

Article

School Bus Lighting Effectiveness and Improvements: Results from a Driving Experiment

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Abstract: In Korea, drivers should come to a complete halt and proceed cautiously when encountering a school bus displaying its red warning lights and other safety features, a requirement that is often disregarded in practice. The reason for this might stem from a lack of awareness about the law, and we set out to investigate whether an innovative lighting system employing road projections or VMS could encourage compliance. We found that while 63% of drivers in surveys indicated they would correctly stop when approaching a stopped school bus, in driving experiments, we found that only 18% of drivers did. Our study also uncovered a knowledge gap, with just 53% to 60% of respondents correctly answering basic about the purpose of existing lighting and laws related to school buses. With on-road experiments, when we introduced road projection systems for enhanced non-connected vehicle-to-vehicle (V2V) communication, we found that understanding would increase and compliance could increase by up to 77% (from surveys) and 93% (in road tests); these findings underscore the potential of road projections or potentially VMS as effective V2V tools for enhancing road safety in proximity to school buses.

Keywords: school bus safety; road projection; road safety; school transportation; lighting



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1. Introduction

School buses are a popular form of public transport which provides a useful and safe alternative to cars or motorcycles. These vehicles are known to have seriously reduced accidents for school children [1–6] but they only offer limited additional protection when children are outside of the school bus. Indeed, many studies have found that the most dangerous portion of the journey to and from school is when the child is a pedestrian, especially getting on or off the school bus [3,4,6]. Although a huge improvement in school bus safety has been made over the last few decades in Korea, injuries or deaths of children while traveling to school are still significant. In 2022 in Korea, 18 children were killed in traffic accidents, while more than 10,000 were injured [7]. Many of these accidents occurred during school transportation, and driver errors account for most school transportation-related accidents [8]. In Korea, in 2012, for example, 65% of child traffic accident deaths were pedestrians [9]. Children's safety while crossing the street before or after using a school bus is a major concern not only in Korea but also in other countries. A study from New South Wales, Australia, found that 77% of accidents involving school buses were related to pedestrians crossing the road after alighting or before loading the bus [4]; and 74% of school bus-related accidents in Sweden occurred outside of the school bus [5,6]. Similar results have been found in Austria [10], the U.S. [2,3], and China [11]. Pedestrian fatalities in school bus-related accidents outnumber school bus occupant fatalities by more

than three to one [2]. Other research also shows that pedestrians are more likely to be injured or killed at night when visibility is low [12–14], and thus, special attention is needed to reduce accidents at night.

Projected light systems (or road projections), which have emerged as a promising technology in the automotive industry [15,16], can potentially transform how drivers interact with vehicles on the road at night. The systems are also expected to contribute to improving drivers' behavior when stopping for school buses. Road projections may provide a range of benefits including enhanced safety [17–20] and improved driving experience [18,21], among others. Road projection technology has been proposed and/or studied for a variety of applications including parking assistance [22], displaying a stop sign or other road markings [23], displaying the width of the vehicle [24,25], navigation content [26], displaying warning messages [24], and communicating driving intention or warnings [20,27–31], especially in the context of connected and autonomous vehicles (CAVs) as so-called external human–machine interfaces (e-HMIs) [32–37]. On the other hand, some research investigates whether there is a possibility that these types of projections could distract drivers [23,38–40]. As part of a series of measures to increase traffic safety, Korea first regulated and introduced school buses in 1997 [9]. Like in many other countries, school transport vehicles in Korea are required to be painted yellow and be equipped with a stop sign and flashing lighting system to be used when children are being loaded or unloaded into or out from the vehicles. Since their introduction in 1997, school bus lighting regulations have not changed significantly.

