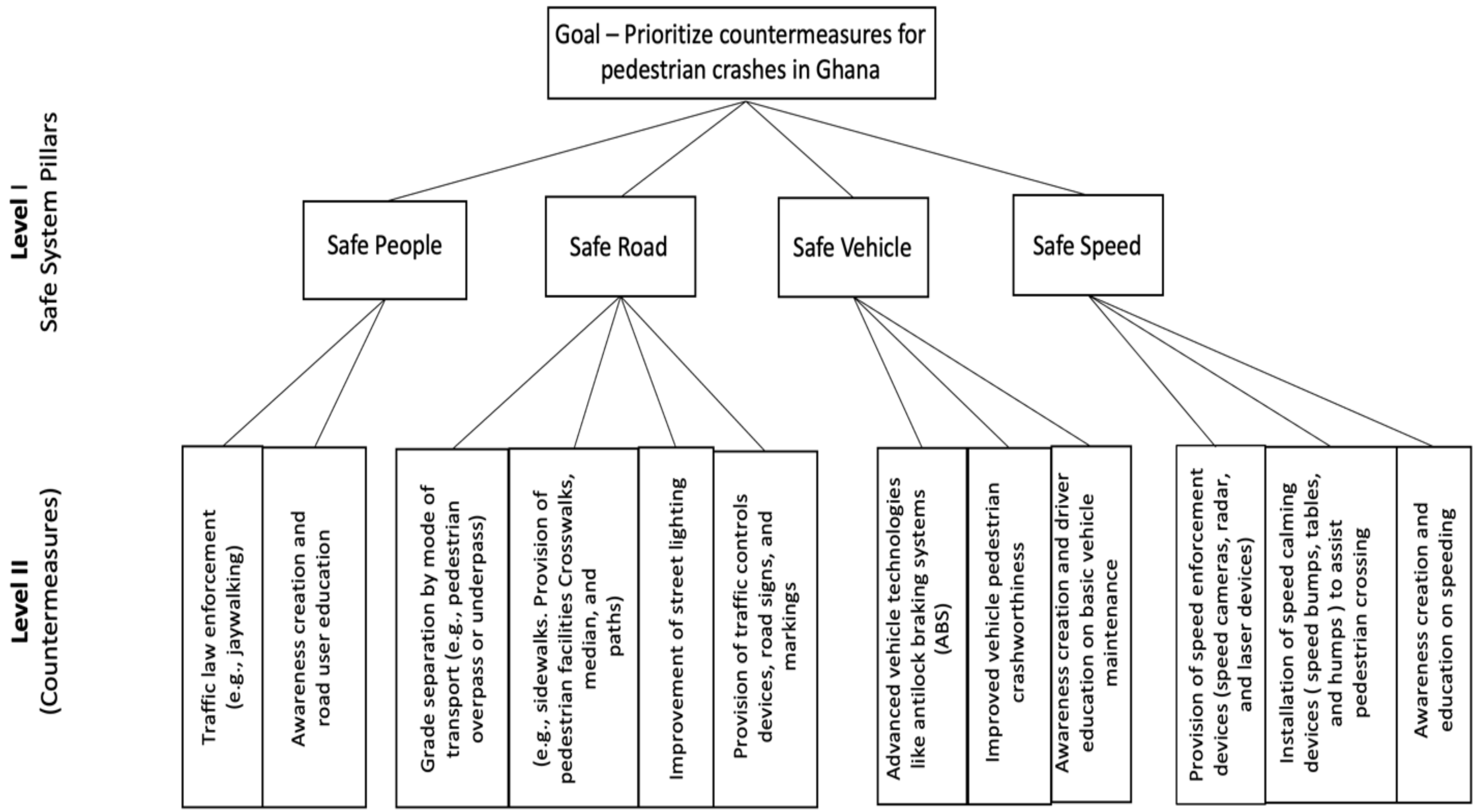


Figure 2.4 AHP framework for prioritizing *Safe Systems* approach to pedestrian crashes

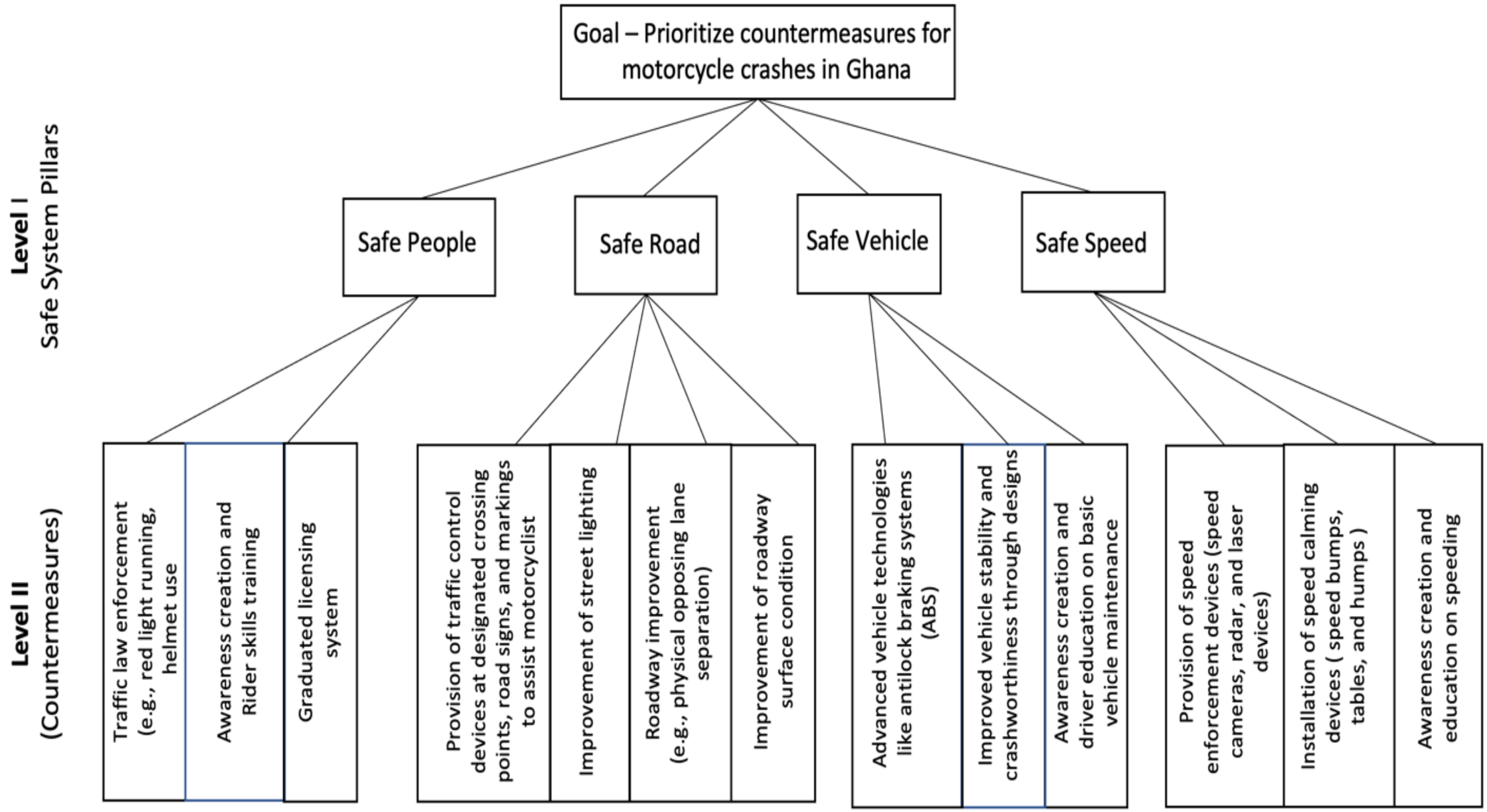


Figure 2.5 AHP framework for prioritizing *Safe Systems* approach to motorcycle crashes

The AHP frameworks were then used to compute weights from the responses for Level I and Level II. Multiplying the Level I and Level II weights is then used to create a composite Safety Systems Priority Score (SSPS) that reflects which of the four *Safe Systems* pillars respondents deem most applicable to each transport mode combined with which of the element-specific countermeasures they deem most effective. Thus, it is possible to "capture' what the local professionals view as the best means of addressing pedestrian and motorcycle safety issues in Ghana according to the relative SSPS of various countermeasures.

#### *2.4.2 Establishing Local Context*

In addition to the AHP work, where responses focused on prioritizing safety countermeasures to reduce pedestrian and motorcycle crashes, an additional set of questions sought specific insight into pedestrian and motorcycle crashes in Ghana. Figure 2.6 lists the questions and choices used to ascertain where and with whom the local professionals attributed the most danger/vulnerability to pedestrian and motorcycle crashes – note as with the pairwise questions in Figure 2.3, The survey provided separate sets of questions for pedestrians and motorcycles.

The survey questions included whether the respondent is familiar with the *Safe Systems* approach to reducing vulnerable road user crashes, the relative importance of *Safe Systems* approach pillars in reducing the occurrence and severity of pedestrian and motorcycle crashes, on a Likert scale, ranking the importance of countermeasures in reducing pedestrian and motorcycle deaths and injuries. The questionnaire also sought to find out roadway environment and locations considered to be most dangerous for both pedestrians and motorcycles and socio-economic and demographic characteristics of the respondents to understand what the local professionals think so that we can develop new knowledge for future policies.

Which roadway environment do you consider to be most dangerous for pedestrians/motorcycles? Please drag and drop in order of danger (i.e., 1 = most dangerous)

- *The open road (e.g., motorways, dual and single carriageways)*
- *Urban Streets*
- *Rural and remote areas with unpaved roads*

Which roadway location do you consider to be most dangerous for pedestrians/motorcycles? Please drag and drop in order of danger (i.e., 1 = most dangerous)

- *Signalized intersections*
- *Unsignalized intersections (e.g., stop or yield control)*
- *Roundabouts*
- *Midblock*

What age group do you think is most vulnerable to pedestrians/motorcycles crashes?

- *Younger than 6*
- *6-16*
- *17-25*
- *26-35*
- *36-56*

Figure 2.6 Questions to ascertain local perspectives on pedestrian and motorcycle safety

The survey also asked whether they thought private riders or commercial riders (i.e.., motorcycle taxis) were more dangerous. Additionally, respondents were asked their opinion as to whether two- or three-wheelers were more dangerous and were given the option to indicate whether such a determination was dependent on the roadway environment in which the vehicle was being used. The questionnaire for the survey is shown in the Appendix.

## 2.5. RESULTS

Again, a total of 78 responses to the survey were received. Roughly three-quarters of respondents indicated that they were previously aware of the *Safe Systems* approach. More than 90% of respondents who indicated they represented some government agency indicated familiarity with *Safe Systems*, whereas 80% of the consultants were. Interestingly, 100% of respondents from multilateral agencies/NGOs were familiar with the approach but only 70% of responding academics were.  There was essentially an even split between respondents who indicated that pedestrians versus motorcycles, respectively were more of a safety concern in the region, and this pattern was consistent among those who had or had not previously heard of *Safe Systems*.

### *2.5.1 Prioritization Results*

Prior to applying the AHP to establish priorities among the various potential countermeasures, it was necessary to check for consistency among the pairwise comparisons. For example, if a respondent stated that safer roads were more important than safer people, that safer people were more important than safer vehicles, and the safer vehicles were more important than safer roads, it would indicate an inconsistency in the logic of their responses.  Saaty (1980) accounted for this by developing a means of testing the consistency among a series of related pairwise comparisons called the consistency ratio (CR). The CR is determined as CR = CI / RI, where:

$$CI = \frac{(\lambda_{max} - n)}{n-1}$$

For a consistent reciprocal matrix, the largest Eigenvalue is equal to the size of the comparison matrix, or $\lambda_{max} = n$

RI = a Random consistency Index related to the size of the square matrix, *n* (Saaty, 1980).

For a 4 x 4 matrix as specified by the current pairwise comparison, RI = 0.9. And Saaty noted that a calculated CR for an individual set of responses equal to or less than 0.10 indicated reasonable consistency. So, for the given analysis *n* was determined to be 78 and the CR was calculated for all survey responses. Given the CR = 0.10 threshold, a total of 19 responses to the pairwise comparison on pedestrian safety were found to be consistent and 13 were found to be consistent among the pairwise comparisons for motorcycles.

Once the acceptable pairwise responses were identified, they were used to determine weights for the Level I pillars in the AHP frameworks for pedestrians and motorcycles, respectively. Tables 2. 1 and 2.2 are examples of Level I individual pairwise comparison responses for pedestrians and motorcycles, respectively, and indicate the resulting weights calculated for the four comparisons (i.e., *Safe Systems* pillars).

Table 2.1 Sample weights from individual Level I responses for pedestrians

| ***Safe Systems* Pillar** | **Compared to** | | | | **Sample Level I weights** |
|---|---|---|---|---|---|
| | **People** | **Vehicle** | **Road** | **Speed** | |
| **People** | 1 | 3 | 1 | 1/5 | 0.237 |
| **Vehicle** | 1/3 | 1 | 1 | 1 | 0.194 |
| **Road** | 1 | 1 | 1 | 1 | 0.216 |
| **Speed** | 5 | 1 | 1 | 1 | 0.353 |

Table 2.1 indicates that this individual deemed safer people somewhat more important than safer vehicles with regard to pedestrian safety – this is indicated by the score “3” comparing safer people to safer vehicles and the reciprocal “1/3” for safer vehicles compared to safer people. In other words, it appears that this perceives behavioral aspects of driving and walking to have more of an impact on pedestrian safety than whether a vehicle is properly maintained or has modern safety features (e.g., anti-lock brakes). The same individual respondent perceives safer speeds as much more important than safer people for addressing pedestrian safety. Similar observations can be gleaned regarding the individual perception of motorcycle safety from Table. 3.

Table 2.2 Sample weights from individual Level I responses for motorcycles

| ***Safe Systems* Pillar** | **Compared to** | | | | **Sample Level I weights** |
|---|---|---|---|---|---|
| | **People** | **Vehicle** | **Road** | **Speed** | |
| **People** | 1 | 1 | 5 | 5 | 0.694 |
| **Vehicle** | 1 | 1 | 5 | 1 | 0.139 |
| **Road** | 1/5 | 1/5 | 1 | 1/5 | 0.028 |
| **Speed** | 0.2 | 1 | 5 | 1 | 0.019 |

The weights were calculated by first dividing all the elements in each column by the sum of each column of the pairwise comparison matrix. After that, we sum all the elements in each row of the resulting matrix and divide them by the size of the pairwise comparison matrix to get the normalized criteria weights for each respondent. All the individual Level I weights were determined and then averaged into an overall weight for Level I responses comparing *Safe Systems* approach for pedestrians and motorcycles. Table 2.3 summarizes the final weights for all respondents for each mode as well as the resulting ranking among pillars.

Table 2.3 Transport professionals' ranking of *Safe Systems* pillars

| **Level I weight among respondents under the *Safe Systems* approach** | **Pedestrian** | | **Motorcyclists** | |
|---|---|---|---|---|
| | **Weight** | **Ranking** | **Weight** | **Ranking** |
| Safe People | 0.355 | 1 | 0.316 | 1 |
| Safe Road | 0.240 | 2 | 0.228 | 3 |
| Safe Vehicle | 0.192 | 4 | 0.235 | 2 |
| Safe Speed | 0.213 | 3 | 0.221 | 4 |

Table 2.4 indicated that the local transport professionals from Ghana perceive the safer people pillar as the most important tool in addressing both pedestrian and motorcycle safety. The second-

ranked pillar was safer roads for pedestrians and safer vehicles for motorcyclists. This difference appears logical and is especially relevant given the well-documented concern of motorcycle maintenance and repair in the region (Pius et al., 2018), and especially those associated with the importation of low-quality used motorcycles from abroad (Kernen and Mohammed., 2016). Ranking safer speeds higher than safer vehicles to improve pedestrian safety appears to reflect the understanding that pedestrians are less likely to be struck by slower-moving vehicles and, if they are, crash severities are likely to be less severe. Respondents indicated that it was more important to provide safer roads than safer speeds, perhaps reflecting issues associated with local road conditions negatively affecting the safe operation of motorcycles at a range of speeds.

After respondents provided pairwise comparisons among *Safe Systems* pillars, they ranked according to perceived effectiveness sets of specific countermeasures within each pillar. The rankings were provided via a 5-point Likert scale wherein "1" connoted not effective and "5" very effective. Table 2.4 summarizes responses to the Likert scale questions for Level II of the AHP for pedestrian safety and those for motorcyclist safety are shown in Table 2. 5. Additionally, Tables 4 and 5 reports the Level II weights by "normalizing" the geometric mean as doing so has been reported by Saaty (2008) and others (e.g., Awashthi and Omrani, 2009) as an appropriate method for synthesizing group judgments.

