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Bridging the Divide: Investigating the Connection between Bus Crashes and Advanced Driving Technologies

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Abstract

This research analyzes Taiwan region's five years of accident data (2016-2020), focusing on bus-related incidents to identify prevalent accident types, crash factors, and locations. Simultaneously, this study has collected interviews with 40 bus drivers, which were conducted to understand their experiences with ADAS and perceived blind spots. The findings reveal that the right front, right side, and front of the bus are the most common impact areas in crashes, often involving motorcycles and pedestrians. Despite the potential benefits of ADAS in enhancing safety, the bus drivers remain system inconvenient. These factors included a high failure rate of the ADAS system, delays in video information transmission between the bus camera and the ADAS system, low image resolution and inadequate panel screen size, distracting warning tones of the system and inadequate knowledge of ADAS systems. The study emphasizes the necessity for tailored ADAS functions that address specific blind spots and driving conditions encountered by bus drivers. Recommendations include enhancing ADAS features to improve driver awareness of potential hazards, aiming to reduce the severity and frequency of bus-related accidents. The results underscore the importance of aligning technological advancements with professional drivers' practical needs and concerns, advocating for further research to enhance ADAS effectiveness in real-world driving scenarios.

Keywords

ADAS, Bus Driver Behavior, Traffic Safety

1. Introduction

Road traffic injuries and deaths have become an alarming global health problem (Peden & Sminkey, 2004). Road safety has been extensively studied by researchers for decades due to the severe consequences of road traffic accidents on property and lives, and the WHO predicts that road accidents will rise from the ninth to the seventh highest fatality rate by 2030, causing approximately 1.8 million deaths per year (WHO, 2018). According to the National Safety Council (2020), driver error is the leading cause of traffic accidents, contributing to approximately 94% of accidents in the United States. Previous studies (Seppelt et al., 2017; Asadianfam et al., 2020; Gu et al., 2019) in Western countries (mainly in the United States) have shown that driver inattention (e.g., visual distraction and driver fatigue), the driver's failure to comply with rules (Wang et al., 2020; Jansen, & Varotto, 2022) and driving-related visual scanning (e.g., looking in the mirror) are the leading causes of commercial vehicle accidents (Engström et al., 2013; Woodrooffe et al., 2012; Schindler & Piccinini, 2021). Therefore, automobile manufacturers endeavor to eliminate or minimize driver errors related to recognition, decision-making, and performance and reduce collisions by improving their vehicle design and manufacturing. For instance, various advanced driver assistance systems (ADAS) and automation functions are deemed effective solutions to assist or, in some cases, take over human driving operations. The frequent ADAS features include adding road environment awareness, driver behavior planning, and vehicle motion control. Greenwood et al. (2022) summarized seven ADAS functions commonly used by car drivers, including adaptive cruise control (ACC), automatic emergency braking (AEB), lane departure warning (LDW), active lane keeping (LKA), forward collision warning (FCW), and blind spot warning (BSW). Therefore, driver behavior is an issue of concern in the field of Intelligent Transportation Systems (ITS), and the impact of ADAS on driving has been discussed in many papers under different conditions. The effectiveness of ADAS is to improve driving safety by identifying potential hazards related to driving behavior and those on the road.

Despite the benefits of the ADAS systems in helping reduce driving risk (Baldwin et al., 2014; Souders et al., 2020), Drivers do not always actively use or are even reluctant to use the ADAS systems. McDonald et al. (2024) reported that only 29% of survey respondents felt comfortable while the system was in action. Several reasons are reported in past studies, such as overdependence of the users and distrust of the automation functions (Saffarian et al., 2012; Hancock et al., 2020) changing driving experience and behavior (Eckoldt et al., 2012), challenging the traditional role of the driver as a vehicle operator, having misconceptions about the ADAS system, and lacking adequate knowledge on how to use the ADAS system (Greenwood et al., 2022) adequately.

Accepting the ADAS system for bus drivers is a critical research issue. Although there are fewer accidents involving buses than other private vehicles, the consequences of accidents involving buses are always more severe due to the potential for multiple injuries and fatalities (Wang et al., 2021). Safety is a crucial priority for bus services, which benefits the operators in terms of higher service performance, reliability, and lower insurance costs (Cicchino, 2017). The ADAS systems attract bus companies or operators because they can address specific driver safety benefits (Schindler & Piccinini, 2021). However, the acceptance rate to the ADAS systems is not as high as anticipated (Johansson et al., 2022) for bus drivers, who are professional drivers with skills and experience in operating heavy vehicles. In particular, the complex driving tasks in service, such as frequent stops at bus stops, hurdle bus drivers to willingly use the ADAS systems that provide noisy warning sounds or signals when detecting the occurrence of designated danger scenarios (Xu et al., 2021). Blind spots are frequent dangerous problems for bus drivers since drivers cannot fully see these areas. When a vehicle or pedestrian enters these blind areas, drivers are unlikely to notice and avoid them immediately. Hence, whether the one-to-ADAS systems hit the pain points and fit the needs of bus drivers deserves deeper investigation.