In Korea, there is anecdotal evidence and general sentiment that drivers simply do not stop for school buses as they are supposed to, perhaps due to ignorance or apathy. Government agencies are aware of the issue, and in the past, safety and information campaigns have been relatively common, especially from the Korea Expressway Transportation Corporation, but it is unclear how effective they have been [41]. Additional safety policies, like off-street pick-up and drop-off for kids, have been implemented thanks to these campaigns. However, any potential improvements to road safety for children are highly relevant and an important consideration for all transport researchers, and further policies or projects are needed in Korea to further reduce accidents to zero. Improved lighting systems, like road projections or variable message signs (VMS), could contribute to improving the sustainable use of school-based public transportation, and safety by reminding drivers of their responsibilities during the most critical moment of the travel to school journey: getting on and off the school bus. This study is the first to systematically measure in on-road situations whether drivers are stopping for school buses, and measure objectively how new lighting systems could potentially increase the number of drivers stopping.

Therefore, in this exploratory study, we performed a survey and field experiments to investigate (1) the level of understanding of public of the existing lights on school buses (2) drivers' actual compliance with the traffic rules under existing conditions, and (3) the effectiveness of improved lighting systems using road projections and VMS. A total of 237 licensed drivers participated in a survey, and a field experiment conducted on a publicly accessible road had 29 participants. In the on-road test, we observed the effectiveness of the existing lighting systems as well as several enhanced lighting systems using road projection which is designed to convey messages such as stopping or not overtaking to drivers, simulating a situation where children are being loaded or unloaded onto the school bus. Survey data provided additional insights.

Road safety for children especially remains of utmost importance; in this paper, we will review the literature related to the technologies being proposed for these systems including road projection and VMS, followed by an introduction/review of the legislation related to the school bus and driver behavior in Korea, and finally examine where there are gaps in the literature. We follow this with our research design and methodology, provide the results of the study with a focus on the on-road experiments, and finally provide a discussion and conclusion. This work is part of a wider effort from a consortium of groups, private companies, and universities working to make school transportation safer in the

Republic of Korea. This exploratory study shows that innovative changes to the lighting systems are effective and worthy of further study including modifications to acts and other legal instruments that will allow such systems to be installed on school bus vehicles. As a first step, a standard for road projection for school buses was developed by Shin et al. [42].

2. Literature Review

In this literature review, we will examine the distinctions between textual and non-textual on-road signage, and various techniques for presenting dynamic text to drivers, such as road projection and variable message signs (VMS). Finally, we provide a summary of school bus-related road safety regulations in Korea.

2.1. Road Projection

Projected light systems have emerged as a promising technology in the automotive industry [15,16], and could potentially transform how drivers in vehicles interact with other vehicles (V2V communication) or pedestrians (V2P communication) without the need for complex wireless networks, especially at night, when projections would be visible. They use light to project images or text onto roadways or other surfaces [15,16,24]. Road projection has not been widely adopted in consumer vehicles. However, many vehicle manufacturers, such as Mercedes-Benz [21], Audi [43], Hyundai [19], Ford [44], Jaguar Land Rover [45], and vehicle-related technology companies, such as OSRAM [45] and Texas Instruments [32], have announced that they are currently developing road projection technology or have built prototypes. For example, Hyundai's [19] headlights in development will be able to project a variety of symbols and information on the road surface, including "under construction" signs, or pedestrian crosswalks. Ford [44] claims their new headlights will be able to project other information, such as pathways, weather information, and a projection of the width of the vehicle.

Hamm et al. [15–17] have extensively explored the potential advancements in lighting technology about digitalization and autonomous driving and how lighting technology could play a crucial role in enhancing safety, communication, and overall driving experience. According to the authors, using intelligent lighting systems enables the car to adapt to road conditions, weather, and traffic situations dynamically. This integration can improve visibility and provide valuable information to both the driver and surrounding vehicles. Advanced lighting systems can create personalized and comfortable environments for passengers, as well as assist in conveying information and warnings effectively.

