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A REVIEW OF BUS CRASH SEVERITY ANALYSES

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Abstract. The bus plays an important role in serving the urban travel demand in both developed and developing countries. Unfortunately, the heavy operation of this mode may come together with crashes, which may cause adverse effects on its image and service quality from the view of the public, thereby leading to a reduction in ridership. The knowledge on characteristics of crashes is, therefore, desired. While most of the research focus is on the probability of crash occurrence, the severity of crashes has recently attracted increasing attention from researchers. This paper aims to synthesize previous studies on crash severity. By means of looking at 11 studies carefully selected from the SCOPUS database, this paper has provided a detailed synthesis of data collection, research areas, used samples, seven factor groups associated with the crash severity (*Temporal characteristics, Location and infrastructure characteristics, Service and vehicle characteristics, Traffic characteristics, Crash characteristics, Weather characteristics, Driver characteristics and behaviours*), and analytical methods. Afterwards, research gaps and shortcomings of the existing research are highlighted for proposing future research directions. This review could help to save efforts to obtain a clear understanding of bus crash severity. It may be an informative reference for those newly accessing the field of bus crash severity and/or intending to develop solutions to this problem.

Keywords: Bus, crash, severity, review, factor, safety.

1. INTRODUCTION

The bus plays an important role in serving the urban travel demand in both developed and developing countries [1]. The bus is a critical component of any public transport systems and is undeniably a critical contributing factor to urban sustainability [2]. Effective and efficient bus networks help to make cities more livable and lower a city's per capita carbon footprint. The incorporation of the bus into broader economic and land use planning also enables to expand business opportunities, reduce sprawl, alleviate exclusion, and create a sense of community. And in times of emergency, the bus can contribute considerably to safe and efficient evacuation [3]. In the developed countries, the bus provides feeder services for higher-capacity modes (e.g., metro, monorail, and tramway). In developing countries, bus services are even more important due to the absence or the limited capacity of rail-based transit and poor urban mobility [4–9]. Despite the difference in the roles in the urban transport networks, all agree the necessity of the bus. The importance of bus has recently increased thanks to efforts to improve the service quality and operations of this mode through adopting new and modern bus versions, such as Bus Rapid Transit in Asia and American coupled with Bus High Level Service in Europe [10,11]

Unfortunately, the operation and the use of buses are subject to crashes in both developed and emerging economies. For instance, more than 60,000 buses are related to traffic collisions each year in the US while Florida witnesses over 4.6 thousand bus-related crashes on main roads between 2003 and 2007 [12,13]. The situations in emerging countries are even worse with utilizing bus services being a relatively dangerous experience because the bus is heavily used with a lack of sufficient maintenance and supervision [2,14–16]. High bus-related collision rates are reported in Bangladesh, Lebanon, Ghana, India, Nepal, Tanzania, and Zimbabwe [17–20]. In Ghana, during the period between 1991 and 2014, 90,206 crashes involved in buses and minibuses were occurred, accounting for 23.9% of the total number of vehicles related to crashes [19]. Notwithstanding, in order to capturing comprehensively the safety picture of bus operation, more scientific efforts have been invested into looking at the severity of crashes. It is critical to note that although the number of bus crashes is not large (only about 1% of all traffic crashes – the case of the US [13]), the much larger passenger capacity of the bus compared to private modes (e.g., car) can result in serious crashes with considerable loss of property, personal injuries, and deaths. The five-year period from 2006-2010 recorded over 320 deaths and 550 severe injuries per year in the US. Whereas, bus-involved crashes in Ghana generated 35.7% of the casualties between 1991 and 2014.

For issuing proper and timely policies towards mitigating repercussions of crashes, an array of earlier authors have researched factors associated with the severity of bus-related crashes. Yet, to the best of the authors' knowledge, besides some review of the likelihood of crash occurrence, there has not been a review of crash severity studies. Therefore, for contributing to fill partly this gap, the authors aim to review prior analyses of the bus-involved crash severity. By this way, this study clarifies groups of factors determining the severe levels of bus crashes in developing and developed countries. Then, future research directions are proposed with a focus on the case of developing countries.

The rest of this paper is organized as follows. Section 2 provides how to select relevant studies to review and give a brief description of those selected. Subsequently, Section 3 clarifies factor groups associated with the bus-crash severity and analytical methods used. Next, Section 4 highlights the shortcomings of the existing studies, helping to suggesting future research directions. Finally, Section 5 closes this paper with some conclusions.