Hence, this study aims to first analyze the accident type, crash factors, and vehicle crash location of bus-related accidents by using five years (2016-2020) accident data in Taiwan region to explore the main bus-involved accident types as the basis for identifying necessary functions of ADAS design and implementation. Second, we interviewed a sample of bus drivers to understand the areas of vehicles they find not easy to be aware of potential crash risks with external vehicles or pedestrians. Using the results of accident data analysis and bus driver interviews, we review the prevalent functions of ADAS and provide recommendations for tailored-made ADAS functions for bus vehicles.

The remainder of the paper is structured as follows: Section 2 explains the materials and analytical methods used for bus-related accidents and bus driver interview data in the present study. Section 3 describes the analyzed results, followed by Section 4, which discusses how the ADAS function can solve the problem of driver driving. Section 5 concludes the findings of this study.

2. Methods

2.1. Materials

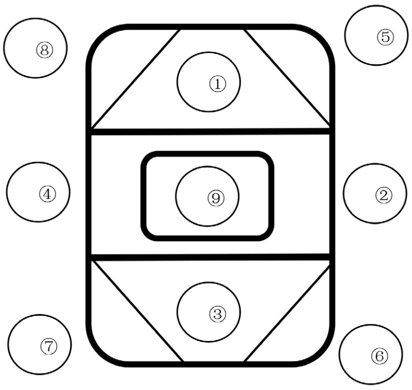
We utilized data on vehicle crashes based on the National Traffic Crash Dataset (NTCD) at Institute of Transportation (2016-2020). In addition to crash occurrence time information, the report records data on crash characteristics, such as roadway characteristics, information about the people and vehicles involved in the crash, narratives describing the crash, and photographs of the crash event. While this report includes all vehicle types of crash types, our study only focuses on those bus-related observations involved in the crash. A total of 11,817 bus-related crashes were obtained. To identify the blind areas of the bus, we examined the status of bus movement at the time of the collision, the impact locations of the bus, and the causes of the crashes.

In addition, this study, stratified sampling was used to sample 40 drivers from 20 - 25 years old to over 60 years old who were actually driving buses equipped with ADAS systems in a bus company in Kaohsiung to investigate their experience with the ADAS system and the perceived blind spots of the bus before and after using the ADAS system. This study A semi-structured interview guideline with a space of open questions to reflect the exploratory element of our research was developed and employed for the interview. The detailed questionnaire shown as **Appendix**. The results obtained from bus driver interviews are compared with the analytical results of crash data to identify the necessary functions of ADAS systems if implemented.

2.2. Data Analysis

2.2.1. Analysis of the Relationship among the Impact Area, Accident Type, and Accident Cause

An explicit framework of bus impact area and accident type is defined in Figure 1. Figure 1 shows the nine impact areas where the bus crashed in this study. For example, area ① (F) is the front of the bus, etc. In addition, we proposed the framework of crash typology to classify the situation of bus crashes. Table 1 presents the typologies based on the combination of the impact area of a crash (e.g., the front of the bus) and the accident type of bus (e.g., rear-end collision). The crash typology "RS-S", for example, indicates that the bus has a side collision, and the impact area is the right side of the bus.



① (F): The front of the bus
② (RS): the right side of the bus
③ (R): The rear of the bus
④ (LS): the left side of the bus
⑤ (RF): the right front of the bus
⑥ (RR): The right rear of the bus
⑦ (LR): The left rear of the bus
⑧ (LF): the left front of the bus
⑨ (O): the roof of the bus

Figure 1. The impact area of the bus crash.

Table 1. Crash typology classified.

accident type	The impact area of a crash								
	① F	② RS	③ R	④ LS	⑤ RF	⑥ RR	⑦ LR	⑧ LF	⑨ O
head-on collision (H)	F-H	RS-H	R-H	LS-H	RF-H	RR-H	LR-H	LF-H	O-H
side collision (S)	F-S	RS-S	R-S	LS-S	RF-S	RR-S	LR-S	LF-S	O-S
rear-end collision (R)	F-R	RS-R	R-R	LS-R	RF-R	RR-R	LR-R	LF-R	O-R
intersect collision (I)	F-I	RS-I	R-I	LS-I	RF-I	RR-I	LR-I	LF-I	O-I
same line collision (SL)	F-SL	RS-SL	R-SL	LS-SL	RF-SL	RR-SL	LR-SL	LF-SL	O-SL
pedestrian crossing on the road (P)	F-P	RS-P	R-P	LS-P	RF-P	RR-P	LR-P	LF-P	O-P

2.2.2. Defining the Impact Area and Accident Type

Since the variables of interest, such as accident cause, impact area of bus, vehicle involved, and crash typology, are nominal variables, we used correspondence analysis to understand the relationship between the factors and impact areas. Correspondence analysis is a method of information condensation for categorical variables, and it summarizes a set of variables in a two-dimensional graphical form for visualization. We also used text analysis to elicit significant concerns about the ADAS system from the content of bus drivers' interview narratives.