Budanow and Neumann [24] also explored the concept of road projections as a novel external human–machine interface (e-HMI). By projecting symbols, messages, and warnings directly onto the road surface, vehicles can convey their intentions and status to pedestrians and other road users clearly and intuitively. They discuss various potential applications of road projections, such as indicating the trajectory of a turning vehicle, warning pedestrians about a vehicle's blind spots, or displaying information related to the vehicle's current mode of operation (e.g., autonomous mode or manual control). This research highlights the importance of designing road projections that are easy to understand and appropriate, culturally. This research also suggests that consideration should be given to the use of universally recognized symbols and the adaptation of projections to different cultural contexts. They conclude that road projections as a promising human–machine interface can improve communication between vehicles and pedestrians.

A variety of technologies have been proposed to project light such as LED projection modules [46,47], adaptive beam technology (ADB) [23,48], digital light projection (DLP) [31,49], and pixel-light or digital micromirror devices (DMD) [19–21,37,50]. Some experimental designs have been researched and tested. Light projection systems have been studied for vehicle-to-vehicle communication, vehicle-to-pedestrian communication, and enhancing driving performance and safety. In the following sections, examples of each of these applications are discussed.

Kato et al. [23] investigated the potential of driver assistance projections using adaptive driving beam (ADB) technology. ADB systems are designed to automatically adjust the headlight beam pattern to optimize visibility while avoiding glare for oncoming drivers; in addition, they can be used to project images or symbols on the road. The authors discussed the concept of utilizing ADB technology to project symbols or patterns onto the road surface as a means of communication. These projections can convey information such as the vehicle's intended trajectory, warnings, or messages to pedestrians and other road users. The experimental results of 16 participants were used to evaluate the legibility and recognition of driver assistance projections in this study. Factors such as projection brightness, color, size, and timing are examined to determine the most effective parameters for conveying information to road users. It was found that there was a minor delayed response time, of around 0.1–0.2 s, for participants to read the road projection, and this may be affected by the condition of the road surface. Although this study focused on images and symbols as the sole projection means, in other cases, textual indicators were found to be preferred by experiment respondents [32].

Further, Shibata et al. [29,30] described road projection systems focusing on parameters for readability and other factors. They studied projections scenarios of a vehicle reversing system [30] and a projected turn signal [29]. Parameters examined include ambient luminance, luminance contrast/brightness, visibility range, projection angle, color, and the ability to display clear and recognizable symbols or patterns. This study discusses the relationship between brightness and visibility range, noting that an appropriate balance is required. While a higher brightness level increases visibility, excessively bright projections may cause glare and hinder perception. The projection angle is another crucial parameter. They suggest that the projection angle should be optimized to ensure that the projected information is visible to the driver while avoiding unnecessary distractions for pedestrians or other road users. Unsurprisingly, it is found that in brighter ambient conditions (i.e., sunlight or daylight), the detection of the projection is more difficult.

Road projections could be beneficial for school buses in particular since they are a novel lighting system that is particularly visible at night, which is among the most dangerous periods for pedestrians due to reduced visibility [12–14]. Communications between drivers using road projections have been shown to increase safety due to their ability for explicit communication, including studies by De Ceunynck et al. [51], who found that some symbol choice is important as some increased safety, while others simply distracted drivers. For school buses, there is some research illustrating that advanced technologies, including roadside smart LEDs, are effective in increasing compliance and safety [52], but there are no studies yet confirming if road projections on school buses increase safety.

2.2. Variable Message Signs (VMS)

Variable Message Signs (VMS) are a series of signs that can display information dynamically through digital means. A typical application of VMS for road traffic is as fixed infrastructure on the sides of highways or other major roads which generally displays traffic conditions, safety messages, or other information to passing cars [53–56]. Other smaller VMS are portable [57–59] meaning they can be mounted on the backs of vehicles like trucks. Bus-mounted VMS are less commonly used; however, in jurisdictions with yield-to-bus laws (motorists must yield to all transit buses when they are pulling back into a lane after stopping), some buses use flashing or dynamic yield signs mounted to the back of the bus. These types of dynamic signs, analogous to VMS, have been found to change driver behavior [60,61], compared to static markers, which are ineffective [62].