Table 2.4 Computed Level II weights for prioritizing pedestrian countermeasures

| **Sub-criteria** | **Likert scale** | | | | | **Geometric mean (GM)** | **Level II weights (Normalized GM)** |
|---|---|---|---|---|---|---|---|
| | **5** | **4** | **3** | **2** | **1** | | |
| | Number respondents | | | | | | |
| Safe people (0.355) | | | | | | | |
| Enforcing pedestrian laws | 33 | 14 | 8 | 3 | 2 | 4.01 | 0.350 |
| Pedestrian outreach and education | 28 | 21 | 13 | 4 | 2 | 3.83 | 0.334 |
| Drivers outreach and education | 17 | 13 | 6 | 3 | 3 | 3.62 | 0.316 |
| Safe road (0.24) | | | | | | | |
| Grade separation | 42 | 16 | 9 | 2 | 0 | 4.33 | 0.254 |
| Pedestrian facilities | 41 | 20 | 6 | 4 | 1 | 4.19 | 0.246 |
| Roadway lighting | 43 | 18 | 7 | 1 | 1 | 4.33 | 0.254 |
| Traffic controls devices | 42 | 14 | 7 | 4 | 1 | 4.19 | 0.246 |
| Safe vehicle (0.192) | | | | | | | |
| Advanced vehicle safety technologies | 23 | 15 | 20 | 8 | 4 | 3.38 | 0.315 |
| Pedestrian crashworthiness | 25 | 17 | 21 | 6 | 2 | 3.60 | 0.336 |
| Maintenance education and outreach | 30 | 15 | 18 | 7 | 1 | 3.74 | 0.349 |
| Safe speed (0.213) | | | | | | | |
| Automated speed enforcement | 31 | 22 | 12 | 4 | 2 | 3.88 | 0.325 |
| Traffic calming | 26 | 30 | 9 | 4 | 0 | 4.03 | 0.337 |
| Speeding education and outreach | 35 | 19 | 13 | 3 | 1 | 4.03 | 0.338 |

Table 2.5 Computed Level II weights for prioritizing motorcycle countermeasures

| **Sub-criteria** | **Likert scale** | | | | | **Geometric mean (GM)** | **Level II weights (Normalized GM)** |
|---|---|---|---|---|---|---|---|
| | **5** | **4** | **3** | **2** | **1** | | |
| | **Number respondents** | | | | | | |
| Safe people (0.316) | | | | | | | |
| Enforcing motorcycle laws | 43 | 12 | 4 | 5 | 0 | 4.32 | 0.270 |
| Motorcyclist education | 31 | 15 | 10 | 8 | 0 | 3.91 | 0.244 |
| Training and licensing systems | 32 | 19 | 6 | 5 | 2 | 3.95 | 0.247 |
| Prohibit traveling between lanes | 40 | 22 | 10 | 6 | 4 | 3.83 | 0.239 |
| Safe road (0.228) | | | | | | | |
| Improving roadway surfaces | 26 | 20 | 11 | 5 | 1 | 3.86 | 0.327 |
| Roadway lighting | 35 | 15 | 5 | 6 | 2 | 3.96 | 0.335 |
| Roadside improvements | 31 | 21 | 5 | 6 | 1 | 4.00 | 0.338 |
| Safe vehicle (0.235) | | | | | | | |
| Advanced vehicle safety technologies | 16 | 15 | 6 | 14 | 1 | 3.35 | 0.335 |
| Regulating sellers and importers | 19 | 14 | 9 | 15 | 4 | 3.16 | 0.316 |
| Maintenance education and outreach | 24 | 13 | 11 | 11 | 2 | 3.50 | 0.350 |
| Safe speed (0.221) | | | | | | | |
| Automated speed enforcement | 32 | 9 | 15 | 7 | 2 | 3.72 | 0.327 |
| Traffic calming | 19 | 22 | 15 | 5 | 1 | 3.69 | 0.325 |
| Speeding education and outreach | 33 | 15 | 9 | 6 | 1 | 3.95 | 0.348 |

As noted in the methodology, the Level I and Level II weights were multiplied to produce a composite score called the Safe Systems Priority Score (SSPS). The final SSPS are shown in Tables 2.6 and 2.7 for pedestrians and motorcyclists, respectively. Additionally, each individual countermeasure is ranked according to the magnitude of its SSPS.

Table 2.6 shows that “Enforcing pedestrian laws” under the safer people pillar received the highest weighting among the Level II choices for pedestrian safety. Similarly, Table 2.7 indicates that “Enforcing motorcycle laws” was the highest weighted for motorcyclist safety. Both results are interesting in that a very small percentage of total respondents identified as being law enforcement professionals but shows the current emphasis in the region towards behavioral road safety treatments. This emphasis is further reinforced in that the second and third-ranked pedestrian countermeasures focus on outreach and education, one aimed at increasing awareness among drivers and the other aimed at pedestrians themselves. The second-ranked motorcyclist countermeasure focuses on education and outreach-related motorcycle maintenance, while the third emphasizes the need for advanced vehicle technologies such as anti-lock braking systems on motorcycles. Training and licensing of motorcyclists as well as general motorcyclists' education and outreach were ranked very close as fourth and fifth, respectively. In general, countermeasures related to the safer roads pillar were ranked among the lowest.

Table 2.6 Safety Systems Priority Score (SSPS) for pedestrian countermeasures

| **Pillar/Countermeasure** | **SSPS** | **Ranking** |
|---|---|---|
| Safe people | | |
| Enforcing pedestrian laws | 0.125 | 1 |
| Pedestrian outreach and education | 0.118 | 2 |
| Drivers outreach and education | 0.112 | 3 |
| | | |
| Safe road | | |
| Grade separation | 0.061 | 8 |
| Pedestrian facilities | 0.059 | 9 |
| Roadway lighting | 0.061 | 8 |
| Traffic controls devices | 0.059 | 9 |
| | | |
| Safe vehicle | | |
| Advanced vehicle safety technologies | 0.061 | 8 |
| Pedestrian crashworthiness | 0.064 | 7 |
| Maintenance education and outreach | 0.067 | 6 |
| | | |
| Safe speed | | |
| Automated speed enforcement | 0.069 | 5 |
| Traffic calming | 0.072 | 4 |
| Speeding education and outreach | 0.072 | 4 |

Table 2.7 Safety Systems Priority Score (SSPS) for motorcycle countermeasures

| **Pillar/Countermeasure** | **SSPS** | **Ranking** |
|---|---|---|
| Safe people (0.316) | | |
| Enforcing motorcycle laws | 0.085 | 1 |
| Motorcyclist education | 0.077 | 5 |
| Training and licensing systems | 0.078 | 4 |
| Prohibit traveling between lanes | 0.076 | 7 |
| Safe road (0.228) | | |
| Improving roadway surfaces | 0.074 | 8 |
| Roadway lighting | 0.076 | 6 |
| Roadside improvements | 0.077 | 5 |
| Safe vehicle (0.235) | | |
| Advanced vehicle safety technologies | 0.079 | 3 |
| Regulating sellers and importers | 0.074 | 8 |
| Maintenance education and outreach | 0.082 | 2 |
| Safe speed (0.221) | | |
| Automated speed enforcement | 0.072 | 9 |
| Traffic calming | 0.072 | 9 |
| Speeding education and outreach | 0.077 | 5 |

### *2.5.2 Local Context Results*

The results from the prioritization analysis indicate that local transport professionals in Ghana place significant emphasis on behavioral-related (i.e., safer people) countermeasures. To the extent that such efforts are people-focused, the survey also ascertained what groups of people, survey respondents deemed to be most at risk. As might be expected, males were deemed to be most at risk for both pedestrian and motorcycle crashes. Two-thirds of respondents indicated that males were most at risk for motorcycle crashes while only 45% indicated males were most at risk for pedestrian crashes.  Most of the respondents indicated that, for motorcycle crashes, the age group between 17- 25 were most at risk compared to the age group 6 -16 deemed most at risk for pedestrian crashes. Figure 2.7 summarizes the distribution of age groups deemed at risk for the different modes. Such information can then be useful in crafting and targeting the outreach, education, and enforcement activities that the local professionals indicate as their highest priority countermeasures.

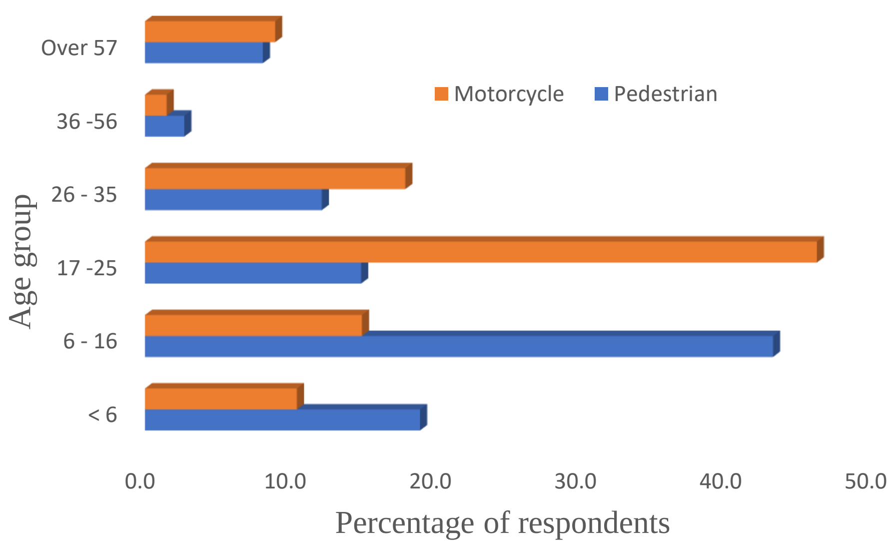


Figure 2.7  Percentage of age groups most at risk for pedestrian and motorcycle crashes

The majority (66.2%) of respondents indicated that the open road (motorways, dual and single carriageways) are the most dangerous environment for pedestrians followed by the urban environment (29.2%). In terms of less dangerous roadway environment, the respondents indicated that the rural setting (76.9%) is much safer for pedestrians as shown in Fig 2.8. Fig 2.9 presents a similar trend for roadway environment for motorcyclists.

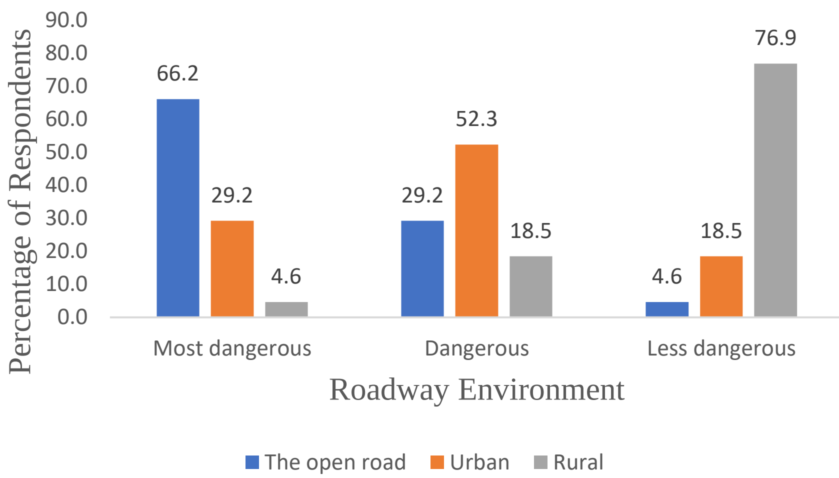


Figure 2.8  Road environment most dangerous for pedestrian crashes

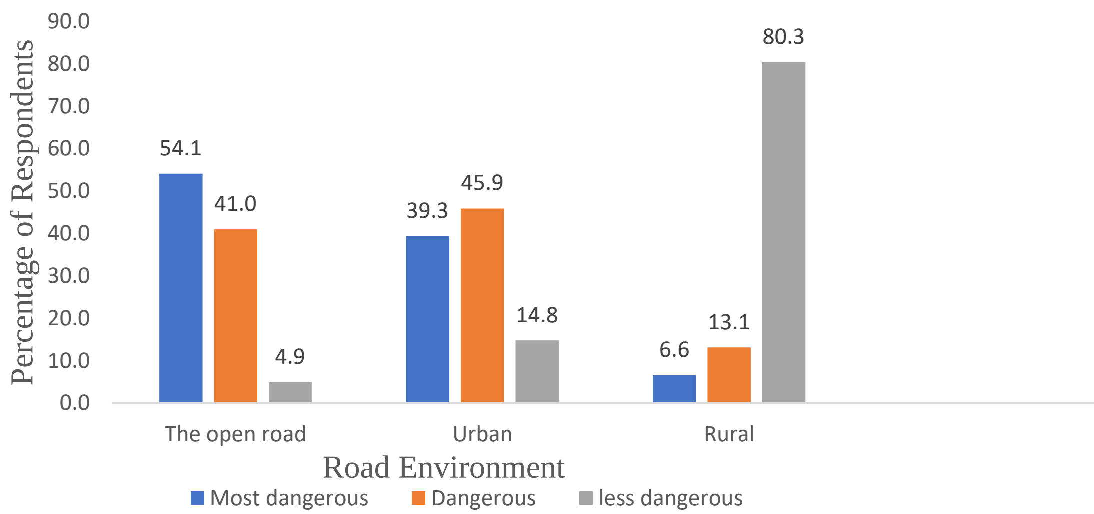


Figure 2.9 Road environment most dangerous for motorcycle crashes

More than half of the respondents indicated that the roadway location which is most dangerous for pedestrian crashes was unsignalized intersections (62%) as presented in Fig 2.10. And the least dangerous locations were attributed to the signalized intersections (52.1%) by the transport professionals. With respect to motorcycle crashes in Fig 2.11, similar to pedestrian crashes, over two-thirds (78.5%) of the respondents attributed the most dangerous roadway location of motorcycle crashes to unsignalized intersections while the signalized intersections and midblock were the least dangerous locations.

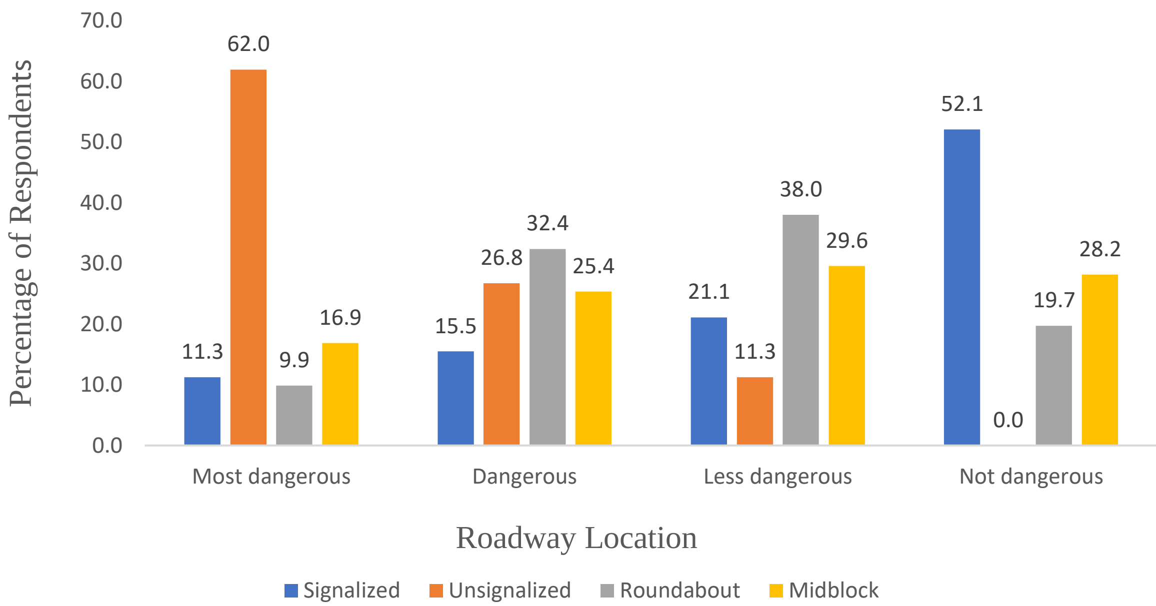


Figure 2.10 Roadway location considered most dangerous for pedestrian crashes

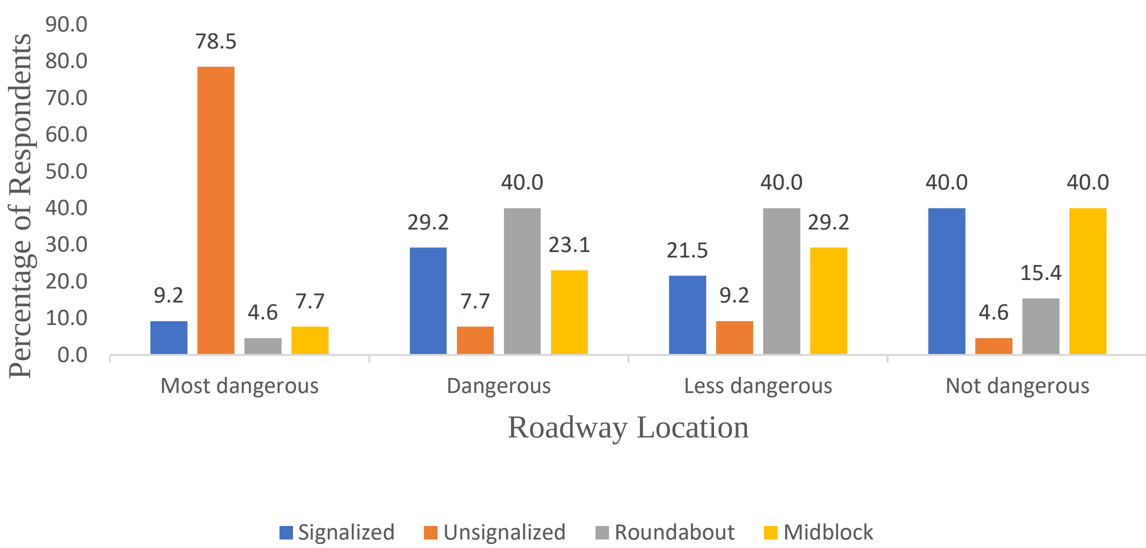


Figure 2.11 Roadway location considered most dangerous for motorcycle crashes

## 2.6. DISCUSSION

The goal of this study was to determine and analyze the understanding of transport professionals' views on vulnerable road users' safety issues in Ghana using the *Safe Systems* approach aimed at contributing to national policy development, stakeholder engagements, and public safety education campaigns. The criteria in level I and sub-criteria level II have been evaluated by the transport professionals using the geometric mean method for the primary concerns of both pedestrians and motorcyclists and presented in Tables 5, 6, and 7, and to prioritize the criteria in level I by the professionals, the CR was estimated for the level I pairwise comparisons for all individual respondents and those with CR < 0.1 were included in the decision-making process of the AHP. This is in confirmation of research work done by (Saaty, 1980). Tables 5, 6, and 7 show the summaries of the relative level I priorities by the transport professionals for pedestrians and motorcyclists for all respondents and calculated priorities for the *Safe Systems* approach variables. The results indicate the professionals were more concerned for safe people, followed by safe roads, then safe speeds, and lastly safe vehicles for pedestrians whereas for motorcyclists, safe people were rated first, safe roads, safe vehicles, and then safe speeds.