3. Results

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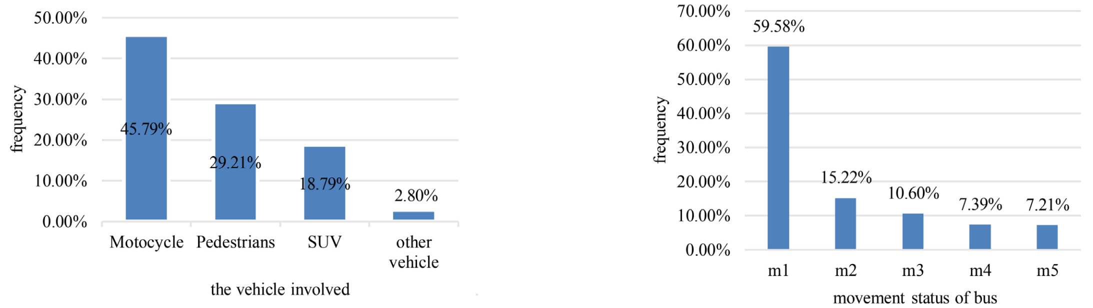
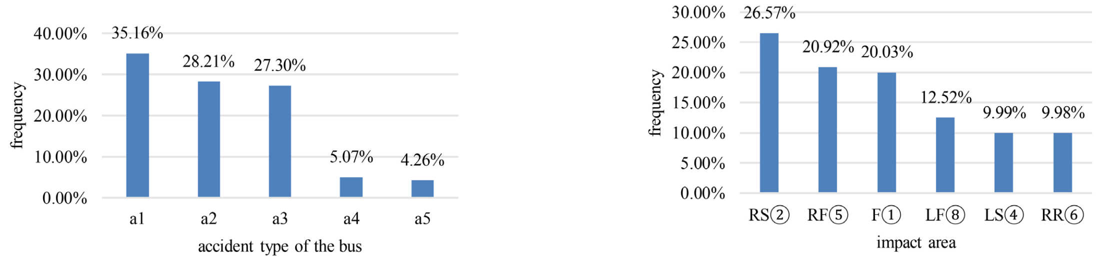


m1: straight ahead; m2: stop and wait (the engine is not turned off); m3: turn left; m4: start; m5: right turn

(a) the vehicle involved

(b) movement status of the bus

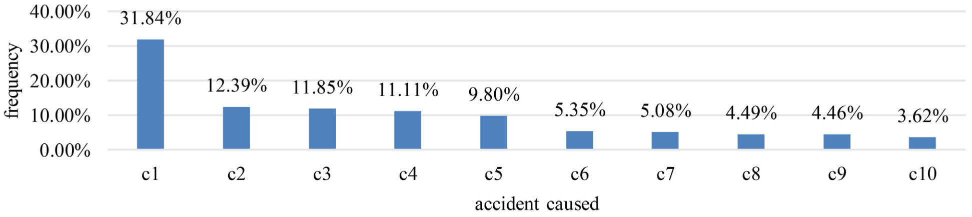


a1: head-on collision; a2: side collision; a3: rear-end collision; a4: intersect collision; a5: same line collision

①: the front of the bus; ②: the right side of the bus; ③: the rear of the bus; ④: the left side of the bus; ⑤: the right front of the bus; ⑥: the right rear of the bus; ⑦: the left rear of the bus; ⑧: the left front of the bus); ⑨: the roof of the bus

(c) accident type of the bus

(d) impact part of the bus



c1. not paying attention to the state of the vehicle; c2. Changing lane illegally; c3. Failing to maintain safe driving distances; c4. Failing to give way to other vehicles; c5. Not keeping a safe distance; c6. Starting without paying attention to the safety of other vehicles (people); c7. Violating signal control or police command; c8. Making a left turn illegally; c9. Violating a specific sign (line) prohibition; c10. Making a right turn illegally

(e) accident caused by bus crashes

Figure 2. The descriptive statistics of bus crashes.

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3.1. Patterns of Bus Crashes

From Figure 2(a), motorcycles and pedestrians are found to be the significant vehicle or road users involved in bus crashes. The bus drivers were mainly in the process of going straight (Figure 2(b)), with three major accident types: head-on collision, side collision, and rear-end collision (Figure 2(c)). The major impact points of the bus are the right side, the right front, and the front of the bus (Figure 2(d)). Figure 2(e) shows that the prominent cause of accidents is related to driver error, such as drivers not paying attention to the situation in front of or around the bus, followed by causes of bus crashes, such as changing lanes illegally; 3. failing to maintain safe driving distances; 4. failing to give way to other vehicles; 5. the driver does not keep a safe distance.