2. PAPER SELECTION FOR REVIEW

For making this review systematic, searching for journal papers by November 2021 on the SCOPUS database was conducted using five keywords ‘bus’, ‘public transport’, ‘accident’, ‘crash’, and ‘severity’. The SCOPUS was chosen because this is a reputable and comprehensive database that was launched in 2004, before the publication of the first studies on bus crash severity, such as [18]. Hence, it can cover almost all relevant studies. The Web of Science is another reputable source; however, the authors did not have access to it. Moreover, the SCOPUS and the Web of Science are in duplicate when it comes to papers published in high-quality journals. As a result, ignoring the Web of Science did not affect (much) the paper selection of this review. Among keywords of searching, ‘accident’ is recommended not to use recently because although it means `unintentional’, it is often interpreted as meaning `unavoidable’. More importantly, `accident’ is sometimes used to refer to the event (crash/collision/fall) and sometimes to the consequence (casualty/injury/fatality). However, some previous research on bus severity used this word, such as [18]. Only journal articles published officially and in English were regarded. Conference papers were ignored because their contents are frequently not presented in detail. Moreover, accessing many of such papers was limited.

After having a list of papers matching keywords, the screening of their titles and abstracts, were undertaken. Papers that did not focus on the severity of the bus were eliminated. Subsequently, the three criteria were adopted to choose the most relevant articles, that is:

(1) Available full text,

(2) Showing clearly method(s) with variables/features used,

(3) Achieving ≥ 1 citation, ≥ 3 citations and ≥ 6 citations for those published in 2021, 2018-2020 and before 2018, respectively. The third criterion enabled the removal of publications with low impacts on the literature. The number of citations is based on statistics of Google Scholar.

Eventually, eleven studies were selected to include in this review (*Table 1*). To ensure that no relevant studies can be missed. The authors carefully checked the list of references in the selected ones. No further studies were found.

It can be seen that over the last decades, the literature on the analysis of bus crash severity has emerged significantly, particularly in developed countries. Among them, eight studies are set in developed countries [12,13,21–26] compared to three ones based in developing countries [16,18,19]. The publication of many more analyses in developed countries can be explained by the systematic record of crash characteristics there, whereas the statistics of crashes in developing countries is generally poor. This should be a both practical and theoretical gap since crashes in developing countries, as mentioned in Section 1, are more serious in terms of not only the number but severity also. Three emerging countries considered are Bangladesh, Ghana, and Vietnam while five developed countries considered encompass the US, Denmark, Australia, South Korea, and Canada. Most studies analyse crashes involved in urban buses; however, the study in Ghana [19] focuses on collisions related to minibus and the research in South Korea [25] concentrates on crashes related to express buses. The difference in the bus service types considered may affect the findings on factors contributing to the severity.

Table 1. Selected papers for review.

Authors and articles	Barua and Tay [18]	Sam et al. [19]	T.C. Nguyen et al [16]	Chimba et al. [12]	Rahman et al. [21]	Kaplan and Prato [22]	Prato and Kaplan [23]	Feng et al. [13]	Yoon et al. [24]	Tamakloe et al. [25]	Samerei et al. [26]
Research avenue	Developing countries			Developed countries							
	Bangladesh	Ghana	Hanoi, Vietnam	Florida, the US	Alberta, Canada	the US	Denmark	the US	South Korea	South Korea	Victoria, Australia
Data collection period	1998-2005	2011-2015	2015-2019	2003-2007	2000-2007	2005-2009	2002-2011	2006-2010	2010-2014	2010-2016	2006-2019
Sample used	2,662 bus crashes	33,694 bus and mini-bus crashes	529 bus crashes	4,528 bus crashes	9,485 bus crashes	2,576 bus crashes	3,434 bus crashes	1,380 bus crashes	27,731 local bus crashes	2,997 express bus crashes	1,705 bus crashes
Analytical methods	Ordered probit model	Generalized ordered logit model	Ordered logit model	Multinomial logit model	Logistic model	Generalized ordered logit model	Generalized ordered logit model	Ordered logit model	Hierarchical ordered probit model	Bivariate copula-based methodology	Two-step method: clustering and association rules
Exploratory variable groups											
(1) Temporal characteristics (time of day, day of week, etc.)	Yes	Yes			Yes		Yes	Yes	Yes	Yes	Yes
(2) Location and infrastructure characteristics (road, median barrier, shoulder, lane, light condition, area, etc.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(3) Service and vehicle characteristics (vehicle age, capacity, service type, etc.)		Yes	Yes			Yes		Yes	Yes	Yes	
(4) Traffic characteristics	Yes	Yes	Yes	Yes	Yes			Yes	Yes	Yes	Yes
(5) Crash characteristics (vehicle/user involved, manner of collision, etc.)	Yes	Yes	Yes		Yes	Yes	Yes	Yes		Yes	Yes
(6) Weather characteristics (raining, normal, and also including the status of surface (e.g., dry, wet, snow of freezing))		Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes
(7) Driver characteristics and behaviors (age, gender, driving license, history crashes, etc.)		Yes				Yes	Yes	Yes	Yes	Yes	Yes
Outcome variable: *Crash severity*	4 levels	4 levels	3 levels	3 levels	2 levels	5 levels	4 levels	3 levels	4 levels	4 levels	3 levels