Assessing the concerns of pedestrians under the *Safe Systems* approach, for safe people, the professionals rated enforcing pedestrian law as the most priority. There must be conscious efforts to enforce and stop jaywalking by pedestrians and use only designated approved walkways to cross the road. According to the transport professionals, for safe roads, grade separation (e.g., pedestrian overpass or underpass) and roadway lighting were the topmost priority countermeasures. In terms of cost, it will cost less with roadway lighting, especially at night compared to grade separation so that the pedestrian could be seen by the drivers. Considering safe vehicles under the *Safe Systems* approach, education, and outreach to improve vehicle maintenance were evaluated to be the important countermeasure by the professionals in improving the safety of pedestrians. For safe speeds, construction and installation of traffic calming devices (e.g., speed tables) and education and outreach to improve awareness of speeding dangers to pedestrians were both evaluated to be crucial by the professionals. With limited budget constraints, efforts must be concentrated on education and outreach of awareness of speeding dangers to pedestrians.

Similar to safe people for the pedestrians, the transport professionals evaluated enforcing the traffic laws as the priority countermeasure for motorcyclists followed by formalized motorcycle driver training and licensing systems as far as the *Safe Systems* approach is concerned. For safe roads, roadside improvements (e.g., clear zones or guardrails) were recommended as the prime concern for the motorcyclists by the professionals. Education and outreach to improve vehicle maintenance and awareness of speeding dangers to motorcyclists were the highest ranked priorities for safe vehicles and safe speeds respectively by the professionals.

## 2.7. CONCLUSIONS

A framework for capturing priorities by views of local Ghanaian transport professionals using the *Safe Systems* approach in addressing vulnerable road user needs and safety was developed and presented as a case study for pedestrians and motorcyclists in Ghana. The decision model consisting of the final weights of the design criteria is very useful for assessing the most important countermeasures perceived by the transport professionals for vulnerable road users for future implementation by the policymakers. The results show that safe people stand high as a priority among the four pillars for both pedestrians and motorcycles in reducing vulnerable road user crashes. More especially with the enforcement of pedestrian traffic laws, followed by education and outreach programs to pedestrians and for the motorcycle, the perception of the transport professionals was enforcing traffic laws and followed by education and outreach to improve vehicle (motorcycle) maintenance. There is the need as a matter of policy, that the NRSA should make sure all the implementing agencies use the principle of a *Safe Systems* approach which aims to ensure a safe transport system to improve the safety of VRUs. It is suggested that training, education, and outreach program must be organized for road users and practitioners to have more knowledge in *Safe Systems* approach principles. The NRSA should concentrate their efforts and future budget on these two areas for at least and evaluate the measures thereafter to assess the safety impact that would bring.

The NRSA should make a mandatory policy for all road agencies to adopt the *Safe Systems* approach going forward as their design guide. We recommend further research be conducted to compare the transport expert perceptions to what the actual crash data reveals.

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# CHAPTER 3 A *SAFE SYSTEMS* BASED COMPARISON OF MOTORCYCLE CRASH SEVERITY IN RURAL AND URBAN AREAS OF GHANA

## 3.1 ABSTRACT

Like many countries in Sub-Saharan Africa, Ghana has witnessed an increase in the use of motorcycles for both commercial and private transport of people and goods. The rapid rise in commercial motorcycle activities has been attributed to the problem of urban traffic congestion and general lack of reliable and affordable public transport in the rural areas. This study investigates and compares factors that are associated with motorcycle crash injury outcomes in rural and urban Ghana. Preliminary analysis of the crash data revealed that more of the rural area crashes occurred under dark and unlit roadway conditions while urban areas recorded more intersection-related crashes. Also, it was found that more pedestrian collisions happened in urban areas while head-on collisions happened more in rural areas. The model estimation results show that collision with a pedestrian, run-off-road, collisions that occur under dark and unlit roadway conditions were more likely to result in fatal injury. Findings from this study are expected to help in crafting and targeting appropriate countermeasures to effectively reduce the occurrence and severity of motorcycle crashes throughout the country and, indeed, Sub-Sahara Africa.

## 3.2 INTRODUCTION

Globally, road crashes are a leading cause of deaths and injuries, the burden of which is disproportionately borne by low- and middle-income countries which account for more than 90%

of the global road traffic fatalities. Motorcyclists, along with pedestrians and bicyclists, are among the vulnerable road users (VRUs) that represent more than 50% of road fatalities in Sub-Saharan Africa (WHO, 2018). This is alarming because motorcycles provide relatively high levels of mobility at costs that are typically much lower than other modes such as private automobiles, taxis, minibuses, and other forms of public transport. For being a relatively cheaper option for getting around and to beat the increasing traffic congestion, there has been a proliferation of motorcycle transport in much of the developing world, especially throughout sub-Saharan Africa (Kumar, 2011, Olvera et al., 2012). Despite the harm caused by motorcycles in death and injuries, they remain (and will likely continue to be) an important source of mobility and employment throughout the African continent (Ehebrecht et al., 2018). As motorcycles and their usage continue to increase across the continent, there is an urgent need to identify and understand factors that contribute to the occurrence and severity of crashes involving them in order to implement appropriate policies and countermeasures.

Like many countries in sub-Saharan Africa, Ghana has witnessed an increase in the use of motorcycles for both commercial and private transport of people and goods. The rapid rise in commercial motorcycle activities has been attributed to the problem of urban traffic congestion and general lack of reliable and affordable public transport in the rural areas. In most urban areas of the country, motorcycles have become the preferred alternative transport mode to the popular informal public transport minibuses (locally referred to as "tro-tros"). Motorcycles typically provide decreased travel time reliability compared with the tro-tros as travelers do not have to wait for drivers to pick up additional passengers to ensure that the tro-tros are full and therefore as profitable as possible. Commercial motorcycles have also become popular due to often shorter travel times attributable to their ability to maneuver through traffic as well as being able to pick up and drop off passengers much closer to their origins and destinations, thereby overcoming the first/last mile challenge of the public transport modes. In rural areas of Ghana, commercial motorcycles are often the only affordable and accessible means of motorized transport. Additionally, they often transport goods (e.g., agricultural produce) in addition to passengers and, in some instances, are used as ambulances. So, it is understood that motorcycles are an important transport mode throughout Ghana that plays different roles in rural and urban areas of the country. As such, they provide essential mobility for many travelers throughout the country (Oteng-Ababio and Agyemang, 2015). Furthermore, the thriving trade of commercial motorcycles in Ghana has provided employment for many youths (Zuure and Yiboe, 2017). In response to the necessity and popularity of commercial motorcycle transport, Ghana is working to amend a national legislation (Legislative Instrument 2180) that currently prohibits the use of motorcycles for fare-paying passenger transport services (Ministry of Transport, 2019).

The safety impacts of commercial motorcycle activity in Ghana continue to complicate attempts to regulate, enforce, and encourage their use. Indeed, motorcycle crashes have been on a steady increase across Ghana for several years and have garnered attention not only from legislators but also from the local transport safety community. Numerous earlier studies focused on the use of helmets as key to motorcycle safety (e.g., Ackaah and Afukaar, 2010; Ackaah et al., 2013; Akaateba et al, 2015; Aidoo et al, 2018), with findings revealing that factors such as age gender, educational levels, and presence of passengers (pillion riders) affected their usage. Other, more recent studies have focused on identifying relationships among various crash risk factors (weather, road geometry, etc.) and injury severity outcomes of motorcycle crashes (e.g., Aidoo and Amoh Gyimah, 2019; Dapilah et al, 2017). In addition to the obvious negative health impacts of motorcycle crashes in Ghana, they also have a negative economic impact. For example, Kudebong et al., (2011) estimated the economic burden of motorcycle crashes in the Bolgatanga Municipality in Northern Ghana to be upwards of one million dollars as crash victims were largely found to be males in what would have otherwise been their most economically productive years.

Recognizing the previous works and ongoing complex nature of the motorcycle use and safety concerns, this study analyzed motorcycle crashes in Ghana with a specific focus on understanding the differences in injury severity between those that occurred in urban and rural settings. The rationale for this comparison stems from the fact that commercial use of motorcycles and their rapid growth in urban areas of the country is a new phenomenon, in contrast to rural areas where the practice has gone on for many years. Additionally, traffic and roadway conditions are significantly different between urban and rural areas. As such, segmentation of the motorcycle crashes based on the crash location would allow for detailed understanding of the differences and similarities in the contributing factors of the crash outcomes. We applied a mixed logit modeling technique to attempt to capture unobserved heterogeneity in the crash data in order to better inform future efforts towards crafting and targeting appropriate countermeasures to effectively reduce the occurrence and severity of motorcycle crashes in Ghana and, hopefully by extension, elsewhere in sub-Sahara Africa.

## 3.3 LITERATURE REVIEW

There have been myriad studies on the contributing factors and outcomes of motorcycle crashes throughout the world. These contributing factors observed range from human factors such as gender, age, rider condition at the time of the crash (Shankar and Mannering, 1996; Pai and Saleh, 2007; Savolainen and Mannering, 2007; Bjørnskau et al., 2012; Oxley et al., 2013; Shaheed et al., 2013; Chichom-Mefire et al., 2015; Wu and Loo, 2016; Zuure and Yiboe 2017; Lam et al., 2019; Thompson et al., 2020; Li et al., 2021), roadway geometric characteristics such as road width, horizontal and vertical curves, number of lanes and shoulder width (Quddus et al., 2002; Haque et al., 2010; Geedipally et al., 2011), environmental factors like weather, roadway surface condition, crash scene lighting condition and location of crash (Islam and Brown, 2017; Waseem et al., 2019) and vehicle factors (Quddus et al., 2002; Waseem et al., 2019; Kitali et al., 2020). Different road user behaviors increase the risk of motorcycle crashes. Pai et al., (2009) assessed motorist right-of-way (ROW) violation at T-junction and their safety concerns for motorcyclists. Findings from the study revealed that motorcyclists' ROW was likely to be violated in non-built-up areas, under poor lighting conditions, and by older females. Multiple factors have been found to be linked with various injury outcomes of motorcycle crashes. For instance, Shaheed et al., (2013) found that rear-end collision, speeds greater than or equal to 55mph, location of crash, lighting condition, rider gender, road surface condition, and helmet use affect the outcomes of crashes involving motorcycles. Haque et al., (2010) investigated how roadway characteristics, environmental factors, traffic factors, maneuver types, and driver behavior influence right-angle crashes involving motorcycles at intersections. Their study found that nighttime riding, driving on curb and median, and driver running red light affect the severity of motorcycle crashes.

Lin et al., (2003) identified the factors that affect the severity of motorcycle injuries among young adult riders in rural and urban areas in Taiwan. The proportional odd model was used to investigate the study. The result revealed that factors such as being on rural roads, collision with heavier objects, makes of motorcycle and darkness and greater speed might increase the injury severity of motorcycle riders among young adults. Further, the adjusted odd ratio (OR) of rural to urban roads have a greater level of injury severity of 1.64 from the study results. (Budd and Newstead, 2018) accessed the current and future motorcycle-related crashes and injury risk in rural and urban areas in Australia. The study found that injury crashes in rural regions occurred at higher proportions than expected in urban regions. Thirty-five percent of injury crashes (and 40% of fatal and serious injury crashes) were in rural regions and just under 30% (and just over 30% for fatal and serious injury crashes) occurred in speed zones of 80 km/hr or more. Research conducted to compare factors affecting motorcycle crashes in rural versus urban context (Islam and Brown, 2017) revealed that variables such as clear weather and roadway without light were found significant only in the rural model, variables like older female motorcyclists and horizontal curve were found significant in only urban model and for both models variables like alcohol influence, non-usage of a helmet and high speed were significant. Islam et al., (2014) explored the contributing factors to the injury severity resulting from single-vehicle (SV) and multi-vehicle (MV) large trucks at-fault crashes in rural and urban locations in Alabama. The findings revealed that there are differences associated with the injury severities among rural versus urban SV and MV trucks at-fault crashes with respect to the variety of variables. This indicates that some variables are were found significant to only one or the other location or both locations.

Geedipally et al., (2011) observed that impaired riding, rider gender, lighting, and the roadway geometry, affect the severity of crashes. Ospina-Mateus et al., (2019) performed a bibliometric analysis to identify relevant publications on risk factors associated with motorcycle crashes and their implications. The findings of the study revealed that an average growth of 9% of studies on motorcycle crashes were published on prevention of motorcycle crashes between 2000 and 2017. Bjørnskau et al., (2012) identified the risk factors associated with motorcycle crashes and specifically found that younger riders under 19 years were most at risk and half of the fatal motorcycle crashes in Norway involved sport motor bikes. Like Bjørnskau et al., (2012), Oxley et al., (2013) observed that 62% of children who were involved in fatal and serious injury motorcycle crashes were aged between 10-16 years. The study further found that majority of the crashes happened on rural roads with speeds between 50-70 km/h and over 50% of the children who sustained head injuries did not use helmet. Ding et al., (2019) found that at 70km/h, the risk of a motorcyclist sustaining serious injury in collision with wide objects, crash barrier, and narrow objects are 20%, 51%, and 64% respectively whereas the risk in a head-on collision between a motorcycle and a passenger car at 60km/h was estimated to be 55%. Harnen et al., (2003) explored the relationship between the geometric characteristics and traffic flow characteristics of non-signalized intersections and the incidence of motorcycle crashes while Waseem et al., (2019) found riders with no formal education to have higher chances of getting into serious injury crashes.

Oluwadiya et al., (2016) observed that pillion riders were more at risk of sustaining injuries compared to motorcycle riders as the pillion riders were less likely to use a crash helmet and Akaateba et al., (2015) found that gender, age, marital status, and license status affect helmet use. Rosenberg et al., (2020) investigated motorcycle-related road traffic crashes in Kigali, Rwanda. The result revealed that 80% of the victims were male, with most of the injuries occurring at the lower extremities (33%), head (30%), and upper extremities (16%). Bello et al., (2012) investigated the incidence and trend of motorcycle injuries. The study revealed that riders were the most killed (84%), followed by Pedestrians (16%) and the rate of helmet wearing was very low (0.3%). Sanusi and Emmelin, (2014) explored the risk perception of commercial motorcyclists in Ibadan, Nigeria where they found that there was the need for regulations for training and licensing of motorcyclists and stringent measures to enforce road traffic rules.

Zimmerman et al., (2015) investigated crash characteristics and socio-economic impact of low volume roads in Tanzania. The results from the study show that majority of crashes that caused an RTI involved motorcycles (71%) of which most of the victims are male (82%) of an average age of 27 years. Oliver et al., (2020) examined the growth of motorcycles and the functioning of the motorcycle taxi industry in Lomé, Togo. The result shows that the heterogeneous characteristics of the players in the industry and strong linkages with formal activities have contributed to its sustainability. Starkey, P (2016) observed the benefits and challenges of usage of motorcycles in rural areas of sub- Sahara Africa. The findings from this study show that regulatory frameworks and enforcement of safety need to be improved. Further, the formation of motorcycle associations is paramount for improved safety. Olvera et al., (2016) examined the operations of the motorcycle taxi in Lomé, Togo. The results of the study indicate the need to identify measures to formalize the operations of the motorcycle business and improve its safety concerns. The goal of doing away with the use of the commercial motorcycle, especially in the rural areas would have a negative effect on their livelihood. Sumner et al., (2014) accessed the wearing of free reflective fluorescent motorcycle vests to improve the safety of motorcyclists. The results revealed an increase of 6.2% wearing rate of the free reflective vest by motorcyclists which indicate the importance of removing economic barrier in support of safety improvement.

## 3.4 METHODOLOGY

Many motorcycle crash studies have previously been carried out to understand factors that influence motorcyclists' behaviors and how crash factors are associated with injury severity outcomes. For instance, Oluwadiya et al., (2016) used odd ratio and Chi-Square tests to assess the relative vulnerability of motorcyclists and passenger injury severity while Ackaah and Afukaar (2010) used cross-sectional observations and Chi-Square test to investigate the prevalence of helmet use among motorcycle riders and pillion riders in Ghana. Due to the classification of crash severities into discrete outcomes, discrete-outcome models, ordered (probit and logit models), and unordered models (such as the multinomial logit model), have been used to analyze crash severity (see Shankar and Mannering, 1996; Savolainen and Mannering, 2007; Geedipally et al., 2011;

Savolainen et al., 2011; Mannering and Bhat, 2014 and Islam & Brown 2017for injury-severity methodology reviews). Previous motorcycle injury severity studies have used mixed logit (Shaheed et al., 2013; Pai et al., 2009; Haque et al., 2010), mixed logit with heterogeneity in means and variances (Waseem, 2019), logistic regression (Bjørnskau et al., 2012; Akaateba et al., 2015; Wu and Loo, 2016; Aidoo et al., 2018; Ding et al., 2019; Thompson et al., 2020), generalized ordered logit models (Aidoo and Amoh-Gyimah 2019; Quddus et al., 2002).