Subsequently, we analyzed the relationships between the impact point, the vehicle involved, and the accident cause of the crash and depicted the perceptual maps of correspondence analysis. Figure 3 indicates that the impact areas of buses differ regarding different types of accidents. For instance, regarding the impact area at the bus front (i.e., ① F), most crashes (59%) belong to the accident type of rear-end collision. In terms of the impact area at the right front of the bus (i.e., ⑤ RF), the accident types of same-line collision (37%) and side collision (36%) are the two major accident types.

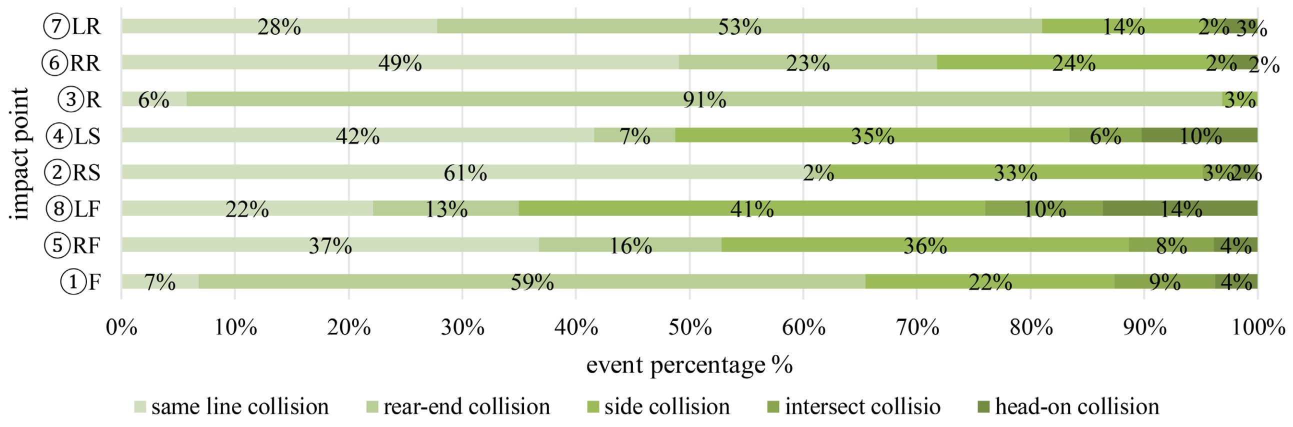


Figure 3. Relationships between accident type and impact areas of buses.

As shown in Figure 4, the perceptual map indicates that (i) side collision is close to both ⑤ RF and ④ LS, (ii) head-on collision and intersection collision are close to ⑧ LF, (iii) same-line collision is close to both ② RS and ⑥ RR, and (iv) rear-end collision is close to both ③ R and ⑦ LR.

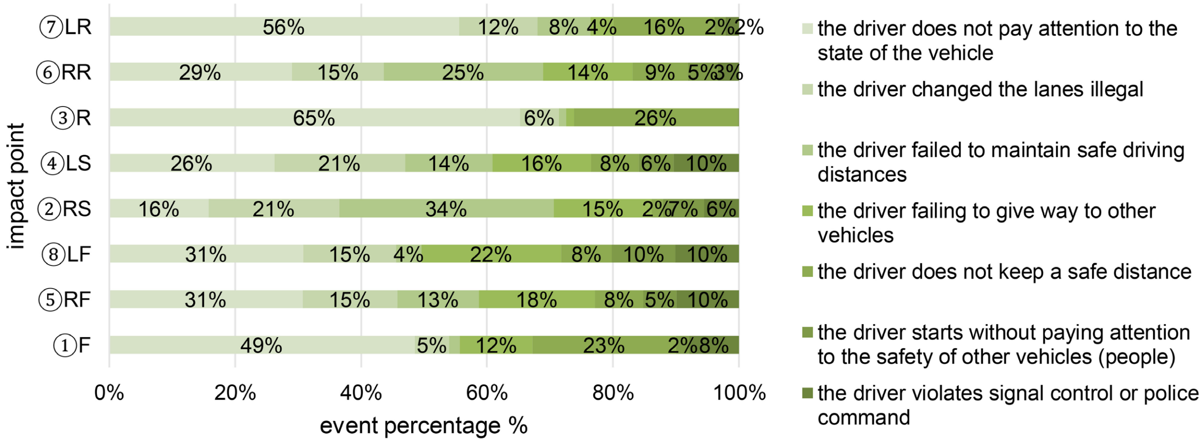


Figure 4. The perceptual map of correspondence analysis between accident type and bus impact area.