2.3. Legislation Related to School Buses and Lighting in Korea

Traffic rules related to school buses are defined in Article 51 of the Road Traffic Act [63]. Article 51 states the following (translated for this study):

[...] When a school bus for children stops on the road [...] the driver of any motor vehicle driving in the lane in which the school bus has parked and [...] in the lane just beside the

former shall temporarily stop before reaching the school bus and then proceed carefully [...]

[...] the driver of any motor vehicle driving in the opposite direction of a road having no central line marked [...] shall temporarily stop the motor vehicle before reaching the school bus and then proceed carefully [...]

The requirements for school bus lighting are described in Article 48 of the Act of the Rules on the Performance and Standards of Automobiles and Automobile Parts [64]. School buses in Korea are equipped with very basic V2V communication lamps and signage. School buses must be equipped with an indicator lamp that with “two red lights and two yellow or amber lights which flash at least 60 times per minute and less than 120 times per minute on the front and back sides. . .” among other requirements. The lights must comply with the following flashing procedures:

1. The red lights must automatically flash when the main door opens.
2. When the door closes for departure, the yellow or amber lights must automatically flash again.
3. The red and yellow lights or amber lights shall not flash at the same time when the other types of lights are flashing.

School buses should be equipped with at least two plastic signs that state “Child Protection Zone”. Operators of the school bus should display these signs from the front and rear of the vehicle when in operation with children on board.

2.4. Research Gap

As a relatively new and emerging technology, there are numerous areas in which there is a lack of studies and data related to road projections. To the extent of our knowledge, any other field experiments using road projection or VMS to enhance safety in school buses were not found. Our research could fill this gap by sharing our relevant results of a real driving experiment, testing the effects of enhanced lighting to increase compliance with the law, and as a result, potentially increase safety for school children.

3. Research Design and Methodology

The purpose of this study is to investigate if enhanced lighting systems would be effective tools for improving the compliance of drivers with traffic rules and safety for school children using school buses at night. To do this, we first undertook a survey which had a large sample (237 individuals) covering a wide geographic area and later an on-road test with 29 participants which also included a pre-and-post questionnaire. The purpose of the survey was to ensure that the results from the small sample were relatively in line with the population at large. However, the focus is generally on the results from the on-road test.

3.1. Concepts Evaluated

In both the survey and road experiments we evaluated three different concepts for enhanced lighting systems in addition to the existing lighting systems, which were (1) a horizontal projected light, (2) road projection from the front of the vehicle into the opposite lane, (3) road projection from rear of the vehicle into the opposite lane. In the survey only, a (4) variable message sign (VMS) (which could in theory display a variety of messages) was also evaluated.

The horizontal light projects a horizontal red light behind the school bus vehicle to warn the drivers of other vehicles driving behind the school bus as shown in Figure 1 below.