Unobserved heterogeneity in crash data is an important concern in traffic safety research Mannering et al., (2016). Choosing an appropriate model that accounts for unobserved heterogeneity can achieve a better fit of the data, improve model estimates, and ultimately the inferences that are made from the model estimates. To account for the effects of unobserved heterogeneity, this study used mixed logit modeling techniques. Details of the mixed logit model formulation are summarized in Table 3.1.

Table 3.1 Equations used in mixed logit model formulation

| Equation | Description |
|---|---|
| $S_{in} = \beta_i X_{in} + \varepsilon_{in}$ | $S_{in}$ = severity function for category *i* in crash *n*<br>$\beta_i$ = estimable severity parameters for category *i*,<br>$X_{in}$ = explanatory variables of severity category *i* in crash *n*,<br>$\varepsilon_{in}$ = error term – generalized extreme value distributed (McFadden, 1981) |
| $P_n(i) = \frac{\exp(\beta_i X_{in})}{\Sigma\, exp(\beta_i X_{in})}$ | $P_n(i)$ = probability of an *i*th outcome occurring in the *n*th observation (Washington et al., 2020 ) |
| $P_n(i\|\varphi) = \int \frac{exp\,(\beta_i X_{in})}{\Sigma\, exp(\beta_i X_{in})} f(\beta_i\|\varphi)\beta_i$ | $P_n(i\|\varphi)$ = probability of injury severity *i* conditional on $f(\beta_i\|\varphi)$<br>$\varphi$ = vector of parameters with known density function (McFadden and Train, 2000) |

The mixed multinomial logit model, a generalization of the traditional multinomial logit model, allows the parameter vector $\beta_i$ to vary across observations. This model form allows for the heterogeneity within the observed crash data by varying the elements of $\beta_i$ . The outcome specific constants and elements of $\beta_i$ may either be fixed or randomly distributed over all parameters with fixed means. The mixed multinomial logit model is therefore obtained by introducing random parameters with $f(\beta_i|\varphi)$, where $\varphi$ is a vector of parameters of the chosen density function (mean and variance). A variable is considered to be random if it produces a statistically significant standard deviation, else the variable is restricted to be fixed instead of random. Due to the computational complexity in estimating the maximum likelihood of mixed logit models is computationally complex, simulation-based methods are typically used. The Halton sequence (or Halton draws), based on a methodology developed by Halton (1960) to generate a systematic non-random sequence of numbers, is the widely used approach to achieve this. Studies have shown that Halton draws are more efficient and achieve accurate probability approximations with less draws, than purely random draws (Train, 1999; Bhat, 2003). 500 Halton draws was used to estimate mixing distributions for this study. To gain a better understanding of the relationship between the crash factors and crash outcomes, marginal effects were computed to investigate the effect of individual parameters on the probability of the injury-severity outcomes Washington et al., (2020).

### 3.5 DATA AND EMPIRICAL SETTING

Motorcycle crash data used for this study were obtained from the Ghana National Road Traffic Accident database at the Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR). The data were retrieved from the Motor Traffic and Transport Department (MTTD) of the Ghana Police Service. The database at BRRI has served as the primary source of crash data for research and policy decision-making in Ghana since 1991.

Five years of motorcycle crash records, covering the period from 2014 to 2018 were used for this study. The database was queried to select crash factors such as rider demographic characteristics, environmental conditions, weather conditions, time of the crash, roadway geometry, and vehicle characteristics. For analysis and modeling purposes, the data was further divided into urban and rural areas. Four injury severity levels (Fatal injury, Incapacitating injury, Minor injury, and No injury) were used as classification criteria for the crash outcomes. Figure 1 shows a comparison of the distribution of motorcycle crash injury severity between rural and urban areas over the study period and Table 3.2 presents the descriptive statistics of the variables that were used in model estimations.

Figure 3.1 revealed that rural areas recorded more (21 percentage points higher) fatal motorcycle crashes than urban areas. The proportion of incapacitating injury crashes were similar for both rural and urban areas, but urban areas recorded more minor injury and no injury crashes

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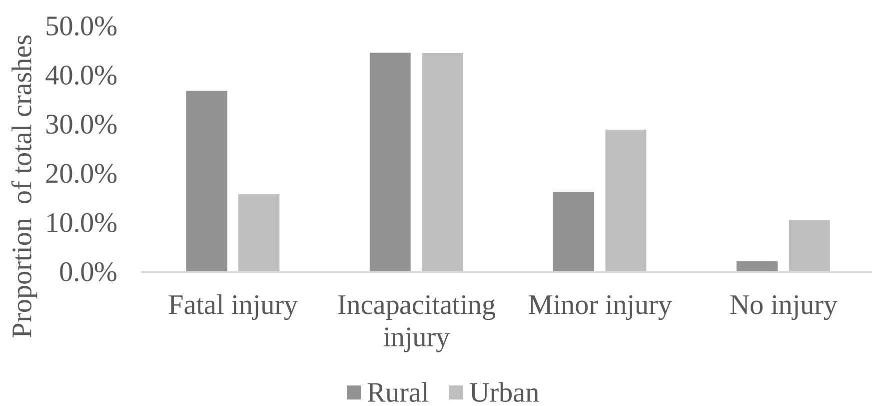


Figure 3.1 Distribution of motorcycle crash severity

Preliminary data analysis (Table 3.2) shows that 28.2% of all motorcycle crashes in rural areas are head-on collisions whereas, in urban areas, head-on collisions make up 15.1% of the crash observations. Also, 8.5% of rural area crashes were run-off-road compared to 4.3% in urban areas, while urban areas recorded more read-end collisions (25.5% compared to 20.5 % in rural areas) and collisions at 4-way stops (7.2% compared to 0.8% in rural areas). As expected, it was also observed that more pedestrian collisions happened in urban areas. Only 0.5% of rural area crashes occurred at signalized intersections compared to 11.6% of urban area crashes. Nearly 70% of rural area crashes happened under dark and unlit roadway conditions compared to 30.7% in urban areas.

Table 3.2 Descriptive statistics of variables used in model estimation

| Variable | Rural | | Urban | |
|---|---|---|---|---|
| | Frequency | Proportion | Frequency | Proportion |
| Straight and flat road | 3,429 | 81.5 | 6,266 | 94.7 |
| Collision at 4-way stop | 34 | 0.8 | 476 | 7.2 |
| Collision at T-junction | 362 | 8.6 | 1,085 | 16.4 |
| Gravel road | 290 | 6.9 | 172 | 2.6 |
| Paved roadway | 2,503 | 59.5 | 4,208 | 63.6 |
| Collision at signalized intersection | 21 | 0.5 | 768 | 11.6 |
| Rider age more than 60 | 72 | 1.7 | 60 | 0.9 |
| Rider age between 45 and 60 | 332 | 7.9 | 483 | 7.3 |
| Male rider | 4,173 | 99.2 | 6,538 | 98.8 |
| Rider age less than 21 | 635 | 15.1 | 834 | 12.6 |
| Rider not at fault | 1,027 | 24.4 | 1,667 | 25.2 |
| Steering defect | 97 | 2.3 | 112 | 1.7 |
| Multiple motorcycle defects | 29 | 0.7 | 53 | 0.8 |
| Wet pavement | 29 | 0.7 | 40 | 0.6 |
| Light rain condition | 59 | 1.4 | 46 | 0.7 |
| Poor visibility | 13 | 0.3 | 13 | 0.2 |
| Dark and unlit lighting condition | 2,941 | 69.9 | 2,031 | 30.7 |
| Head-on collision | 1,186 | 28.2 | 999 | 15.1 |
| Rider loss control | 164 | 3.9 | 179 | 2.7 |
| Sideswipe | 673 | 16.0 | 1,191 | 18.0 |
| Run-off-road | 358 | 8.5 | 285 | 4.3 |
| Collision with pedestrian | 652 | 15.5 | 1,436 | 21.7 |
| Multi-vehicle collision | 3,105 | 73.8 | 4,837 | 73.1 |
| Rear-end crash | 862 | 20.5 | 1687 | 25.5 |

## 3.6 RESULTS

Separate mixed logit injury severity models were estimated for rural and urban motorcycle crashes in Ghana. Like previous crash injury severity studies (e.g., Adanu et al., 2020; Islam and Brown, 2017; Islam et al., 2014), during model estimation, variables were included in the specification if they had t-statistics corresponding to the 90% confidence interval on a two-tailed t-test. The random parameters, however, were included if their standard deviations had t-statistics corresponding to the 90% confidence interval. Results of likelihood-ratio tests conducted justify the development of separate models for rural and urban motorcycle crashes (Washington et al., 2011).

Tables 3.3 and 3.4 show that the rural and urban mixed logit models exhibited McFadden pseudo-$\rho^2$ values 0.2348 and 0.1494 respectively. A wide variety of crash factors were found to be associated with the motorcycle crash injury severity outcomes. In the urban area crash model, 22 factors were found to influence the injury severity outcomes of motorcycle crashes, whereas 21 factors were found to influence the injury severity outcomes in rural areas. The injury outcome for which a variable was defined during model estimation is placed in a bracket as: fatal injury [FI], incapacitating injury [II], minor injury [MI], and no injury [NI]. The effects of the variables on injury severity probabilities were found to vary as measured by the magnitude of their marginal effects. Detailed model estimation results for rural and urban motorcycle crashes are presented in Tables 3.3 and 3.4 respectively. Average marginal effects based on population of observations are also presented in Tables 3.3 and 3.4. Marginal effects describe the effect of a unit change in the independent variable on the injury severity outcome probabilities. In case of indicator variables, marginal effect gives the effect of independent variable moving from zero to one on the injury severity outcome probabilities (Washington et al., 2011).

Two random parameters were found to be statistically significant in the rural model and only one was found significant in the urban model, indicating their varying influences on the injury severities. The normal distribution provided the best statistical fit for these random parameters. The effects of the rest of the crash factors were fixed across the populations for the crashes. The two random parameters found to be statistically significant in the rural mixed logit model are the indicator variables for multi-vehicle collision and roadway lighting conditions being dark and unlit. The dark and unlit roadway indicator variable was also found to have a statistically significant random parameter in the urban mixed logit model.

The rural multi-vehicle collision variable defined for incapacitated injury was found to be a random parameter with a mean of 0.257 and standard deviation of 2.837 and assumed to be normally distributed. This indicates that for 53.6% of the multi-vehicle collision crashes data, the probability of incapacitated injury is high, whereas the remaining 46.4% of the crashes the likelihood of incapacitated injury is low. This shows that the likelihood of incapacitated injury for motorcycle crashes in rural settings is high. The dark and unlit roadway indicator variable (defined for incapacitated injury) for rural areas had a mean of -0.321 and a standard deviation of 1.092. This implies that for 38.4% of rural crashes that occurred on dark and unlit roadways, the probability of an incapacitated injury is low while the chance of incapacitated injury is high for the remaining 61.8% for motorcycle crashes. This further shows that there is high chance of incapacitating injury in rural area motorcycle crashes. Similarly, interpretation of the mean and standard deviation values for the dark and unlit roadway indicator variable for urban motorcycle crashes, defined for incapacitating injury, revealed a decrease in the probability of incapacitated injury in 48.9% of the crashes while variable increases the likelihood of incapacitated injury in the remaining 51.1% of the crashes. For the remaining fixed variables, those with similar attributes are grouped, compared between the two models, and discussed accordingly.

Table 3.3 Mixed logit model estimation results for rural motorcycle crashes

| Variable | Parameter estimate | t-Statistic | Marginal effects: Fatal injury | Incapacitating injury | Minor injury | No injury |
|---|---|---|---|---|---|---|
| Constant [FI] | 2.732 | 15.93 | | | | |
| Steering defect [FI] | 0.563 | 2.11 | 0.0023 | -0.0015 | -0.0007 | -0.0001 |
| Straight and flat road [FI] | -0.320 | -3.01 | -0.0442 | 0.0225 | 0.0191 | 0.0026 |
| Rider age more than 60 [FI] | 0.975 | 3.04 | 0.0028 | -0.0016 | -0.001 | -0.0002 |
| Rider age between 45 and 60 [FI] | 0.471 | 3.11 | 0.0064 | -0.0036 | -0.0024 | -0.0004 |
| Head-on collision [FI] | 1.273 | 10.89 | 0.0572 | -0.0321 | -0.0223 | -0.0029 |
| Rider loss control [FI] | 0.460 | 2.37 | 0.0035 | -0.0022 | -0.0011 | -0.0002 |
| Sideswipe [FI] | -0.575 | -4.60 | -0.0129 | 0.0048 | 0.0071 | 0.001 |
| Constant [II] | 1.613 | 2.15 | | | | |
| Multi-vehicle collision [II] | 0.257 | 2.07 | -0.0315 | 0.0419 | -0.0091 | -0.0013 |
| Standard deviation for "Multi-vehicle collision" (normally distributed) | 2.837 | 4.49 | | | | |
| Dark and unlit lighting condition [II] | -0.321 | -2.65 | 0.0065 | -0.109 | 0.0038 | 0.0006 |
| Standard deviation for "Dark and unlit roadway" (normally distributed) | 1.092 | 1.86 | | | | |
| Male rider [II] | 1.249 | 1.70 | -0.1088 | 0.1674 | -0.0522 | -0.0064 |
| Collision at 4-way stop [II] | 1.201 | 1.69 | -0.0007 | 0.0011 | -0.0004 | -0.0001 |
| Collision at T-junction [MI] | 0.227 | 1.74 | -0.0016 | -0.0009 | 0.0026 | -0.0001 |
| Constant [MI] | 2.135 | 13.76 | | | | |
| Paved roadway [MI] | -0.432 | -4.63 | 0.0175 | 0.0097 | -0.0286 | 0.0014 |
| Rider not at fault [MI] | 0.339 | 3.11 | -0.0067 | -0.0034 | 0.0107 | -0.0006 |
| Rider age less than 21 [MI] | 0.320 | 2.65 | -0.0039 | -0.0026 | 0.0068 | -0.0003 |
| Ran off road [MI] | -0.667 | -3.65 | 0.003 | 0.0023 | -0.0055 | 0.0002 |
| Collision with pedestrian [NI] | -2.939 | -2.91 | 0.0003 | 0.0003 | 0.0002 | -0.0007 |
| Wet pavement [NI] | 1.729 | 2.64 | -0.0005 | -0.0003 | -0.0002 | 0.001 |
| Rear-end crash [NI] | 0.431 | 1.88 | -0.0015 | -0.0007 | -0.0009 | 0.0031 |
| *Model statistics* | | | | | | |
| Number of observations | 4207 | | | | | |
| Log-likelihood restricted | -5832.14 | | | | | |
| Log-likelihood at convergence | -4462.51 | | | | | |
| McFadden pseudo $\rho^2$ | 0.23 | | | | | |

Table 3.4 Mixed logit model estimation results for urban motorcycle crashes

| Variable | | | Marginal effects | | | |
|---|---|---|---|---|---|---|
| | Parameter estimate | t-Statistic | Fatal injury | Incapacitating injury | Minor injury | No injury |
| Constant [FI] | 1.448 | 2.67 | | | | |
| Straight and flat road [FI] | -0.441 | -3.14 | -0.0488 | 0.0214 | 0.0205 | 0.0069 |
| Rider age more than 60 [FI] | 0.915 | 2.98 | 0.0015 | -0.0007 | -0.0006 | -0.0002 |
| Rider age between 45 and 60 [FI] | 0.513 | 4.08 | 0.0056 | -0.0024 | -0.0023 | -0.0009 |
| Light rain condition [FI] | 1.055 | 2.62 | 0.0011 | -0.0003 | -0.0005 | -0.0002 |
| Poor visibility [FI] | 1.648 | 2.70 | 0.0007 | -0.0003 | -0.0003 | -0.0001 |
| Head-on collision [FI] | 1.441 | 15.18 | 0.0436 | -0.0184 | -0.0169 | -0.0083 |
| Rider loss control [FI] | 0.402 | 1.98 | 0.0016 | -0.0007 | -0.0007 | -0.0002 |
| Sideswipe [FI] | -0.544 | -4.25 | -0.0065 | 0.0027 | 0.0025 | 0.0012 |
| Multi-vehicle collision [II] | -0.363 | -4.08 | -0.0297 | 0.0126 | 0.0116 | 0.0055 |
| Constant [II] | 2.057 | 3.95 | | | | |
| Dark and unlit lighting condition [II] | -0.125 | -0.53 | -0.0025 | 0.0062 | -0.0026 | -0.0012 |
| Standard deviation for "Dark and unlit roadway" (normally distributed) | 4.463 | 1.95 | | | | |
| Gravel road [HI] | 0.315 | 1.70 | -0.0005 | 0.0016 | -0.0008 | -0.0003 |
| Constant [MI] | 1.778 | 3.40 | | | | |
| Collision at T-junction [MI] | 0.432 | 5.68 | -0.0035 | -0.0086 | 0.0152 | -0.0031 |
| Paved roadway [MI] | -0.310 | -5.22 | 0.0094 | 0.0195 | -0.0355 | 0.0066 |
| Collision at signalized intersection [MI] | 0.148 | 1.68 | -0.0008 | -0.002 | 0.0036 | -0.0007 |
| Collision with pedestrian [NI] | -5.437 | -5.43 | 0.0002 | 0.0003 | 0.0003 | -0.0008 |
| Male rider [NI] | 0.924 | 1.77 | -0.0155 | -0.0338 | -0.0313 | 0.0805 |
| Steering defect [NI] | 0.866 | 3.54 | -0.0005 | -0.0009 | -0.0008 | 0.0022 |
| Multiple motorcycle defects [NI] | 1.210 | 3.35 | -0.0003 | -0.0006 | -0.0006 | 0.0015 |
| *Model statistics* | | | | | | |
| Number of observations | 6617 | | | | | |
| Log-likelihood restricted | -9173.11 | | | | | |
| Log-likelihood at convergence | -7848.12 | | | | | |
| McFadden pseudo $\rho^2$ | 0.14 | | | | | |

3.6.1 Collision Types

The difference in mass between motorcycles and vehicles contributes to the severity outcome of motorcycle involved multi-vehicle crashes. In this study, it was observed that the probability of fatal injury for motorcycle crashes involving sideswipe and rear-end collisions in rural settings is lower by 0.0129 and 0.0015, respectively. However, there is a high probability that sideswipe crashes could lead to other injuries severities in both rural and urban areas.