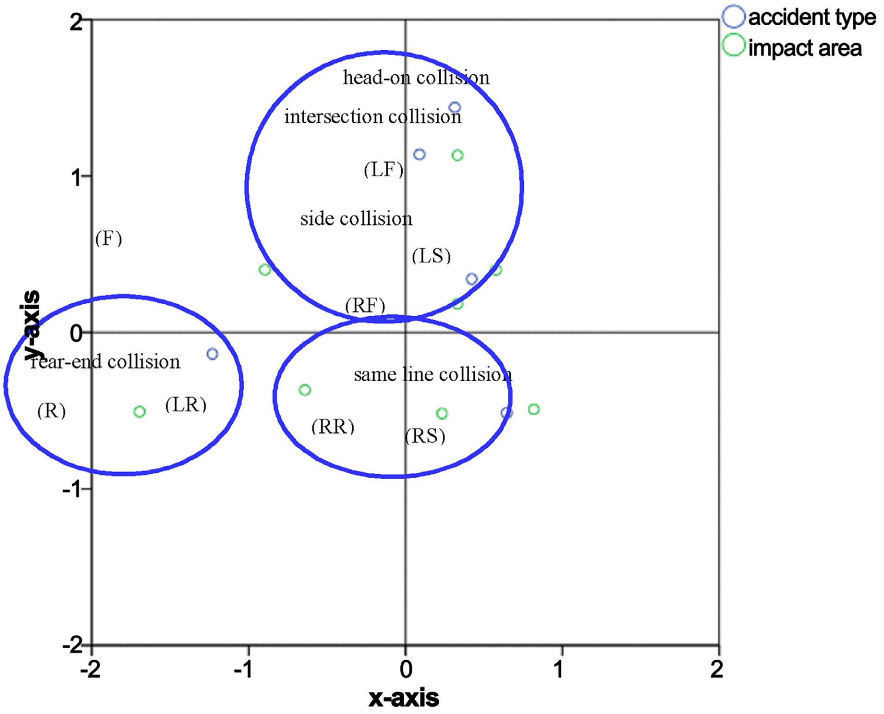


Figure 5. Relationships between accident causes and impact areas.

Figure 5 indicates the propensity of various accident causes for each impact area of buses. Taking the impact area of the right front of the bus (⑤ RF), for example, 31% of crashes are attributed to the cause that the driver ignores the state of the vehicle. According to bus drivers' interviews, the right front of the bus (⑤ RF) is also reported as the top rank of the blind spot. The actual reason for this impact area might not be wholly due to drivers' inattention but because of drivers' inability to see the situation within the blind spot. Hence, the function of inspecting and warning for this specific blind spot should be provided when the ADAS system is introduced. **Figure 6** depicts the closeness between accident causes and impact area. The impact areas of ② RS ⑥ RR are more likely associated with accidents caused by illegally changing lanes and failing to maintain safe driving distances. The impact areas of ③ R and ⑦ LR are more approximately associated with the accident causes of not paying attention to the vehicle's state and not keeping a safe distance. The impact areas of ④ LS, ⑤ RF, and ⑧ LF are more approximately associated with the accident causes of failing to give way to other vehicles, starting without paying attention to the safety of other vehicles (people) and violating signal control or police command.

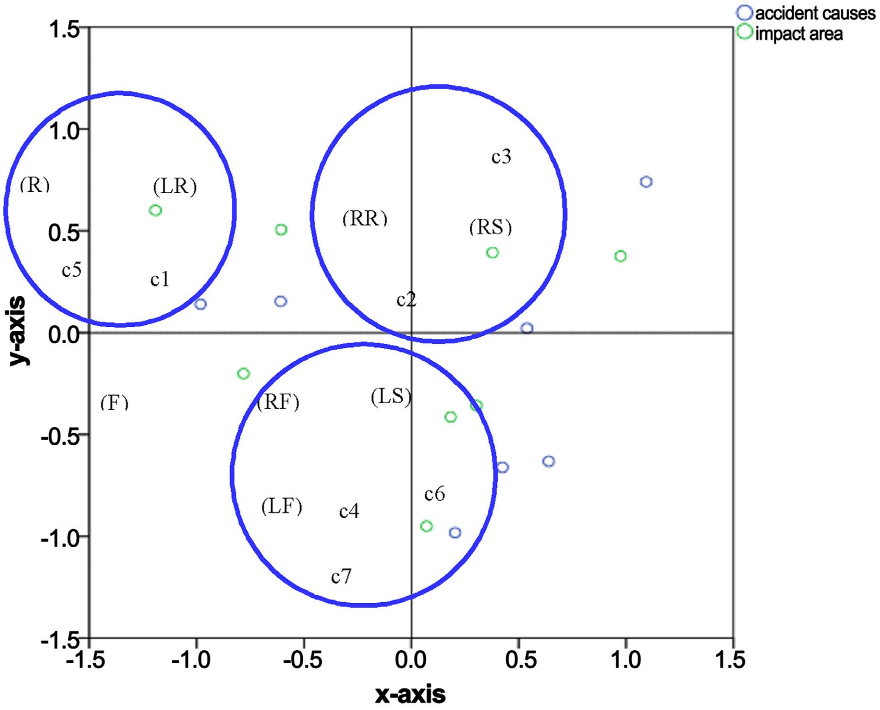


Figure 6. The perceptual map of correspondence analysis between accident type and impact areas.