'Yes' refers to the variables considered in studies

Of eleven studies, six analyse the data of a five-year period [12,13,16,19,22,24] while the studies [18,21,23,25] rely on the data of periods of 6-10 years. Samerei et al [26] use the longest data (14 years from 2006 to 2019). Notably, a longer period considered does not mean more recorded crashes. The number of bus crashes occurring from 2011 to 2015 was over 33.6 thousand in Ghana compared to 3.4 thousand recorded in Denmark between 2002 and 2011 or 1.7 thousand in Australia recorded from 2006 to 2019 [19,23,26]. This difference, on the one hand, may come from the dissimilarity in the area and population of research avenues. It, one the other hand, mirrors how citizens depend on the bus and the lack of safety in bus operations in regions.

3. REVIEW OF INFLUENTIAL FACTORS AND ANALYTICAL METHODS

3.1. Factors associated with the bus-involved crash severity

So far, the determinants of the severity of bus crashes can be described under seven components, including (1) temporal characteristics, (2) location and infrastructure characteristics, (3) service and vehicle characteristics, (4) traffic characteristics, (5) crash characteristics, (6) weather characteristics, and (7) driver characteristics and behaviors *(see Table 1)*.

Regarding temporal characteristics, the research in Bangladesh highlights an upward trend in the severity of bus crashes over time [18]. In Ghana, crashes occurring on weekends, relative to weekdays, are associated with an increase in the severity [19]. This result is in agreement with the case of Victoria, Australia [26]. Season and time of day are taken into consideration in some studies undertaken in developed countries [13,21,25]. Similar to Feng et al. and Samerei et al., Nguyen et al. conclude that driving in the evening and at night cause a higher level of the crash severity [13,16,26]. This can stem from the fact that drivers may face difficulty in visibility, hazard perception, and drowsiness [27].

Location and infrastructure characteristics are well demonstrated to play an essential role in affecting the severity albeit with some inconsistent findings. For instance, the curve road has a positive association with the bus crash severity in Ghana [19]; however, an opposite association is reported in the US [13]. More lanes are positively associated with the likelihood of more serious collisions. Improving the width of the lane and shoulder can help to decrease the severity of bus crashes [12]. Two-way road without a physical barrier is demonstrated to involve more serious crashes [16]. Median, which helps to mitigate the risk of head-on crashes, contributes to a reduction in the crash severity [18,19]. Yet, the availability of fixed concrete median barrier is also found to be an insignificant factor in modelling bus crash severity [25]. Bus-involved crashes occurring at intersections tend to result in more serious injuries [22]. Area of crash is found to be a predictor of bus collision severity in several studies set in developed countries [13,23]. Recently, the study from Vietnam reports that the number of urban bus crashes is larger; however, urban bus crashes are less severe [16].

When it comes to factors related to bus and service kinds, small buses (mini-buses) are more inclined to be involved in less severe crashes in both emerging [16,19] and developed countries [25]. High-deck buses, due to having a higher center of gravity, may increase the risk of severe crashes and casualties [26]. The limitation of maneuverability is found to contribute to serious damage in collisions [24].