The results also show that head-on collision indicator for rural areas increases the probability of fatal injury by 0.0572 compared to slightly lower chance (0.0436) of fatal injury in urban areas. It was further observed that the collision with pedestrian indicator variable reduces the likelihood of no injury by 0.0008 and 0.0007 in rural and urban settlements respectively. This indicates that motorcycle crashes that involved collision with a pedestrian have higher chances of resulting in some form of injury. Run-off-road motorcycle crashes in rural areas were more likely to lead to death. The model estimation results further reveal that crashes in which the rider lost control had a higher likelihood of resulting in fatal injury in both rural and urban settings.

***3.6.2 Roadway and Environmental Characteristics***

It has been observed that weather conditions (e.g., rainfall) affect injury severity of motorcycle crashes (Kasantikul et al. 2005; Abdul Manan et al. 2017). In this study, it was observed that the rain indicator variable increases the likelihood of fatal injury by 0.0011 in urban areas while the likelihood of other injury outcomes is lower. In rural areas, motorcycle crashes that happened on wet roadways were less likely to record any form of injury. With respect to the roadway curvature and conditions, the straight and flat roadway variable was found to reduce the probability of fatal injury by 0.0442 and 0.0488 in rural and urban areas respectively while the likelihood of other injury outcomes is higher. This shows that the chances of fatal motorcycle crashes are high on roadways with some form of curvature and grade, in both rural and urban areas.

The results further suggest that, with exception of minor injury outcomes, the paved road indicator variable increases the probability of all the other injury outcomes in both rural and urban areas. In urban areas, motorcycle crashes that occurred on unpaved gravel roads were more likely to record incapacitating injury. The dark and unlit roadway indicator variable increased the likelihood of fatal injury outcome in rural areas by 0.0065 whereas the probability of fatal injury is lower by 0.0025 in urban areas. However, motorcycle crashes that happened in urban areas under poor visibility conditions were more likely to result in fatalities. The indicator variable for collision at four-way intersection increased the chance of incapacitating injury by 0.0011 in rural areas, while the T-junction variable increased the probability of minor injury by 0.0026 in the rural area motorcycle crash model, and 0.0152 in the urban area model.

### *3.6.3 Vehicle characteristics*

As shown in Tables 3 and 4 only one and two vehicle-related variables were found to be significant in the rural and urban setting models, respectively. The results show that motorcycle crashes that occurred as a result of steering defects have increased the likelihood of fatal injury by 0.0023 in rural areas whereas in urban areas crashes that occurred due to steering defects were less likely to be fatal by 0.0005. Urban crashes that involve motorcycles with multiple defects were less likely to result in injury. This shows that fatal crashes due to steering defects are more pronounced in rural areas in Ghana.

### *3.6.4 Rider Characteristics*

Motorcycle rider ages were classified into three groups: younger than 21, between 40 and 60, and above 60 years of age. All three age group variables were found to be significant in the models. The model estimation results show that the indicator variable for riders aged between 45 and 60 years increased the probability of fatal injury by 0.0064 and 0.0056 in the rural and urban models, respectively. The study also found that the variable for adult riders aged above 60 years increased the probability of fatal injury by 0.0026 and 0.0015 in rural and urban areas, respectively. These findings are consistent with other studies (e.g., Islam and Brown, 2017). However, younger riders (rider age less than 21) were less likely to be killed in rural settlements. The male gender variable was found to be significant in both models. This variable increased the probability of incapacitating injury by 0.1674 in rural areas and increased the likelihood of no injury by 0.0805 in urban settlements. In situations where another vehicle, other than a motorcycle, was deemed to be at fault in motorcycle involved crashes in rural areas, the chance of minor injury is increased by 0.0068.

### 3.7 DISCUSSIONS

Motorcycle crashes often lead to severe injury outcomes because by design motorcycles provide minimal physical protection to riders. This makes motorcyclists more vulnerable to injuries than other motor vehicle users when they get into crashes (Rifaat et al., 2012; Shaheed et al., 2013). Indeed, the World Health Organization classifies motorcyclists as vulnerable road users (WHO, 2018). The rapid increase in the use of motorcycles to meet daily mobility demands in developing countries, in an informal and often unregulated manner, may be a barrier to achieving the Sustainable Development Goal (SDG) target 3.6, which called for a 50% reduction in the number of road traffic fatalities by 2020. The critical roles of commercial motorcycles in providing employment to youth and filling a basic mobility gap in many developing countries make banning or regulating their activities a political issue that governments find difficult to undertake, even though the increased activity of motorcyclists have significantly contributed to many traffic fatalities. This study contributes to efforts to identify areas for countermeasure implementation to reduce motorcycle crashes and injury severity in Ghana.

The model results presented in the previous section reveal some interesting findings that can support efforts towards improving overall traffic safety in Ghana. It has been observed that motorcycle defects contribute significantly to fatal injury outcomes across the country. This finding calls for a comprehensive education on basic motorcycle maintenance practices for commercial motorcyclists as their motorcycles tend to be overused to meet daily sales targets, compared to recreational riders. It was also found that collision with pedestrians has also resulted in many fatalities across the country. It would be important for the National Road Safety Authority (NRSA) to advocate for the implementation of safer speed policies in mixed traffic zones especially in urban areas where pedestrian collisions were observed to be high. Speed calming measures may be provided to reduce some of these crashes. While law enforcement and punitive measures may also be employed to achieve rider discipline on the road, enforcement can sometimes be compromised by bribery and corruption. To address the challenge of corruption in traffic law enforcement, comprehensive education of motorists about their rights and responsibilities can ensure that they are not coerced to pay bribes to law enforcement officers to get away with minor traffic violations. Also, punitive measures would need to be stringent but not too stringent to make bribery appear to be a better option. Further, technology may be introduced into traffic law enforcement to minimize motorist-enforcement officer interactions. If traffic law enforcement is effectively and appropriately implemented, it will ensure compliance with helmet use laws by both riders and pillion riders.

Additionally, the findings from this study provide evidence for the adoption and implementation of the *Safe Systems* approach to road safety improvement. For instance, the finding that run-off-road crashes were more likely to result in fatal injury in rural areas suggests that measures such as installation of reflective guardrails to prevent riders and indeed, drivers from running into ditches or colliding with trees and other fixed objects off the roadway, particularly at night in rural areas. It would also be important to provide clear zones and to improve sight distance in curves. Warning signs may be installed at high-risk locations, such as intersections, to warn riders and drivers on upcoming transitions in roadway geometry and traffic bottlenecks ahead. Also, roadway shoulders need to be properly maintained to help riders bring their motorcycles to a safe stop when the need arises. The findings and recommendations from the study, therefore, provide a foundation for *safe systems* approach (Bambach and Mitchell, 2014) to improving motorcycle safety in Ghana. Table 3.5 provides recommendations of countermeasures that may be implemented within the *Safe System's* framework to improve motorcycle safety in the country.

Table 3.5 Safe Systems approach for the rural and urban environment with respect to fatal injury

<table>
<tr><th>Variable</th><th>Safe Systems indicator</th><th>Countermeasures</th></tr>
<tr><td>Steering defect (Vehicle defects)</td><td>Safe vehicle</td><td rowspan="18">Safe vehicle: Advance riding/driving assistance systems, regular basic maintenance checks<br><br>Safe people: Education and training for motorcyclists, legal framework to regulate activities of motorcyclists, targeted law enforcement, road safety campaigns for pedestrians<br><br>Safe road: Physical opposing lane separation, increase roadway capacity, creation of clear zones that allow drivers/motorcyclists to recover and re-enter the roadway or guardrails at embankments, road signs and markings, provision of lighting systems, and roadway shoulder<br><br>Post-crash care: Provision of first aid to accident victims by medical professionals and early transport of victims to hospital by ambulances<br><br>Safe speed: Installation of speed cameras, road signs, and markings, law enforcement, an over-speeding warning system for motorcyclists, speed calming measures</td></tr>
<tr><td>Rider age (rider demographic characteristics)</td><td>Safe people</td></tr>
<tr><td rowspan="4">Head-on collision</td><td>Safe road</td></tr>
<tr><td>Safe speed</td></tr>
<tr><td>Safe vehicle</td></tr>
<tr><td>Safe road</td></tr>
<tr><td rowspan="2">Collision with pedestrian</td><td>Post-crash care</td></tr>
<tr><td>Safe people</td></tr>
<tr><td rowspan="2">Rider loss control/Ran-off-road</td><td>Safe road</td></tr>
<tr><td>Safe vehicle</td></tr>
<tr><td rowspan="2">Paved roadway/Roadway geometry</td><td>Safe road</td></tr>
<tr><td>Safe speed</td></tr>
<tr><td rowspan="3">Poor visibility/Lighting condition</td><td>Safe road</td></tr>
<tr><td>Safe speed</td></tr>
<tr><td>Safe people</td></tr>
<tr><td rowspan="3">Rainy condition/Road surface condition</td><td>Safe road</td></tr>
<tr><td>Safe speed</td></tr>
<tr><td>Safe people</td></tr>
</table>

## 3.8 LIMITATION

The Ghana crash data does not contain alcohol-related and crash helmet use information hence this information was not available for analysis in this paper. While acknowledging this limitation, the authors believe that findings from previous studies on the effects of alcohol involvement and non-use of a helmet on motorcycle crash severity are highly likely applicable even in the Ghanaian context. Despite this limitation, the findings of the study provide some relevant information to improve motorcycle safety concerns in the country.

### 3.9 CONCLUSIONS

The rising use of commercial motorcycles for daily commute in many developing countries in a largely unregulated environment can be a barrier to achieving safe transport systems. As part of efforts to reduce motorcycle-involved crashes, this research provides a disaggregate injury severity analysis of motorcycle crashes on rural and urban roadways in Ghana. Preliminary data analysis of the data revealed that more of the rural area crashes occurred under dark and unlit roadway conditions while urban areas recorded more intersection-related crashes. Also, it was found that more pedestrian-motorcycle crashes happened in urban areas while head-on collisions with other vehicles happened more often in rural areas. Separate mixed logit models for rural and urban motorcycle crashes were developed to identify various crash factors that influence motorcycle crash outcomes. The findings of the study are expected to lead to effective, and targeted policy decisions aimed at improving motorcycle safety particularly in rural Ghana where motorcycle transport is playing a vital role in place of traditional public transport. The goal of doing away with it especially in the rural areas would have a negative effect on their livelihood.

Two parameters for the rural model and one parameter for the urban model were found to be random indicating their varying associations with the injury severity due to unobserved heterogeneity effects. The results of the study showed some similarities and differences between the factors that influence the injury severities of motorcycle crashes that occur in rural and urban areas in Ghana. For example, variables such as dark and unlit roadway and collision at T-junctions were found significant in both the rural and urban models. Similarly, the run-off-road variable was found to be significant in both models. The model estimation results show that collision with a pedestrian, run-off-road, collisions that occur under dark and unlit roadway conditions were more likely to result in fatal injury. It was also found that while steering defects contributed significantly to fatal injury in rural areas, crashes involving steering defects were less likely to record any injury in urban areas.

Ultimately, the findings of this study provide the basis for adopting *Safe Systems* measures to improve motorcycle safety in Ghana, considering the relevance of motorcycles in filling in the needed daily mobility gap for many people. While law enforcement strategies are recommended to reduce the occurrence of crashes, the finding on the role of motorcycle defects in fatal crashes calls for a comprehensive education on basic motorcycle maintenance practices for commercial motorcyclists.

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# CHAPTER 4 A LATENT CLASS MULTINOMIAL LOGIT ANALYSIS OF FACTORS ASSOCIATED WITH PEDESTRIAN INJURY SEVERITY OF INTER- URBAN HIGHWAYS CRASHES

## 4.1 ABSTRACT

Over the years, the uncontrolled interaction of human and high-speed vehicular activities at settlement areas along highways in Ghana has resulted in many pedestrian fatalities and injuries. This phenomenon has been attributed to the land-use and right-of-way planning and lack of pedestrian crossing facilities for safe crossing of highways. The slow response to developing strategies to reduce pedestrian fatalities along the nation's highways has led to many public protests. To advance a data-driven and evidence-based approach to finding appropriate countermeasures, this study investigated the factors associated with pedestrian injury outcomes of inter-urban highway crashes in Ghana. The latent class multinomial logit modeling method was employed to account for unobserved heterogeneity in the crash data used. Pedestrian-vehicle crash data from 2014 to 2018 on highways totaling 3,037 was used for the modeling. The model estimation results show that speeding, hit and run and crashes that occurred at highway sections with no shoulder were more likely to result in fatal injury. Further, crashes involving pedestrians who were crossing the highway had a 6.44% increased likelihood to lead to fatal injury. Also, it was found that multiple-vehicle crashes involving pedestrians had increased likelihood of minor injury outcome. The findings of the study provide basis for the development of appropriate countermeasures to reduce the number of pedestrian deaths and injuries on high-speed inter-urban highways in Ghana and other countries with similar characteristics in the sub-region.

## 4.2 INTRODUCTION

Globally, road traffic crashes claim more than 1.35 million lives each year and cause up to 50 million injuries (World Health Organization, 2018). Statistics reveal that more than 90% of these deaths occur in low-and middle-income countries (LMICs), of which vulnerable road users (pedestrians, cyclists, and motorcyclists) constitute 55%, even though these countries have about 60% of the world's vehicle population (World Health Organization, 2018). Specifically, pedestrians and cyclists make up 26% of the deaths, while those using motorized two- and three-wheelers comprise another 28%. These road user groups are particularly prone to injuries and fatalities because they are not protected by any external vehicular body and their vulnerability is higher in mixed traffic conditions (Olszewski et al., 2015). Regions that have high levels of mixed traffic conditions tend to record high number of vulnerable road user deaths. For instance, the percentage of vulnerable road users involved in road traffic crashes is highest in Africa, where many cities and towns are characterized by highly mixed traffic conditions. Indeed, it is estimated that pedestrian and cyclist fatalities make up more than 40% of all road fatalities in Africa (WHO, 2018).

Road traffic crashes have major social and economic impacts which may result in loss to Gross Domestic Products (GDP) and profound impacts to affected individuals and families (World Bank, 2017; Ouni and Belloumi, 2018). Consequently, plans and policies to improve road safety are being developed across the world by all governments to stem the spate of road traffic crashes (Hoque et al., 2010; Kim et al., 2017). Attempts to mitigate road crashes and their negative impacts across the African continent, however, are often informed by policies and programs developed in high-income countries like Australia, the United Kingdom, and North America although, road user behaviors, road conditions, and overall perception towards the shared use of road space are quite different (Obeng, 2008). For example, Figure 4.1 shows street vendors selling goods within the traffic stream of a high-speed multi-lane highway in Accra, Ghana. Implementing the appropriate policies and best practices in sub-Sahara Africa will help to improve road crashes especially crashes involving vulnerable road users. Doing so, however, requires the *Safe Systems* approach that is both informed by and sensitive to the local context. As part of an effort to reduce pedestrian injury severity in sub-Sahara Africa, myriad studies have identified contributory factors that lead to vehicle-pedestrian crash occurrence and factors that influence the severity of the crash outcome (e.g. Damsere-Derry et al., 2010; Yasmin et al., 2014; Osama and Sayed, 2017).