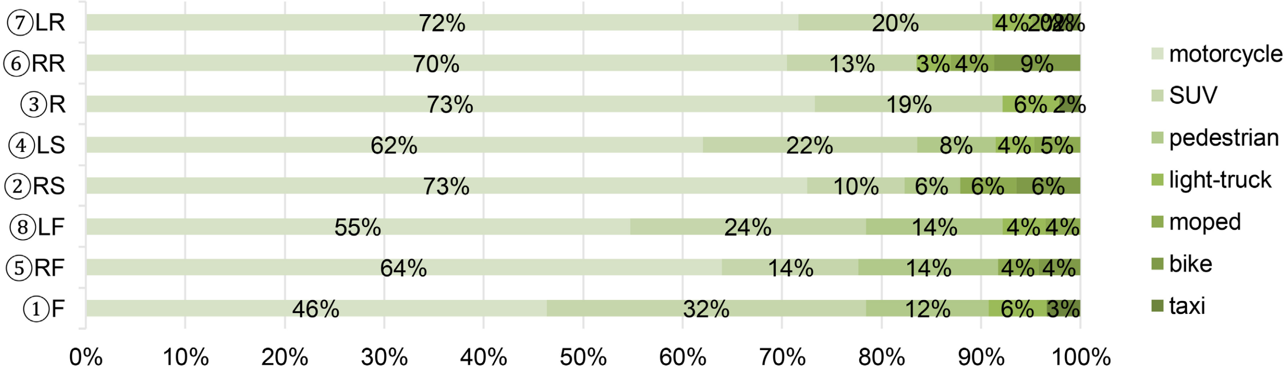


Figure 7. Relationships between the vehicle involved and the impact area of the bus.

Figure 7 presents the relationships between the impact area of the bus and the vehicle involved. In general, motorcycles account for the vast majority (ranging from 46% to 73%) of bus-related crashes in various impact areas of buses. Given the top three blind spots (i.e., right front (⑤ RF), left front (⑧ LF), and right side (② RS)) ranked by the bus drivers interviewed, a sound ADAS system should be equipped with the function of inspecting the presence of motorcycle within the blind sport and providing warning information. Figure 8 presents the perceptual map between the vehicle involved and the impact area. It shows that motorcycles, bicycles, and mopeds are the primary vehicles involved in bus-related accidents with various impact areas such as ② RS, ④ LS, ⑤ RF, and ⑧ LF.

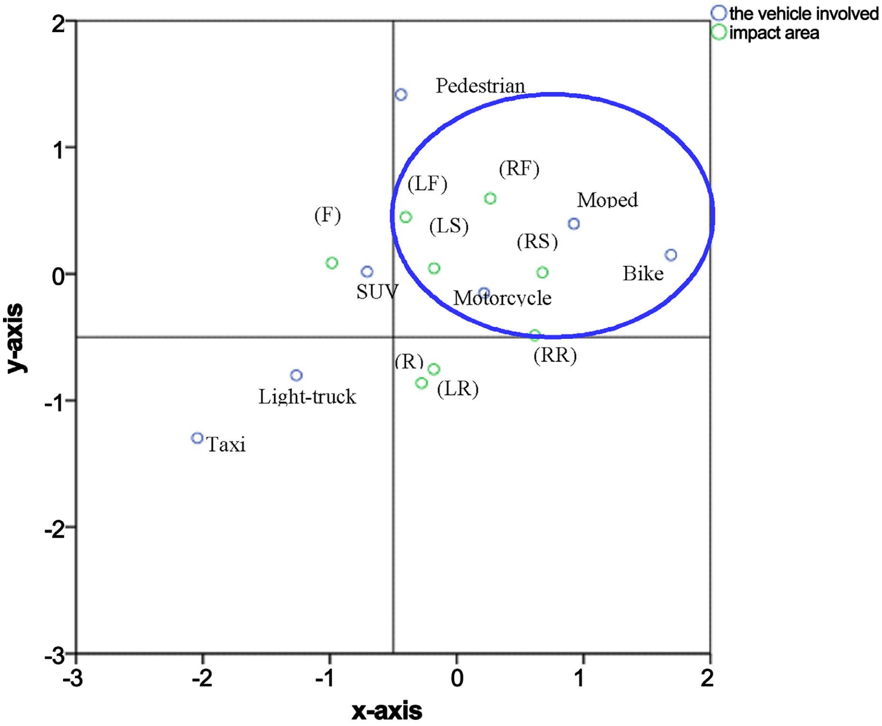


Figure 8. The perceptual map of correspondence analysis between vehicles involved and bus impact areas.