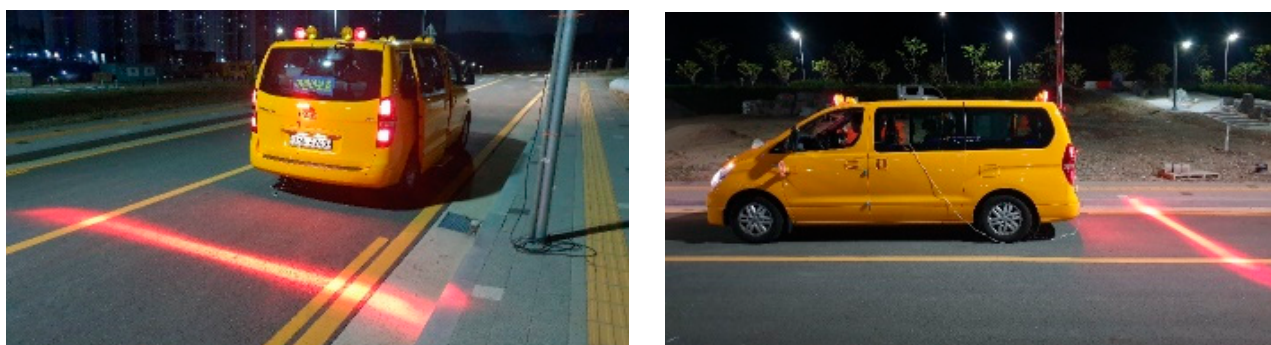
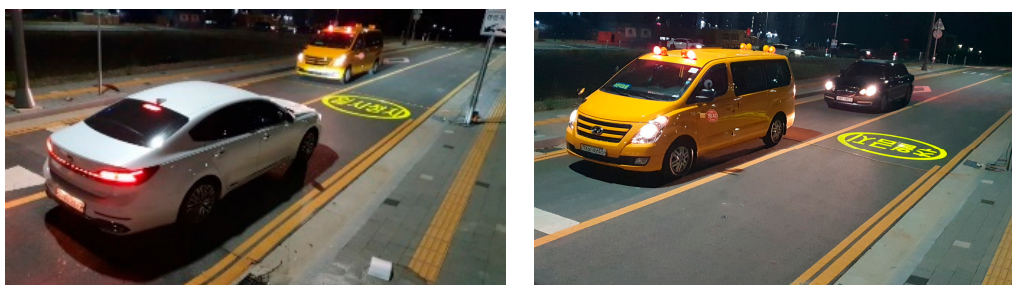


Figure 1. Horizontal projected light. Text on back of van: “Children’s Safety Zone” (translated from Korean).

If the horizontal light projection is commercialized and released to the market, it is expected that the lamp or light source will be installed on the vehicle. However, in this exploratory experiment, the goal of setting up the light is to observe if the light projection could improve drivers’ behavior, rather than fully designing the light projection systems for practical use; therefore, a commercially available LED lamp was used and affixed to a nearby mast on the roadside.

The road projections produced an illuminance of 800 lx when it was measured on the road surface. The symbols for road projections are a combination of a yellow circle and text in the middle and are shown below. The size of the circle and text is based on the reference to the Korean road sign code [65]. The edge of the circle was projected 2 m from the vehicle. In this exploratory study, only a single text option was chosen for projection from the front or rear, due to time and other constraints. Messages chosen were “No Overtaking” when displayed from the rear, and “Temporarily Stop” when displayed from the front. Refer to Figure 2 below. The message “Temporarily Stop” is chosen as this is the same text that appears on the stop sign which is currently used by school buses in Korea.



Projected text: “No Overtaking”
(translated from Korean)

Projected text: “Temporarily Stop”
(translated from Korean)

Figure 2. Road projection (front and rear).

In the survey only, a Photoshopped concept of a VMS was shown to users. The VMS was described as being able to display a variety of messages, including “Child Protection Zone” or “Children Getting On or Off”, refer to Figure 3 below.



Figure 3. VMS concept. VMS is displaying the text “Children Getting on and Off” (translated from Korean)

3.2. Samples

For the survey, respondents were recruited from across Korea using the Pickply service platform and were emailed a link to the survey form. This platform provides a small reward to survey respondents in the form of points which can be used to buy gift cards, etc. Any licensed driver in Korea on the platform was eligible to participate in the survey. Although the average age of respondents is not exactly known, it is thought that most respondents were between 40 and 50. In terms of gender, 35% were female and 65% were male.

Participants for the field experiment and related surveys were recruited from the Chungju, Chungcheongbuk-do area (around 120 km southeast of the capital Seoul). Participants were required to be licensed to drive in Korea; a total of 29 participants were recruited. Although the average age of participants is not exactly known, most participants are between 30 and 40. In terms of gender, 31% were female and 69% were male. About half of the respondents had over 20 years of driving experience, refer to Table 1 below.