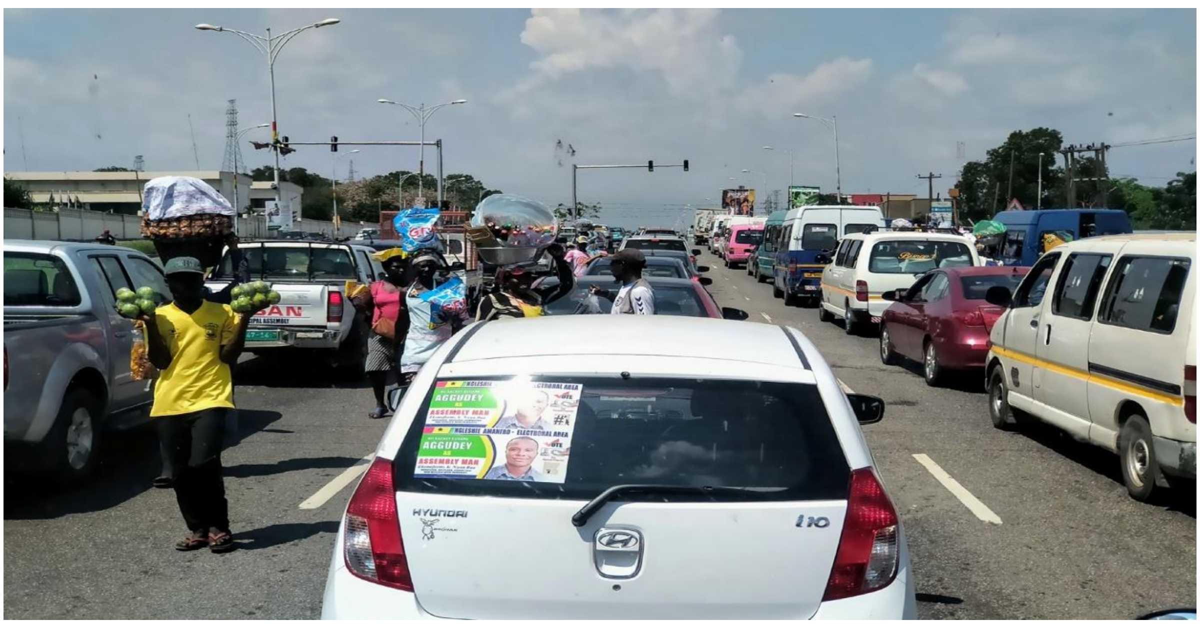


Figure 4.1 Street Vendors Working in the Traffic Stream on a High-speed Multi-Lane Arterial

Many of these studies have reported on the vulnerabilities of pedestrians in urban areas of LIMCs (World Bank, 2017; Damsere-Derry et al., 2010; Amoako et al., 2014; Mfinanga, 2014).

Less literature, however, has explicitly focused on pedestrian safety in the context of relatively high-speed roads and highways which pass through settlement areas. As such, this paper contributes to the body of knowledge on pedestrian injury severity analysis by focusing on pedestrian crashes that occur on high-speed facilities. The study used Ghana as a case study to identify the factors associated with pedestrian injury outcomes. The findings of the study are expected to provide basis for the development of appropriate countermeasures to reduce the number of pedestrian deaths and injuries in Ghana and by extension other countries in the sub-region. The latent class multinomial logit (LC-MNL) modeling method was employed to account for unobserved heterogeneity in the data, and to ensure that the policy decisions that may arise from the findings of the study are appropriate and based on data-driven evidence.

### 4.3 REVIEW OF PREVIOUS LITERATURE

Pedestrian injury severity is influenced by many factors. For example, past studies have identified many different contributory factors of pedestrian injury severity (e.g., Yasmin et al, 2014; Osama and Sayed, 2017). Understanding pedestrian crash contributing factors is an important step in developing appropriate countermeasures to reduce the frequency and injury outcomes. Globally, including some from the African continent, studies of pedestrian safety have identified a range of contributing factors affecting the occurrence and severity of pedestrian-related crashes such as the driver age, driver gender, and alcohol/drug involvement (Roudsari et al., 2004; Sze and Wong, 2007; Ulfarsson et al, 2010; Cinnamon et al., 2011; Amoako et al., 2014; Liu et al., 2019; Billah, et al., 2021;), speeding (Afukaar, 2003; Eluru et al., 2008; Kim et al., 2008; Damsere-Derry et al, 2010; Li et al., 2015; Mukherjee and Mitra, 2020), while others have reported relationship between pedestrian crashes and weather and lighting conditions (Lee and Abdel-Aty, 2005; Kim et al., 2008; Clifton et al., 2009; Aziz et al., 2013; Behnood and Mannering, 2015; Li et al., 2015; Billah, et al., 2021). Temporal factors such as day of the week (Sze and Wong, 2007; Kim et al., 2008; Osama and Sayed, 2017) and time of the day (Greene and Hensher, 2003; Eluru et al., 2008; Ackaah and Adonteng, 2011; Toran Pour et al., 2018) have been shown to affect pedestrian crashes. Previous studies have also identified factors such as vehicle type (Olukoga, 2003; Roudsari et al., 2004; Clifton et al., 2009; Aziz et al., 2013; Yasmin et al, 2014; Kim et al., 2017), roadway geometry, and roadway conditions as contributing factors to pedestrian injury severity (Jones et al., 2005; Eluru et al., 2008; Lasmini and Indriastuti, 2010; Zegeer and Bushell, 2012; Yasmin et al, 2014; Kim et al., 2017; Obinguar and Iryo-Asano., 2021). Islam and Jones (2014) performed a comparative analysis of the factors associated with the injury outcomes of pedestrian at-fault crashes in rural and urban areas in Alabama. With respect to high-speed roadways, Behrens (2010) observed pedestrian crossing behavior on freeways and found that despite the greater speed differential and risk associated with freeways, many pedestrians (62% of the observed sample) were reluctant to detour even short distances to use a grade-separated facility.

Many statistical methods have been used to estimate the association between pedestrian severity and contributing factors. During the past decade, several models were proven to be appropriate in modeling and predicting crash injury severity. For instance, a study by Roudsari et al (2004) used logistic regression to identify factors associated with pedestrian injury severity outcomes. Lee et al (2015) and Osama and Sayed (2017) compared two statistical methods: the Poisson Multivariate and Univariate Models for predicting pedestrian injury severity. The results showed that the Multivariate Poisson lognormal Conditional Autoregression Model provided the best fit compared to the Univariate model in terms of DIC value. The Negative Binomial Model has also been used in predicting pedestrian injury severity outcomes (Lasmini and Indriastuti, 2010; Schneider et al., 2010; Mukherjee and Mitra, 2020; Obinguar and Iryo-Asano., 2021; Su et al., 2021). Many other studies used random parameters multinomial models to identify the effects of human, roadway, and environmental factors on pedestrian injury severity (Aziz et al., 2013; Islam and Jones, 2014; Behnood and Mannering, 2015). Other studies, (e.g., Lee and Abdel, 2005; Kim et al., 2008; Clifton et al., 2009; Kim et al., 2017) used a generalized ordered probit model in predicting pedestrian injury severity outcome levels.

## 4.4 METHODOLOGY

Road crashes are complex events that often involve a variety of factors; many of which may be unknown and not recorded by the reporting police officer. Indeed, it is impossible to observe and include all probable factors that are associated with a crash in the standard crash report form. Ultimately, this information gap can affect the accuracy of model estimation results from some of the traditional statistical analyses, hence limiting the accuracy of decisions made from such crash models. Various statistical methods can be used to overcome this inherent problem, typically referred to as unobserved heterogeneity, in crash data and analysis (Mannering et al., 2016). For instance, random parameters (mixed logit) models (Milton et al., 2008; Morgan and Mannering, 2011; Anastasopoulos and Mannering, 2011; Kim et al., 2017) and latent class (finite mixture) models (Yasmin et al., 2014; Shaheed and Gkritza, 2014; Lidbe et al., 2020) have been used extensively to address unobserved heterogeneity in data analysis by allowing parameters to differ across crash observations (Morgan and Mannering, 2011; Behnood and Mannering, 2015; Mannering et al., 2016). Methodologically, the random parameters approach uses continuous mixing distributions to capture heterogeneity by allowing the analyst to specify the functional form of the mixing distribution (for example, normal, lognormal, uniform, triangular, etc.), whereas the latent class approach identifies unobserved classes by replacing the continuous distribution assumption of random parameter model with a discrete distribution in which unobserved heterogeneity is captured by the membership of distinct classes (Greene and Hensher, 2003; Mannering and Bhat, 2014). This study used LC-MNL as it has previously been shown to perform better than random parameters logit models in accounting for unobserved heterogeneity (Greene and Hensher, 2003; Adanu and Jones, 2017).

For this study, the latent class multinomial (LC-MNL) model allows the pedestrian injury severity to have $C$ different classes so that each of the classes will have its parameters with the probability given by (Behnood et al., 2014):

$$P_n(c) = \frac{exp(\alpha_c Z_n)}{\sum_{\forall C} exp(\alpha_c Z_n)} \quad (1)$$

where $Z_n$ represents a vector that shows the probabilities of $c$ for crash $n$, $C$ is the possible classes $c$, and $\alpha_c$ represents the estimable parameters (class-specific parameters). The unconditional probability that a crash will result in injury severity $i$ is given by:

$$P_n(i) = \sum_{\forall C} P_n(c) * P_n(i/c) \quad (2)$$

where $P_n(i/c)$ is the probability of crash $n$ to result in injury severity $i$ in class $c$. Based on the two equations above, the latent class logit model for class $c$ will be:

$$P_n(i/c) = \frac{exp(\beta_{ic} X_{in})}{\sum_{\forall I} exp(\beta_{ic} X_{in})} \quad (3)$$

where $I$ represents the possible number of injury severity levels and $\beta_{ic}$ is a class-specific parameter vector that takes a finite set of values.

Marginal effects are commonly computed from the partial derivative for each observation, to investigate the effect of individual parameters on the crash-severity outcome probabilities. The marginal effect in an LC-MNL model for binary variables is computed for each class as the difference in the estimated probabilities with the indicator changing from zero to one while keeping all the other variables at their means. The direct and cross-marginal effects can be computed respectively as follows:

$$\frac{\partial P_{ni}}{\partial x_{nik}} = \beta_{ik} P_{ni}(1 - P_{ni}) \quad (4)$$

$$\frac{\partial P_{nq}}{\partial x_{nik}} = -\beta_{ik} P_{ni} P_{nq} \quad (5)$$

The direct marginal effect indicates the effect of a unit change in $x_{nik}$ on the probability, $P_{ni}$, for crash $n$ to result in injury severity $i$. The cross-marginal effect shows the impact of a unit change in variable $k$ of alternative $i$ ($i \neq q$) on the probability $P_{nq}$ for crash $n$ to result in injury severity $q$. The final marginal effect of an explanatory variable is the sum of the marginal effects for each class weighted by their posterior latent class probabilities (Xie et al., 2012).

### 4.5 DATA DESCRIPTION

Pedestrian crash data used for this study were obtained from the Ghana National Road Traffic Accident database at the Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR). The data were retrieved from the dockets of the Motor Traffic and Transport Department (MTTD) of the Ghana Police Service. The database at BRRI has served as the primary source of crash data for research and policy decision-making in Ghana since 1991.

The data was queried to select pedestrians-involved crashes that occurred between 2014 and 2018 on highways (national roads) after the data were error-checked and observations with missing or ambiguous values were omitted from the original dataset. A total of 3037 injury-related pedestrian crashes that occurred on inter-urban highways were used for the model estimation. Even though underreporting is an issue as some crashes are not reported to the police, the majority of them do not involve injuries and hence will not affect our study. For analysis and modeling purposes, three injury severity levels (Fatal injury, Hospitalization Injury (Incapacitating injury), and Minor injury) were used as classification criteria for the crash injury outcomes. The distribution of crashes by pedestrian injury severity shows that 31.9% of the crashes recorded during the study period resulted in fatal injury, 46% were hospitalized injury outcome and 22.1% were minor injury. Table 1 presents the descriptive statistics of the variables that were used and found to be significant in the LC-MNL model estimation. Table 4.1 shows that distracted driving accounted for more than half (51.6%) of the pedestrian crashes while speeding was responsible for 23.4%. Also, more than half (54.9%) of the crashes occurred in urban areas and 25.1% occurred between 6 pm and midnight. Crashes involving pedestrians crossing inter-urban highways made up 62.7% of all the crash observations and motorcycles were responsible for 11.7% of the crashes.

### 4.6 MODEL ESTIMATION RESULTS

A total of 26 variables were found to be statistically significant, mostly at a 0.05 significance level, and the resulting McFadden Pseudo R-Square was 0.129. Two distinct classes (Latent Class 1 with class membership probability of 0.682 and Latent Class 2 with class membership probability of 0.318) with homogeneous attributes were found to be significant. The LC-MNL results are reported in Table 4.2 with each variable having two sets of parameters values. Four variables (median present, four-way intersection, not at a junction, shoulder overgrown with weeds) were found to significantly influence class membership probability. The signs on these variables indicate that Latent Class 1 is predominantly characterized by pedestrian crashes on rural sections of the inter-urban highways. For instance, the positive sign on the shoulder overgrown with weeds variable and the negative sign on the median present variable in Latent Class 1 shows that there is strong evidence that crashes assigned to this class more likely occurred in rural areas. In fact, the parameter estimate on the urban variable was negative in Latent Class 1, confirming that crashes in Latent Class 1 were those that occurred in rural settings. These findings reveal that a higher proportion of pedestrian-involved crashes on inter-urban highways in Ghana occur in the rural settlement areas. From the model estimation results presented in Table 4.2, it can be observed that the speeding, signal, and youth variables had the same sign across the two classes, while brake, urban, no shoulder, and pedestrian crossing the highway variables exhibited opposite signs. Steering, motorbike, old, and bus variables are not significant in both classes. These suggest that there is heterogeneity between the two classes. This makes it inappropriate to interpret the model results based on the magnitude and sign of the parameter estimates hence the marginal effects of the variables were used and shown in Table 4.3.

Table 4.1 Summary statistics of variables included in the LC- MNL model

| Variable | Description | Number of Observations | Proportion |
|---|---|---|---|
| Speeding | Driver error: speeding (1 = yes, 0 = no) | 710 | 23.4 |
| Distracted driving | Driver error: inattentive (1 = yes, 0 = no) | 1567 | 51.6 |
| Hit and Run | Hit and Run (1 = yes; 0 = no) | 176 | 5.8 |
| Pedestrian at fault | Pedestrian error (1 = yes, 0 = no) | 301 | 9.9 |
| Pedestrian crossing the road | Pedestrian action: crossing the road (1 = yes, 0 = no) | 1904 | 62.7 |
| Afternoon | Crash occurred 1.00 pm to 6.00 pm (1 = yes, 0 = no) | 1197 | 39.4 |
| Urban area | Location of crash: urban (1 = yes, 0 = no) | 1667 | 54.9 |
| Nighttime | Crash occurred 6 pm to 12.00 am (1 = yes, 0 = no) | 762 | 25.1 |
| Young driver | Driver age < 25 (1 = yes, 0 = no) | 237 | 7.8 |
| Adult driver | Driver age between 25 and 44 (1 = yes, 0 = no) | 2041 | 67.2 |
| Older driver | Driver age between 45 and 65 (1 = yes, 0 = no) | 577 | 19 |
| Casualty aged less than 25 years | Casualty age < 25 (1 = yes, 0 = no) | 1169 | 38.5 |
| Casualty aged between 25 anc years | Casualty age between 25 and 45 (1 = yes, 0 = no) | 1081 | 35.6 |
| Casualty aged greater than 65 years | Casualty age > 65 (1 = yes, 0 = no) | 134 | 4.4 |
| Female | Casualty sex: female (1 = yes, 0 = no) | 1175 | 38.7 |
| No shoulder | Shoulder type: no shoulder (1 = yes, 0 = no) | 355 | 11.7 |
| Signal | Traffic control: signals (1 = yes, 0 = no) | 164 | 5.4 |
| Clear weather | Weather condition: clear (1 = yes, 0 = no) | 2509 | 82.6 |
| Paved road with potholes | Road surface: paved with potholes (1 = yes, 0 = no) | 264 | 8.7 |
| Brake | Vehicle defect: brake (1 = yes, 0 = no) | 146 | 4.8 |
| Steering | Vehicle defect: steering (1 = yes, 0 = no) | 118 | 3.9 |
| Bus | Vehicle type: bus (1 = yes, 0 = no) | 143 | 4.7 |
| Motorbike | Vehicle type: motorbike (1 = yes, 0 = no) | 355 | 11.7 |
| Multi-vehicle | Number of vehicles involved in crash > 1 (1=yes, 0= no) | 538 | 17.7 |