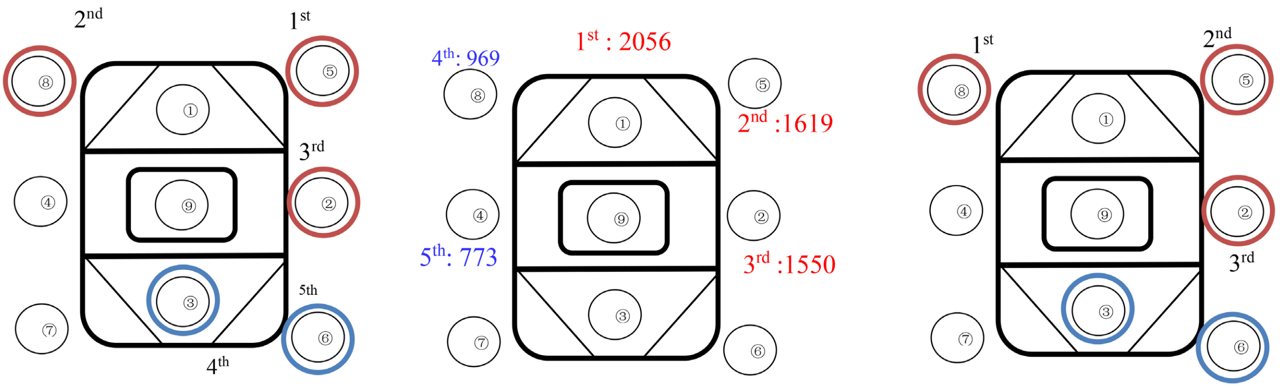
3.2. Results of Bus Driver Interview

Table 2 is the sample profile of the 40 bus drivers interviewed. Most interviewees were male (90%), aged between 40 and 59 years old (72.5%), with less than five years of bus driver experience (42.5%), followed by those with 5 to 10 years (37.5%). Most of them (87.5%) reported having experience with the existing ADAS systems implemented on buses. The most frequently used features include around view monitor (AVM, 82.5%), lane departure warning (LDW, 40%), blind spot warning (BSW, 35%), and forward collision warning (FCW, 25%).

We asked interviewees to rank the perceived blind spots from their bus driving experience using the figure of the vehicle's impact in the crash report analyzed above, i.e., Figure 1. We intend to check whether the most frequent impact areas of buses are likely caused by blind spots where bus drivers find it difficult to detect the occurring hazard situations. The results (as shown in Figure 9(a)) indicate that the right front (⑤ RF), left front (⑧ LF), and right side (② RS) of the vehicle are the top three ranked perceived blind spots in order. Compared with the top three impact areas of bus crashes (as shown in Figure 9(b)), which are right front (⑤ RF), right side (② RS), and bus front (① F), both right front and right side are consistent in common. Taking both together, it suggests that a functional ADAS system should provide practical functions for detecting and warning the areas of ⑤ RF, ② RS, ⑧ LF, and ① F of vehicle.

Table 2. Sample profile of interviewed bus drivers (N = 40).

Gender	Male	90%
	Female	10%
Age	20 - 29	2.5%
	30 - 39	17.5%
	40 - 49	**35%**
	50 - 59	**37.5%**
	Over 60	7.5%
Years of driving	Less than three years	10
	More than three years less than five years	7
	More than five years less than 10 years	15
	More than ten years, less than 20 years	4
	More than 20 years	4
Have you ever used intelligent vehicle systems?	Yes	87.5%
	No	12.5%
What intelligent vehicle system have you used?	AVM	33
	LDWS	16
	BLIS	14
	FCW	10
	Vehicle recorder	8
	TPMS	5
	DMS	3
	Alcohol locks	1



(a). Ranks of perceived blind spots (b). Ranks of impact areas of bus crashes (c). Ranks of blind spots remaining of existing ADAS implementation

Figure 9. Comparisons between perceived blind spots and impact areas of bus crashes.

We also conducted content analysis on bus drivers' perceptions of and attitudes towards the use experience of the ADAS system. In summary, while the existing ADAS system can provide benefits of warning effect and reduction in blind areas, it also encounters shortcomings such as high failure rate of the device, transmission lag of video information, poor image resolution, insufficient size of panel screen, unnecessary distraction by waning tone, etc. These barriers to use intention could provide insightful improvement directions for designing a more user-friendly ADAS system. As shown in **Figure 9(c)**, more importantly, the responses on the capability of existing ADAS systems to eliminate the blind spots reveal that the top three perceived blind spots (i.e., ⑤ RF, ⑧ LF, and ② RS) remain even after the implementation of ADAS system on the vehicle and suggest the necessity to investigate the causes of associated dysfunction further.