Table 1. Respondent profile. Totals may not add up to 100% due to rounding.

	Experiment		Survey		Licensed in Korea	
Gender						
Female	9	31%	82	35%	14,667,592	43%
Male	20	69%	155	65%	19,466,171	57%
Total	29	100%	237	100%	34,133,763	100%
Age						
10–20	4	14%	0	0%	272,171	<1%
20–30	3	10%	47	20%	4,817,217	15%
30–40	15	52%	63	27%	6,174,728	18%
40–50	6	21%	85	36%	7,544,512	22%
>50	1	3%	42	18%	15,325,135	45%
Total	29	100%	237	100%	34,133,763	100%
Driving Experience						
<1 year	3	10%	27	11%	-	-
2–5 years	3	10%	49	21%	-	-
5–10 years	3	10%	50	21%	-	-
10–20 years	6	21%	56	24%	-	-
>20 years	14	48%	55	23%	-	-
Total	29	100%	237	100%	-	-

3.3. Survey

The survey was undertaken from May to June 2023 and administered to respondents using the Google Forms platform (a link was emailed to willing participants). Consent for participating in the survey and for providing personal information was obtained in the first part of the questionnaire. Participants were advised that their responses in all cases were anonymous and that they did not need to participate if they did not want to. For each concept, a brief explanation was provided and several images depicting the lighting system were shown. In some cases, these were real photographs from on-road experiments, and in

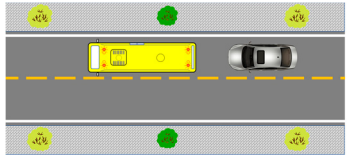
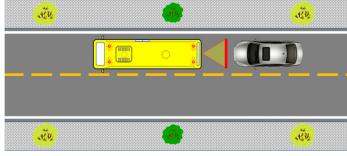
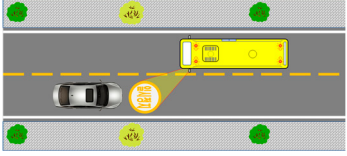
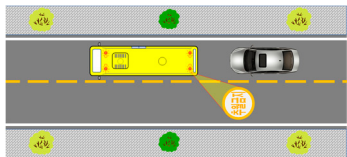


other cases, they were concepts mocked up in Photoshop/equivalent. For each concept, we measured what respondents indicated they would do if they approached each of the four concepts on an actual road. Available choices were as follows:

- “Temporarily stop before continuing slowly” (desired behavior);
- “Drive (or overtake) slowly”;
- “Drive (or overtake) as usual, without any special behavior”.

3.4. Experiments

In the on-road experiments, three enhanced lighting concepts were tested at night, which were as follows in Table 2.

Table 2. Concepts and descriptions.

Type	Description	Message	Image
A	Existing system	None	
B	Horizontal projected light (projected behind the school bus)	None (line)	
C	Road projection in front of the school bus	Temporarily Stop	 Text displayed: “Temporarily Stop” (translated from Korean)
D	Road projection behind the school bus	No Overtaking	 Text displayed: “No Overtaking” (translated from Korean)
E1	Variable message sign (VMS)	Child Protection Zone	 Text displayed on front and rear: “Children Getting On and Off” (translated from Korean).
E2	Variable message sign (VMS)	Children Getting On and Off	 Text displayed on front and rear: “Children Getting On and Off” (translated from Korean).

3.4.1. Experiments and Setups

Five experiments (T1–T5 in Table 3) were undertaken on the same day in July 2022, after sunset, in clear and dry conditions. All 29 drivers participated in the experiments. A van-style school bus (Hyundai Starex) which conforms to the current specifications for lighting systems was used in the experiments. There were no children or other passengers involved in these experiments.

Table 3. Experiments set-ups and conditions.