Table 4.2 Latent class multinomial logit estimation results for pedestrian injury severity

| Variable | Latent class 1 | | | | | | Latent class 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fatal Injury | | Hospitalized Injury | | Minor Injury | | Fatal Injury | | Hospitalized Injury | | Minor Injury | |
| | parameter | t-stat | parameter | t-stat | parameter | t-stat | parameter | t-stat | parameter | t-stat | parameter | t-stat |
| **Variables influence class probability y[a]** | | | | | | | | | | | | |
| Median | -0.555 | -5.04 | | | | | | | | | | |
| Four-way intersection | -0.663 | -2.28 | | | | | | | | | | |
| Not at junction | -0.182 | -1.03 | | | | | | | | | | |
| Shoulder overgrown with weeds | 1.623 | 1.13 | | | | | | | | | | |
| Constant | -4.315 | -3.59 | | | | | -1.766 | -2.11 | | | | |
| **Crash-Specific Characteristics** | | | | | | | | | | | | |
| Speeding | 0.236 | 1.43 | - | - | - | - | 1.187 | 3.22 | - | - | - | - |
| Distracted driving | - | - | 0.026 | 0.19 | - | - | - | - | 0.716 | 1.6 | - | - |
| Hit and run | 1.946 | 5.16 | - | - | - | - | 0.234 | 0.31 | - | - | - | - |
| Pedestrian crossing the road | - | - | 0.587 | 2.49 | - | - | - | - | -2.894 | -0.74 | - | - |
| **Location and time of the crash** | | | | | | | | | | | | |
| Afternoon (from 1.00 pm to 6.00 pm) | -0.22 | -1.58 | - | - | - | - | 0.749 | 2.26 | - | - | - | - |
| Urban area | - | - | - | - | -0.868 | -1.61 | - | - | - | - | 1.363 | 4.08 |
| Nighttime (From 7.00 pm to 12 mid-night) | - | - | -0.553 | -3.53 | - | - | - | - | -0.419 | -0.77 | - | - |
| **Driver/ Rider/Pedestrian Casualty attributes** | | | | | | | | | | | | |
| Young driver (driver age less than 25 years) | - | - | - | - | -6.134 | -0.21 | - | - | - | - | 5.096 | 3.99 |
| Adult driver (driver age between 25 and 44 years) | - | - | - | - | -2.382 | -2.77 | - | - | - | - | 4.27 | 4.08 |
| Older driver (driver age between 44 and 65 years) | - | - | - | - | -0.891 | -1.22 | - | - | - | - | 2.8 | 2.87 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| People aged less than 25 years | - | - | 0.273 | 1.88 | - | - | - | - | 0.729 | 1.62 | - | - |
| People aged between 25 and 44 years | -0.613 | -3.99 | - | - | - | - | -0.197 | -0.58 | - | - | - | - |
| People aged greater than 65 years | -0.224 | -0.65 | - | - | - | - | 1.869 | 2.85 | - | - | - | - |
| Female | - | - | 0.675 | 4.97 | - | - | - | - | -1.599 | -2.53 | - | - |
| **Road and Environmental Characteristics** | | | | | | | | | | | | |
| No shoulder | - | - | - | - | 1.897 | 3.04 | - | - | - | - | -2.031 | -3.04 |
| No shoulder | 0.208 | 0.93 | - | - | - | - | -2.07 | -2.24 | - | - | - | - |
| Signal | - | - | 0.002 | 0.01 | - | - | - | - | 2.173 | 2.66 | - | - |
| Clear weather | - | - | - | - | 1.051 | 1.53 | - | - | - | - | 1.823 | 4.56 |
| Four-way intersection | - | - | - | - | 2.022 | 2.55 | - | - | - | - | -3.452 | -4.62 |
| Paved road with potholes | -0.457 | 1.74 | - | - | - | - | 0.146 | 0.23 | - | - | - | - |
| **Vehicle characteristics** | | | | | | | | | | | | |
| Brake | - | - | - | - | 4.167 | 5.03 | - | - | - | - | -2.413 | -2.45 |
| Steering | -1.045 | -2.63 | - | - | - | - | 0.925 | 1.2 | - | - | - | - |
| Bus | - | - | -0.784 | -2.68 | - | - | - | - | -0.65 | -0.54 | - | - |
| Motorbike | - | - | 1.705 | 5.75 | - | - | - | - | -2.946 | -1.09 | - | - |
| Number of vehicles | - | - | - | - | 2.492 | 3.94 | - | - | - | - | 0.977 | 1.64 |
| Latent class Probability (t-statistics) | | | | | 0.682 | | | | | | 0.318 | |
| Number of observations | | | | | | 3037 | | | | | | |
| Log-likelihood at zero (constant or restricted) | | | | | | -3336.486 | | | | | | |
| Log-likelihood at convergence | | | | | | -2904.68 | | | | | | |
| McFadden Pseudo R^2 | | | | | | 0.129 | | | | | | |
| AIC | | | | | | 5923.4 | | | | | | |

[a] Variables influencing class probabilities are fixed across different injury severity level

Table 4.3 Estimated marginal effects of the variables included in the LC-MNL model

| Variables | in severity function of | Effect on probabilities of the severity outcomes (%) | | |
|---|---|---|---|---|
| | | Fatal | Hospitalized | Minor |
| **Crash-specific characteristics** | | | | |
| Speeding | Fatal | 2.12 | -1.03 | -1.09 |
| Distracted driving | Hospitalized | -0.66 | 1.43 | -0.77 |
| Hit and run | Fatal | 1.24 | -1.08 | -0.16 |
| Pedestrian at fault | Hospitalized | -0.52 | 0.56 | -0.04 |
| Pedestrian crossing highway | Minor | 6.44 | 2.43 | -8.86 |
| **Location and time of the crash** | | | | |
| Afternoon (From 1pm to 6pm) | Fatal | 0.11 | 0.68 | -0.79 |
| Urban area | Minor | -1.73 | -0.71 | 2.44 |
| Nighttime (From 7pm to 12mid-night) | Hospitalized | 2.03 | -2.27 | 0.24 |
| **Driver/ Rider/Pedestrian Casualty attributes** | | | | |
| Young driver | Minor | -0.76 | -0.43 | 1.19 |
| Adult driver | Minor | -6.77 | -3.04 | 9.81 |
| Older driver | Minor | -1.37 | -0.44 | 1.81 |
| Casualty aged less than 25 years | Hospitalized | -1.74 | 2.33 | -0.59 |
| Casualty aged between 25 and 45 years | Fatal | 0.32 | 0.02 | -0.34 |
| Casualty aged greater than 65 years | Fatal | -2.94 | 2.6 | 0.35 |
| Female | Hospitalized | -2.35 | 2.03 | 0.32 |
| **Road and Environmental Characteristics** | | | | |
| | Fatal | -0.3 | 0.01 | 0.29 |
| No shoulder | Minor | -0.06 | 0.09 | 0.03 |
| | Combined effects | -0.36 | 0.1 | 0.32 |
| Signal | Hospitalized | -0.11 | 0.47 | -0.37 |
| Clear weather | Minor | -4.64 | -3.28 | 7.92 |
| Paved road with potholes | Fatal | -0.43 | 0.44 | -0.01 |
| **Vehicle characteristics** | | | | |
| Brake | Minor | -0.32 | -0.92 | 1.24 |
| Steering | Fatal | -0.27 | 0.36 | -0.09 |
| Bus | Hospitalized | 0.54 | -0.64 | 0.09 |
| Motorbike | Hospitalized | -1.19 | 1.18 | 0.01 |
| Multi-vehicle | Minor | -1.03 | -1.36 | 2.38 |

### 4.6.1 Crash-Specific Characteristics

Excessive speeding remains one of the main contributing factors that affect pedestrian injury outcomes. The model estimation results in this study found that the speeding variable increases the likelihood of a fatal injury outcome by 2.1% and decreases the likelihood of the other injury outcomes. This observation is consistent with previous studies (Afukaar, 2003; Peden et al., 2004; Jones et al., 2005; Savolainen and Mannering, 2007; Damsere-Derry et al., 2008). The analysis also shows that hit-and-run crashes are more likely to result in fatal injury outcome. Another interesting finding was that the distracted driving indicator variable increases the probability of hospitalized injury outcome and decreases the likelihood of the other injury outcomes. This is contrary to past studies in which distracted driving was found to be significantly associated with fatal injury outcomes (e.g., Bungum et al., 2005). Crashes involving pedestrians who were crossing the highway were 6.44% more likely to result in fatal injury and 2.43% more likely to record hospitalized injury. In situations where the pedestrian was at fault, the probability of fatal injury was lower by 0.52%.

### 4.6.2 Location and Time of Crash Characteristics

The location and time of crash influence injury severity of pedestrian crashes. The analysis results show that crashes that occurred in urban areas had a 2.44% increased likelihood of minor injury outcome, and the likelihood of the other injury outcomes was low. This is consistent with previous studies in which serious and fatal crashes were found to be less likely in urban areas (e.g., Xie et al 2012) due to relatively lower overall speeds. The model estimation results further reveal that crashes that happened in the afternoon were more likely to record either a fatality or hospitalized injury. Similarly, crashes that occurred at nighttime were less likely to result in hospitalized injury outcome by 2.27% but 2.03% more likely to record fatality.

### *4.6.3 Driver/Pedestrian Casualty Attributes*

Drivers who have been involved in crashes with pedestrians were classified by their ages into four groups: young drivers (aged less than 25), adult drivers (aged between 25 and 44), older drivers (aged from 45 to 64), and drivers aged above 65 years. Three out of the four-driver aged group variables were found to be significant in the model. The model estimation results show that young and older driver variables were more likely to increase the probability of minor injury by 1.19% and 1.81% respectively, with the chances of the major injury outcomes being lower. Similarly, crashes involving adult drivers were more likely to record minor injury. The results also indicate that the female casualty indicator variable decreases the likelihood of fatal injury outcome by 2.35% and the likelihood of the other injury outcomes was high. This means that female pedestrians were less likely to be killed in inter-urban highway crashes in Ghana. Pedestrians involved in the crashes were also grouped into four by age: casualties aged less than 25, those aged between 25 and 45 years, those aged from 46 to 64 years, and those aged above 65 years. Two out of four of the pedestrian age variables were found to be significant in the model. The results show that inter-urban highway crashes that involved pedestrians aged less than 25 years were more likely to result in hospitalized injury outcome. It was also found that crashes that involved casualties aged between 25 and 45 years had a 3.4% lower likelihood of minor injury outcome, but the likelihood of the other injury outcomes was high. This means that pedestrians aged between 25 and 45 years were more likely to be killed on inter-urban highways in Ghana.

### *4.6.4 Roadway and Environmental Conditions*

Previous research works have observed the effect of weather conditions on the injury severity of pedestrian-vehicular crashes (e.g., Tay et al, 2011). In this study, it was observed that the clear weather variable increases the probability of minor injury outcome by 7.92% and the likelihood of the other injury outcomes was low. It was also found that crashes that happened at signalized intersections were more likely to result in hospitalized injury outcome, and the variable for paved road with potholes increased the chance of hospitalized injury outcome by 0.44% while the likelihood of the other injury outcomes was low. The road with no shoulder indicator variable had a 0.36% decreased likelihood of fatal injury outcome while the likelihood of the other injury outcomes was higher.

### *4.6.5 Vehicle Characteristics*

As shown in Table 2, five vehicle-related variables were found to be significant in the estimated model. The estimated marginal effects show that crashes that happened due to steering defects were more likely to result in hospitalized injury outcome while the likelihood of the other injury outcomes was low. Also, the brake failure indicator variable decreased the likelihood of hospitalized and fatal injury outcomes, indicating that pedestrian crashes on inter-urban highways involving vehicles with brake failures were less likely to record severe injury. It was further observed that pedestrian crashes involving buses were more likely to result in fatality. The motorbike variable had a 1.19% lower likelihood to result in a fatal injury outcome and multiple-vehicle crashes were more likely to record minor injury outcome.

## 4.7 DISCUSSIONS

Pedestrian-involved crashes result in more severe injuries and fatalities. This emanates from the fact that pedestrians are not protected by any external vehicular body and as such their vulnerability to injuries increases when they get involved in crashes. High-speed highways that pass through settlement areas with no pedestrian facilities for safe crossing pose threats to pedestrians and threaten community cohesion and livability. This problem is particularly pronounced in LMICs. Efforts to reduce the adverse effects of these poorly planned high-speed highways require a comprehensive analysis of the factors associated with crash outcomes along these corridors. The findings from this study present policy and decision-makers, data-driven evidence of factors that may be controlled to reduce pedestrian crashes, in general, and injury outcomes on inter-urban highways in Ghana. For instance, among the environmental factors analyzed, lighting condition was found to be significantly associated with crash outcomes. The results show that pedestrian crashes that happened at night on inter-urban highways in Ghana are more likely to result in fatality. This observation is consistent with most previous studies on this topic (Quddus et al., 2002, Lee and Abdel-Aty, 2005) and provide basis for recommendations of improved highway lighting at roadway sections that pass through settlement areas. Improved lighting will help drivers to spot pedestrians early enough to avoid colliding with them at locations where it may be too expensive or impossible to construct a grade-separated pedestrian facility. Necessary adjustment of speed limits and proper access management along these high-speed roadways can improve traffic safety. A common phenomenon that contributes to pedestrian crashes along highways in Ghana is roadside commerce. Often, drivers and passengers patronize the roadside businesses by residents and are forced to park on the shoulders of the road. The

National Road Safety Authority (NRSA) should endeavor to advocate for the implementation of safer speed policies in mixed traffic zones especially in the settlement areas where pedestrian collisions are observed to be high. Speed calming measures humps, rumble strips, and over and underpasses may also be provided to protect the pedestrian when using the road. For land-use purposes, social amenities like schools and hospitals should be sited at places where their usage must not be detrimental to the safety of residents.

Additionally, the findings from this study provide evidence for the adoption and implementation of the *Safe Systems* approach to road safety improvement. For instance, the finding that fatal injury is associated with crashes involving pedestrians crossing the road suggests that measures such as the creation of shoulders or walkways along the highways allow pedestrians to use and not share the roadway with vehicles, particularly at night. It would also be important to provide clear zones and to improve sight distance in curves. Warning signs may be installed at high-risk locations, such as intersections, to warn pedestrians, riders, and drivers of upcoming transitions in roadway geometry and traffic bottlenecks ahead. Also, roadway shoulders need to be properly maintained to help pedestrians walk along the road safely when the need arises. Also, observing that hit and run crashes were more likely to result in fatal injury suggests that these crashes are not immediately reported because the drivers leave the scene of the crash and the police or emergency services are not notified promptly. This happens because most of the drivers are afraid of vengeance from the communities nearby and therefore would not stop or report to the police. The guarantee and assurance of judicial justice for crash victims may help to calm down the citizenry and help to reduce hit-and-run crashes. Further, the provision of first aid on time to crash victims by trained professionals and subsequently transporting them to the hospital by ambulances can help to reduce the chances of pedestrian deaths. The findings and recommendations from the study, therefore, provide a foundation for the *Safe Systems* approach to improving pedestrian safety in Ghana. Table 4.4 provides localized recommendations of countermeasures that may be implemented within the *Safe Systems* framework to improve pedestrian safety in the country.

Table 4.4 Safe systems approach to reducing pedestrian fatality on inter-urban highways in Ghana

<table>
<tr><th>Variable</th><th>Safe Systems indicator</th><th>Countermeasures</th></tr>
<tr><td>Steering defect (Vehicle defects)</td><td>Safe vehicle</td><td rowspan="10">Safe vehicle: Advanced driving assistance systems, regular basic maintenance checks<br><br>Safe people: Education and training, legal framework to regulate activities of pedestrians and drivers along high-speed highways, targeted law enforcement, road safety campaigns<br><br>Safe road: Physical opposing lane separation, road signs and markings, provision of lighting systems, and roadway shoulder for the pedestrian to use.<br><br>Safe speed: Installation of speed cameras, road signs, and markings, law enforcement, an over-speed warning system for drivers and pedestrians, speed calming measures<br><br>Other localized interventions: Judicial justice for crash victims, policy against mob justices, training of citizens on administering basic first aid to crash victims.</td></tr>
<tr><td>Pedestrian age (demographic characteristics)</td><td>Safe people</td></tr>
<tr><td rowspan="4">Hit and run</td><td>Safe road</td></tr>
<tr><td>Safe speed</td></tr>
<tr><td>Safe vehicle</td></tr>
<tr><td>Safe road</td></tr>
<tr><td rowspan="2">No shoulder</td><td>Safe road</td></tr>
<tr><td>Safe people</td></tr>
<tr><td rowspan="2">Paved with potholes/Roadway geometry</td><td>Safe road</td></tr>
<tr><td>Safe speed</td></tr>
</table>

## 4.8 CONCLUSIONS

In this paper, the LC-MNL modeling approach was used to investigate the effects of various crash contributing factors, such as pedestrian behavior, demographics, crash characteristics, and roadway and environmental on pedestrian injury outcomes for inter-urban highway crashes in Ghana. A total of 3,037 pedestrian crash observations were obtained from the Ghana National Road Traffic Accident database at the Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR). Preliminary data analysis revealed that more than half of the crashes occurred at urban areas and distracted driving accounted for nearly 52% of the crashes. Also, speeding was responsible for 23.4% and about a quarter of the crashes happened at night. The injury severity model estimation produced two latent classes and the estimated marginal effects revealed the numerical strength of the associations between the various crash factors and crash outcomes. For instance, it was revealed that speed-related crashes and hit and run crashes had 2.12% and 1.24% higher chances, respectively to result in fatality while distracted driving had 1.43% higher probability to result in hospitalized injury. Nighttime was also found to be associated with fatal injury outcome while urban areas were more likely to record minor injury crashes.

To reduce these pedestrian crashes, particularly the fatal injury ones, there is the need to identify localized countermeasures that target specific problems at specific locations. Enhancing education to reduce inappropriate pedestrian and driver behaviors has been proven to improve pedestrian safety. However, engineering solutions that separate pedestrians and vehicle traffic would help reduce both risk and exposure of pedestrian crashes. For instance, provision of pedestrian infrastructures like overpasses, underpasses, crosswalks with activated warning lights, wide shoulders on the highways or sidewalks along the road, sufficient roadway lighting, and pedestrian signs for motorists, can improve pedestrian safety in settlement areas. The findings of this study, therefore, provide important insights for developing effective policies and countermeasures to improve the safety of pedestrians along high-speed inter-urban highways in Ghana.