As for traffic characteristics, traffic control contributes to a fall in the extent of severity of crashes in both developing [18,19] and developed countries [21,24]. Samerei et al. report an increase in bus-crash fatalities in case of the lack of traffic control [26]. In line with the report from the case of South Korea [25], Nguyen et al [16] find that sparse traffic volume pertains to more serious crashes.

Factors based on crash characteristics are broadly tested in the extant literature with the widespread agreement with high severity being correlated to head-on collisions and hit-pedestrian crashes [13,16,18,19,22,23]. Interestingly, where records of crashes are collected in detail, the authors classify vehicles and riders involved in crashes to make informative comparisons. For example, Kaplan et al. consider an array of vehicles crashing buses in the US, including heavy trucks, motorcycles, bicycles, cars, and SUVs [22]. Tamakloe et al. report that compared to vehicle-vehicle crashes, vehicle-pedestrian ones are more likely to be less serious [25]. Based on the subjects related to crashes, it can be seen that the bus-related crashes considered in previous studies would be either active (i.e., colliding with objects) or passive (i.e., colliding with other vehicles). However, it would be more or less unclear to determine if a vehicle-buses crash is a passive one because previous research does not reveal apparently the failure and responsibilities of subjects in the crash.

Weather conditions are an underlying factor for the bus injury severity in Canada, the US, and Denmark [21–24] and in Ghana, Vietnam [16,19]. Yet, the weather is an insignificant variable of the severity in another study set in South Korea [25]. As a result of the existence of collinearity between weather conditions and surface/pavement conditions (e.g., dry, wet), only one of them is taken into consideration in each study [22].

Drivers' characteristics and behaviors (e.g., driver's age, gender, drunk driving, possession of driving license, and crash history) are widely demonstrated to be significant predictors [19,22–25]. Kaplan & Prato [22] reveal that male drivers are more inclined to take part in less serious crashes. Samerei et al. report a positive correlation between older age of drivers and the likelihood of fatalities in bus crashes [26]. Sam et al. [19] report the positive association between drunk driving and the extent of crash severity. Unfortunately, such variables may not be available for the cases of some developing countries (e.g., Bangladesh [18] and Vietnam [16]) where limitations of collecting and storing crash records are a long-lasting matter [15].

3.2. Analytical methods

A range of models has been utilized for investigating the determinants of bus crash severity. The choice of model type relies largely on the way of defining the outcome variable (i.e., the level of severity). Among 11 studies chosen, only one considers a two-level dependent variable [21]. The majority analyze three or four levels of severity. Only the authors of [22] consider a five-level outcome variable.

Because the share of fatal collisions is minor, Rahman et al. fit a logit model to examine factors affecting a binary outcome, including property-damage-only level and injury level [21]. Binary logit model is easily estimated and explained; however, it is much more appropriate for examining the likelihood of crash occurrence rather than the severity, which should include more levels of severity. Therefore, next studies, which analyze dependent variables with more than two categories, do not employ binary logit.

Chimba et al. [12] fit two multinomial logit models to quantify the exploratory variables' (injury severity) impacts on the level 1 (non-incapacitating injury) and level 2 (incapacitating injury) in comparison with level 0 (non/possible injury). While successfully addressing the challenge of including over 2 levels, multinomial logit neglects the ordinal attribute of the severity. Moreover, the explanation of the results is not comprehensive. Specifically, the impacts of the predictors on the level 1 relative to level 2 are ignored [12]. Another shortcoming is the difficulty in interpreting the impacts of predictors when the number of models goes up in accordance with the number of severity levels. As a result of these disadvantages, multinomial logit has not been used further yet.

Ordered logit/probit-based method proposed by Walker and Duncan [28] is the most popular one. It is widely demonstrated to be suited for looking at ordinal variables, values of which are various similar to the severity [13,16,18,24]. Yet, the use of ordered logit needs to meet the assumption of equality of the log odds ratio over all the cut-off points (the proportional odds assumption). Notably, this assumption can be straightforwardly violated in earlier research, particularly considering four or five levels of the severity. Consequently, generalized ordered logit, developed by Williams [29], has been used as an effective alternative [19,22,23].

Tamakloe et al. [25] provide an interesting application of a bivariate copula-based methodology to model both crash size and crash severity jointly coupled with characterizing the dependence between them. An advantage of copulas is its ability to link multivariate distribution functions. Therefore, it can enable to detect the complex interrelationships between multi-outcome and exploratory factor variables simultaneously. Copulas have been widely used in safety research [30]; however, this is the first time it is deployed in a bus-related crash severity analysis.