4. Discussions

Crash avoidance technologies such as ADASs can potentially prevent or mitigate avoidable crashes (Eichelberger & McCartt, 2014; Mele, 2018). **Table 3** summarizes the ADAS functions for detecting potential blind spots of vehicles based upon research evidence as mentioned subsequently. For instance, FCW helps reduce front-to-rear crash rates (Cicchino & McCartt., 2015; Cicchino, 2017, 2018; Hadi et al., 2021). Vehicles with FCW and AEB showed increased crash prevention performance (Hubele & Kennedy, 2018; Asadianfam et al., 2020) and reduced front-to-rear crashes (Cicchino, 2017). LDW and LKA help avoid or mitigate a head-on collision with the opposing vehicle and avoid or mitigate a rear-end collision with the vehicle behind (Consumer Reports, 2019; Reagan et al., 2018; Susilawati et al., 2022). The ACC system, using vehicle-mounted sensors, such as radars and lasers, can detect the front situation of the vehicle and make reactions automatically (Tu et al., 2019) hence preventing front crash prevention (Consumer Reports 2019). BSW is effective in preventing lane-change crashes (Engström et al., 2013). From **Table 3**, RF, RR, LR, and LF are the blind spots that the ADAS functions cannot deal with well.

Table 3. Blind spot areas where ADAS functions can improve.

	① F	② RS	③ R	④ LS	⑤ RF	⑥ RR	⑦ LR	⑧ LF
ACC	○	○	○	○				
WEB	○		○					
LDW			○					
LKA			○					
FCW	○		○					
BSW	○	△	○	△				

○: Significant △: Partial.

One of bus drivers' most significant challenges is the blind spots associated with large vehicles. Our crash analysis results indicate that bus drivers often experience collisions with objects within the blind spot area of the vehicle, consistent with previous studies [19]. In addition, our interview results show that the actual driving blind spots exist at both the right (⑤ RF) and left (⑧ LF) fronts, as well as the right side (④ RS) of the bus. The associated ADAS functions to detect and warn of these three blind spots for bus drivers should be the priority to enhance existing ADAS systems.

5. Conclusion

In this study, we examined the accident type, crash factors, and vehicle crash location of bus-related accidents from five years (2016-2020) of accident data in Taiwan region and explored the relationships between accident variables. The results show that the right side, right front, and front of the bus are the top three impact areas related to bus-related crashes. The close correspondence between vehicles involved (i.e., motorcycle, bicycle, and moped) and impact areas of the bus (i.e., right side, left side, right front, and left front) is also identified. In addition, our results of the bus driver interview indicate that the right front, left front, and right side of the bus are the top three ranked blind spots from their driving experience. This is due to (1) limited vision: buses are usually designed with a high driver's seat and a wide body, which may block the driver's vision, especially in the right front corner; (2) window structure: The thickness of the window frame may also obstruct the driver's field of vision, making it difficult to see the right front position clearly.

Furthermore, these blind spots cannot be satisfactorily detected by the existing ADAS system installed on board. Our results, therefore, provide essential insights into the necessary functions of ADAS design and directions for improving the function performance for the actual pain points of bus driving risk.

Although not investigated by the present study, we inevitably recognize the important role bus drivers' awareness of functions and acceptance of the introduction of ADAS play in assisting safe driving. Hence, future research is recommended to illuminate this direction.

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Although not investigated by the present study, we inevitably recognize the important role bus drivers' awareness of functions and acceptance of the introduction of ADAS play in assisting safe driving. Hence, future research is recommended to illuminate this direction such as enhanced sensors for specific areas or dynamic warning algorithms, which would be a valuable addition function.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Appendix

Session I: The Usage of ADAS System

1) Do you use the company's newly installed ADAS system to assist driving?

☐ Never used ☐ Occasionally used ☐ Frequently used ☐ Always used

2) What do you believe this system helps you overcome the following blind spots after using the company's newly installed ADAS system?

Vehicle Front:

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Vehicle Right Side:

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Vehicle Rear:

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Vehicle Left Side:

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Vehicle Right Front:

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Vehicle Right Rear:

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Vehicle Left Rear:

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Vehicle Left Front:

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

3) What differences and opinions do you have compared to the system you used previously after using the ADAS system

Session II: Background Information about the Bus Driver

1) What is your gender?

☐ 1. Male
☐ 2. Female

2) What is your age?

☐ 25 - 29 years
☐ 30 - 34 years
☐ 35 - 39 years
☐ 40 - 44 years
☐ 45 - 49 years
☐ 50 - 54 years
☐ 55 - 59 years
☐ 60 - 64 years
☐ 65 - 70 years

3) How many years have you been driving a bus?

☐ Less than 3 years
☐ 3 to less than 5 years
☐ 5 to less than 10 years
☐ 10 to less than 15 years

☐ 15 to less than 20 years
☐ 20 to less than 25 years
☐ More than 25 years