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# CHAPTER 5 SUMMARY AND FUTURE WORK

## 5.1 SUMMARY

Global vulnerable road user deaths and injuries remain unacceptably high. This challenging and complex subject requires new efforts, new methods, and innovation in research, policymaking, and implementation. Efforts to reduce this carnage on our roads have been high on the agenda of road safety experts in especially in LMICs as they collectively account for the highest proportion of these deaths and injuries. Over the past decade, there has been a focus on *Safe Systems* approach solutions in many of the advanced countries to address their road traffic crash issues. Although statistics have shown significant successes of this approach, many LMICs are yet to adopt this framework to tackle their road safety problems. Where this approach has been adopted, it has either been poorly implemented or it has not been properly adapted to local conditions. This dissertation focused on vulnerable road user safety issues in the West African country of Ghana, to identify the leading contributing factors that may be targeted for countermeasure implementation using a localized *Safe Systems* framework. To achieve this, the dissertation adopts two major approaches: an assessment of indigenous and experiential knowledge of transportation safety professionals and a rigorous analysis of crash data, to have a holistic understanding of vulnerable road user safety issues in the country. The findings from these studies are expected to provide the foundation for the adoption and guiding the implementation of the *Safe Systems* approach to improve vulnerable road user safety in Ghana. The two major vulnerable road user groups in the country, pedestrians and motorcyclists, were considered in this work. The dissertation was organized into four major chapters, with the current chapter (chapter 5) providing a summary of the various chapters and a proposal for future works.

Chapter 1 presents the general background of the vulnerable road user safety problem from the global level to the local context. In this chapter, the changing geographical transport modal split in Ghana was presented. For instance, it was revealed that besides walking, motorcycles have recently become an integral part of urban transport in the country while they remain a major mode of transport in rural areas. This chapter then delves into the trend of road traffic deaths in Ghana over the past decade and revealed that pedestrians make up the vulnerable road user group with the highest fatality numbers over the period. The *Safe Systems* approach was also introduced and the motivation for the dissertation was also presented in this chapter. This chapter, therefore, sets the tone for the dissertation.

Chapter 2 presents an assessment of the indigenous and experiential knowledge of vulnerable road user safety issues, and knowledge of the *Safe Systems* approach through an online survey of the opinions of transport professionals in the country. This aspect of the dissertation used a multi-criteria decision-making tool, the Analytical Hierarchy Process, to develop a *Safe Systems* based framework that was used to prioritize some selected countermeasures that the transport professionals believe can be adopted for implementation to reduce the occurrence and severity of crashes involving pedestrians and motorcyclists.

Considering that the urban areas of Ghana are now in the early stages of managing the upsurge of motorcycles, Chapter 3 examined motorcycle crash contributing factors in both urban and rural settings in Ghana. This study used historical crash data to develop injury-severity models using mixed multinomial logit modeling techniques to account for unobserved heterogeneity in the data. The findings provide insight into differences and similarities in the crash mechanisms and factors that influence injury outcomes of motorcycle-involved crashes in rural and urban areas in Ghana. Factors ranging from human-centered factors, roadway and environmental characteristics, and vehicle characteristics were examined, in line with the *Safe Systems* approach to developing appropriate crash countermeasures. These findings reinforced the need to localize the implementation of crash countermeasures even in the same country.

Speeding remains the leading contributing factor in road fatalities. In Chapter 4 of this dissertation, factors that influence the injury-severity of pedestrian-involved crashes on high-speed inter-urban roadways that pass through settlement areas in Ghana were explored. This study also used historical crash data and adopted latent class multinomial logit modeling approach. This approach allowed for a detailed examination of pedestrian crash factors clustered in latent classes. Like the motorcycle study, this study also identified factors related to the roadway environment, driver and pedestrian characteristics, and vehicle factors that influence the outcome of pedestrian injuries. The findings reveal the need to focus on an important element of the *Safe Systems* approach – Safe Speeds, in addressing pedestrian safety issues in the country.

The results from the three studies present some interesting findings. While the opinions expressed by the transport professionals (Chapter 2) agree largely with the findings in the two data-driven studies (Chapter 3 and Chapter 4), there have been some contradictions in the opinions on how the safety challenges may be tackled. In fact, more than half of the responses obtained from the transport professionals were found to be inconsistent, hence were not included in the final decision matrices. Generally, human-centered factors (i.e., traffic law enforcement and road user education) were suggested to be the leading countermeasures in addressing vulnerable road user safety problems in Ghana. This is consistent with the model results as many of the factors that were found to be associated with severe injury crash outcomes are related to human factors. Despite these specific findings, there is the need to fully implement countermeasures related to the other elements of the *Safe Systems* approach (i.e., safe vehicles, safe roads, and safe speeds). For instance, roadway lighting and regular motorcycle maintenance have also been suggested as important factors in improving vulnerable road user safety in the country.

## 5.2 FUTURE WORKS

This dissertation has assessed the level of knowledge of transport professionals using the *Safe Systems* approach on pedestrians and motorcycles, investigated, and compared factors that are associated with motorcycle crash injury outcomes in rural and urban areas, and also investigated the factors associated with pedestrian injury outcomes of inter-urban highway crashes. The findings introduce new directions for further research to improve the safety of VRUs. The proposed future studies are expected to cover the following areas:

a) Undertake similar studies using the AHP framework developed, and modeling techniques used in this dissertation for countries in the sub-region to study similarities and differences in trends that may help to develop continent-wide strategies for vulnerable road user safety improvements.

b) Conduct investigation into the contradiction between the opinions of the transport professionals and the data-driven studies. This will assist in understanding why the perceptions do not match the reality on the ground.

c) Investigation of the speed profiles of vehicles passing through high-speed settlement areas to know the percentage of vehicles driving above the posted speed of 50km/h recommended by the highway code of Ghana. This will help to propose efficient designs of VRUs facilities for different locations and education and outreach programs for the VRUs.

d) The two crash studies focused on pedestrian and motorcyclist crash contributing factors. Vulnerable road users also include bicyclists and they also have challenges. Further research is needed to investigate factors that affect bicyclist crashes and their injury severity

## APPENDICES

### APPENDIX 1: BUILDING AND ROADS RESEARCH INSTITUTE QUESTIONNAIRE

**The purpose of the study is to understand how transport professionals view crashes involving pedestrians and motorcycles in Ghana and across West Africa and Africa**

Please help us answer a few questions about vulnerable road users in Ghana and across sub-Saharan Africa. Some of the questions may look quite repetitive, so please think about them a minute before answering. Thanks

1.0 Are you familiar with *Safe Systems* approach to reducing crashes and injury severity?

1) Yes
2) No

If No, then show this.

"The *Safe Systems* approach is to design and operate vehicles and infrastructure in a manner that anticipates human error and accommodates human injury tolerances with a goal of reducing fatal and serious injuries in the event of a crash".

2.0 Between the two choices below, which do you perceive to be the greatest safety concern in your region?

- *Motorcycles*
- *Pedestrians*

**Pedestrians**

3.0 Between road user behavior (safe people) and properly designed/ maintained vehicles (safe vehicles) which do you consider to be most important to reducing the occurrence and severity of pedestrian crashes?

- *Safe people are much more important*
- *Safe people are somewhat more important*
- *They are the same*
- *Safe vehicles are somewhat more important*
- *Safe vehicles are much more important*

4.0 Between road user behavior (safe people) and properly designed/maintained infrastructure (safe roads) which do you consider to be most important to reducing the occurrence and severity of pedestrian crashes?

- *Safe people are much more important*

- *Safe people are somewhat more important*
- *They are the same*
- *Safe roads are somewhat more important*
- *Safe roads are much more important*

5.0 Between road user behavior (safe people) and properly determined/enforced speed limits (safe speeds) which do you consider to be most important to reducing the occurrence and severity of pedestrian crashes?

- *Safe people are much more important*
- *Safe people are somewhat more important*
- *They are the same*
- *Safe speeds are somewhat more important*
- *Safe speeds are much more important*

6.0 Between properly designed/maintained infrastructure (safe roads) and properly determined/enforced speed limits (safe speeds) which do you consider to be most important to reducing the occurrence and severity of pedestrian crashes?

- *Safe roads are much more important*
- *Safe roads are somewhat more important*
- *They are the same*
- *Safe speeds are somewhat more important*
- *Safe speeds are much more important*

7.0 Between properly designed/maintained vehicles (safe vehicles) and properly determined/enforced speed limits (safe speeds) which do you consider to be most important to reducing the occurrence and severity of pedestrian crashes?

- *Safe vehicles are much more important*
- *Safe roads are somewhat more important*
- *They are the same*
- *Safe speeds are somewhat more important*
- *Safe speeds are much more important*

8.0 Between properly designed/maintained vehicles (safe vehicles) and properly designed/maintained infrastructure (safe roads) which do you consider to be most important to reducing the occurrence and severity of pedestrian crashes?

- *Safe vehicles are much more important*
- *Safe vehicles are somewhat more important*
- *They are the same*
- *Safe speeds are somewhat more important*
- *Safe speeds are much more important*

9.0 In terms of encouraging safer road user behavior (safe people), how effective do you think each of the following are, on a scale of 1 to 5 with 1 being ‘not effective’ and 5 – ‘very effective’

| **Measures for safe people** | **Rank** |
|---|---|
| Enforcing pedestrian traffic law (e.g., jaywalking) | |
| Conducting outreach and education to pedestrian | |
| Conducting outreach and education to drivers | |

10.0 On a scale of 1 to 5 with 1 being ‘not important’, 2- slightly important, 3 – moderately important, 4 – important, and 5 – very important, rank the following solutions for safe road in terms of on importance of these countermeasures in reducing pedestrians’ deaths and injuries

| **Measures for safe roads** | **Rank** |
|---|---|
| Grade separation (e.g., pedestrian overpass or underpass | |
| Pedestrian facilities (e.g., sidewalks, crosswalks) | |
| Roadway lighting | |
| Traffic controls devices (e.g., pedestrian signal, warning signs, and pavement markings) | |

11.0 On a scale of 1 to 5 with 1 being ‘not important’, 2- slightly important, 3 – moderately important, 4 – important, and 5 – very important rank the following solutions for safe vehicles in terms of on importance of these countermeasures in reducing pedestrians’ deaths and injuries

| **Measures for safe vehicle** | **Rank** |
| --- | --- |
| Advanced vehicle safety technologies (e.g., antilock braking systems) | |
| Designs to enhance pedestrian’s crashworthiness | |
| Education and outreach to improve vehicle maintenance | |

12.0 On a scale of 1 to 5 with 1 being ‘1 being ‘not important’, 2- slightly important, 3 – moderately important, 4 – important, and 5 – very important, rank the following solutions for safe speed in terms of importance of these countermeasures in reducing pedestrians’ deaths and injuries

| **Measures for safe speed** | **Rank** |
| --- | --- |
| Automated speed enforcement (e.g., cameras, radar) | |
| Traffic calming devices (e.g., speed tables) | |
| Education and outreach to improve awareness of speeding dangers to pedestrians | |

13.0 What roadway environment do you consider to be most dangerous for pedestrians?

- The open road (e.g., motorway, dual and single carriageway
- Urban streets
- Rural and remote areas with unpaved roads

14.0 Which roadway at location do you consider to be most dangerous for pedestrians?

- Signalized intersections
- Unsignalized intersections (e.g., stop or yield control)
- Roundabouts
- Midblock

15.0 What age group of pedestrians do you consider to be at the highest risk of a crash?

- Younger than 6
- 6 - 16 years
- 17 - 25 years
- 26 - 35 years
- 36 – 56 years
- Over 57 years

16.0 Who do you think is most vulnerable to pedestrian crashes?

- Men
- Women
- Neither

**Socio-economic and demographic characteristics of respondents**

17.0 What country are you from? ………………………………………

18.0 What city or region? ………………………………………

19.0 For what type of organization do you work or represent?

- Government Agency (e.g., transport Ministry, roadway authority, city government)
- Road Safety Council
- Local Private Consultancy firm
- Academic or Research Institution
- International Consultancy firm
- Law Enforcement
- Multilateral Development agency (e.g., World Bank, UKAID)
- Non-Governmental Organization (NGOs)

20.0 How many years of professional experience do you have?
…………………………………

21.0 Is there anything else regarding vulnerable road users in your region that you would like to share?

…………………………………………………………………………

**Motorcyclist**

3.0 Between road user behavior (safe people) and properly designed/ maintained vehicles (safe vehicles) which do you consider to be most important to reducing the occurrence and severity of motorcycle crashes?

- *Safe people are much more important*
- *Safe are somewhat more important*
- *They are the same*
- *Safe vehicles are somewhat more important*
- *Safe vehicles are much more important*

4.0 Between road user behavior (safe people) and properly designed/maintained infrastructure (safe roads) which do you consider to be most important to reducing the occurrence and severity of motorcycle crashes?

- *Safe people are much more important*
- *Safe people are somewhat more important*
- *They are the same*
- *Safe roads are somewhat more important*
- *Safe roads are much more important*

5.0 Between road user behavior (safe people) and properly determined/enforced speed limits (safe speeds) which do you consider to be most important to reducing the occurrence and severity of motorcycle crashes?

- *Safe people are much more important*
- *Safe people are somewhat more important*
- *They are the same*
- *Safe speeds are somewhat more important*
- *Safe speeds are much more important*

6.0 Between properly designed/maintained infrastructure (safe roads) and properly determined/enforced speed limits (safe speeds) which do you consider to be most important to reducing the occurrence and severity of motorcycle crashes?

- *Safe roads are much more important*
- *Safe roads are somewhat more important*
- *They are the same*
- *Safe vehicles are somewhat more important*
- *Safe vehicles are much more important*

7.0 Between properly designed/maintained vehicles (safe vehicles) and properly determined/enforced speed limits (safe speeds) which do you consider to be most important to reducing the occurrence and severity of motorcycle crashes?

- *Safe roads are extremely more important*
- *Safe roads are more important*
- *They are the same*
- *Safe speeds are more important*
- *Safe speeds are extremely more important*

8.0 Between properly designed/maintained vehicles (safe vehicles) and properly designed/maintained infrastructure (safe roads) which do you consider to be most important to reducing the occurrence and severity of motorcycle crashes?

- *Safe vehicles are much more important*
- *Safe vehicles are somewhat more important*
- *They are the same*
- *Safe speeds are somewhat more important*
- *Safe speeds are much more important*

9.0 On a scale of 1 to 5 with 1 being ‘not important’, 2- slightly important, 3 – moderately important, 4 – important, and 5 – very important, rank the following solutions for safe people in terms of on importance of these countermeasures in reducing motorcyclists’ deaths and injuries

| **Measures for safe people** | **Rank** |
|---|---|
| Enforcing traffic laws | |
| Conducting outreach and education to motorcyclists | |
| Formalized motorcycle driver training and licensing systems | |
| Laws prohibiting motorcycles from traveling between lanes | |

10.0 On a scale of 1 to 5 with 1 being ‘not important’, 2- slightly important, 3 – moderately important, 4 – important, and 5 – very important, rank the following solutions for safe roads in terms of importance of these countermeasures in reducing motorcyclists’ deaths and injuries

| **Measures for safe road** | **Rank** |
|---|---|
| Improving roadway surfaces | |
| Roadway lighting | |
| Roadside improvements (e.g., clear zones or guardrails) | |

11.0 On a scale of 1 to 5 with 1 being 'not important', 2- slightly important, 3 – moderately important, 4 – important, and 5 – very important, rank the following solutions for safe vehicles in terms of on importance of these countermeasures in reducing motorcyclists' deaths and injuries

| **Measures for safe vehicle** | **Rank** |
|---|---|
| Advanced vehicle safety technologies (e.g., antilock braking systems) | |
| Stricter rules and regulations on importing, reselling, and licensing motorcycles | |
| Education and outreach to improve vehicle maintenance | |

12.0 On a scale of 1 to 5 with 1 being 'not important', 2- slightly important, 3 – moderately important, 4 – important, and 5 – very important, rank the following solutions for safe speeds in terms of on importance of these countermeasures in reducing motorcyclists' deaths and injuries

| **Measures for safe speed** | **Rank** |
|---|---|
| Automated speed enforcement (e.g., cameras, radar) | |
| Traffic calming devices (e.g., speed tables) | |
| Education and outreach to improve awareness of dangers for motorcyclists | |

13.0 Which roadway environment do you consider to be most dangerous for motorcyclists?

- The open road ( motorways, dual and single carriageways)
- Urban streets
- Rural and remote areas with unpaved roads

14.0 Which roadway location do you consider to be the most dangerous for motorcycles?

- Signalized intersections
- Unsignalized intersections (e.g., stop or yield controls)
- Roundabout
- Midblock

15.0 What age group do you think is most dangerous to motorcycle crashes?

- Younger than 6 years
- 6 – 16 years
- 17 - 25 years
- 26 – 35 years
- 36 – 56 years
- Over 57 years

16.0 Who do you think is most vulnerable to motorcycle crashes?

- Men
- Women
- Neither

17.0 Which group do you think are most dangerous on motorcycles?

- Private riders
- Commercial riders (e.g., motor-taxi drivers)

18.0 Do you think three-wheelers are more or less dangerous than two-wheeled motorcycles?

- Three-wheelers more dangerous
- Two-wheelers more dangerous
- No difference
- Depends on the roadway environment

**Socio-economic and demographic characteristics of respondents**

19.0 What country are you from? ………………………………………

20.0 What city or region? ………………………………………

21.0 For what type of organization do you work or represent?

- o Government Agency (e.g., transport Ministry, roadway authority, city government)
- o Road Safety Council
- o Local Private Consultancy firm
- o Academic or Research Institution
- o International Consultancy firm
- o Law Enforcement
- o Multilateral Development agency (e.g., World Bank, UKAID)

22.0 How many years of professional experience do you have?

…………………………………

23.0 Is there anything else regarding vulnerable road users in your region that you would like to share?

……………………………………

## APPENDIX 2: IRB – INFORMED CONSENT FOR SURVEY

No IRB was required for the survey of transportation professionals opinions in Ghana.