Samerei et al. [26] access the crash severity problem in another perspective. A nature of bus-related crash data is the heterogeneity, which comes from the lack of information on some of the variables determining crashes and especially the nun-uniform distribution of factors. As a result, the authors apply the clustering algorithm to detect typical groups of crashes. Next, the factors associated with the groups of crashes are derived using association rules discovery – a non-parametric data mining method. An analysis based on the segmentation of the database possibly results in better understanding of the complex interrelationships between factors and the crash severity.

4. RESEARCH GAPS AND FUTURE RESEARCH DIRECTIONS FOR BUS CRASH SEVERITY ANALYSES

4.1. Research gaps

While the growth in studies of crash severity involved in the bus has been obvious, based on the abovementioned review, some research gaps can be found as follows:

- Compared to developed countries, bus crashes in developing countries have been significantly less explored. This leads to a shortage of knowledge on bus crash severity in emerging countries where the bus safety is such a big challenge [20]. In many Southeast Asia countries like Vietnam where motorcycles are the dominant travel mode, the collisions between buses and motorcycles would be common with serious injuries for motorcyclists. More research on bus crash severity in such countries is needed.

- Most studies consider the conventional urban buses while bus services can be diverse, such as express bus services, dial-call bus services, etc.

- Due to the unavailability of crash profiles, the use of some factor groups (e.g., the characteristics and behaviours of drivers, service and vehicle characteristics) is impossible for many studies, particularly in developing countries. This limits the understandings of factors influencing the severity of bus collisions in the developing world. The transferability of the knowledge and conclusions on factors drawn from developed countries to developing ones would be more or less limited due to differences in urban transport background.

- The definitions of the severity vary across studies, contributing to difficulties in transferring findings on factors among areas.

- There is an evolution in the methods used to analyze bus crash severity. While the usefulness of logit regression models is undeniable, these may fail to detect complex relationships between factors. This requires more powerful models to better derive factors' effects on the severity of bus crashes. Moreover, analyzing the whole dataset would be a weakness of the existing research because the crash data are not homogenous. To put it another way, each pool of crashes may be under different impacts of the same factors.

- In the era of COVID-19, the use of public transport can decrease due to the fear of pandemic infection whereas the use of private motorized modes (e.g., cars and motorcycles) increases substantially [31–33]. This results in more congested roads. Besides, many employees have to (or choose to) work from home or even lose their jobs; thereby leading to more sparse roads [34]. The changes in traffic conditions encourage an update of knowledge on bus crash severity in the COVID-19 era.

4.2. Future research directions

To fill the research gaps, some research directions are suggested as follows:

- In the context of rapid advancement of machine learning and data mining techniques, the use of new and sophisticated algorithms are necessary to attain deeper knowledge on factors governing the bus severity.

- Due to the heterogeneity of crash data, analyses of crash severity should pay more attention to crash groups rather than only to the whole dataset. By this way, the better understandings of factors can be achieved, thus supporting the formulation of effective and proper solutions.

- More research carried out in developing countries and for different bus services types are essential. In addition, the context of COVID-19 may need to be considered through the change in traffic conditions.

- Each of prior studies uses only one dataset; therefore, the findings may be valid for only the research area. Comparative research that takes several datasets of different areas into consideration would provide (more) transferable and valuable contributions.

A very important condition for implementing afore-said directions is the availability of adequate datasets, emphasizing the need for creating a systematic record of bus-involved crashes.

5. CONCLUSIONS

Understanding of bus-related crashes for formulating appropriate solutions are of interest for numerous transport researchers and practitioners [26,35]. The need is burning in some parts of the world where the development of public transport is not formal and not proportional to the urbanization process. Bus crash severity has recently attracted increasing attention, emphasizing a need for a review of the studies of this topic. By means of looking at 11 studies carefully selected from SCOPUS database, this paper has provided a detailed synthesis of data collection, research areas, used samples, factor groups associated with the crash severity, and analytical methods. Afterwards, research gaps and shortcomings of the existing research are highlighted for proposing future research directions. This rigorous review could help to save efforts to obtain clear understanding of bus crash severity. It may be an informative reference for those newly accessing the field of bus crash severity and/or intending to develop solutions to this problem.

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