No.	Lighting Type	Approach from	Illuminance	Date	Conditions
T1	A (Existing)	Rear	N/A	July 2022	Dry
T2	A (Existing)	Front	N/A	July 2022	Dry
T3	B (Horizontal light)	Rear	200 lx	July 2022	Dry
T4	D (Road projection)	Rear	800 lx	July 2022	Dry
T5	C (Road projection)	Front	800 lx	July 2022	Dry

The participants approached the school bus from the rear in the first experiment (T1) and from the front in the second experiment (T2) and their behaviors were recorded. In each case, the red lights on the school bus were flashing. The third, fourth, and fifth experiments (T3, T4, and T5) were undertaken under the enhanced lighting systems. In the third experiment (T3, horizontal projected light) and the fourth experiment (T4, road projection: “No Overtaking”), participants approached the school bus from the rear. In the fifth experiment (T5, road projection: “Temporarily Stop”), participants approached the school bus from the front. Figure 4 shows the on-road experimental setup.

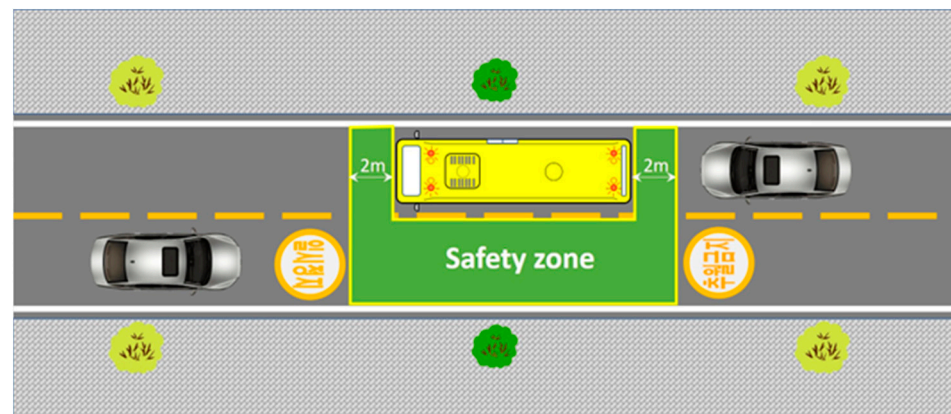


Figure 4. On-road experimental setup. Projected text on left side: “Temporarily Stop” (translated from Korean). Projected text on right side: “No Overtaking” (translated from Korean).

VMS was not tested in driving experiments, as it would be impractical to purchase, program, install, and operate them in this exploratory study. Finally, the results of the experiment were analyzed using a logistic regression model.

3.4.2. Pre-and-Post-Questionnaire

Survey forms were distributed to participants using an emailed link to a Google Form survey. Consent for participating in the study and for providing personal information was obtained in the first part of the questionnaire. Participants were advised that their responses in all cases were anonymous and that they did not need to participate if they did not want to.

Three sections were designed for the questionnaire: (1) demographics and basic information, (2) a test of knowledge, and (3) a post-experiment opinion survey. The knowledge test included eight questions with accompanying images and descriptions with multiple-choice answers, for example:

[...] On a two-way road with one lane in each direction, a school bus is stopped with its lights flashing indicating that children are being loaded or unloaded. You are approaching the school bus from the opposite lane. How should you proceed?

4. Results

In this section, we present the results of the survey and experiment including pre- and post-questionnaires.

4.1. Experiments

Firstly, respondents' understanding of average awareness of the existing school bus lighting systems was tested. The results were from both the survey (237 respondents) and experimental group (29 participants). The respondents were asked the same questions about what the flashing amber and red lights on school buses are supposed to indicate, and Figure 5 (below) shows the results. Participants in the experimental group showed a lower understanding of the meaning of the amber lights compared to the survey. However, for the meaning of the red lights, both the larger sample and experimental groups had a similar understanding. These results confirm our hypothesis that a significant (approximately 40%) portion of drivers in Korea do not have a good understanding of what the existing lighting systems mean.

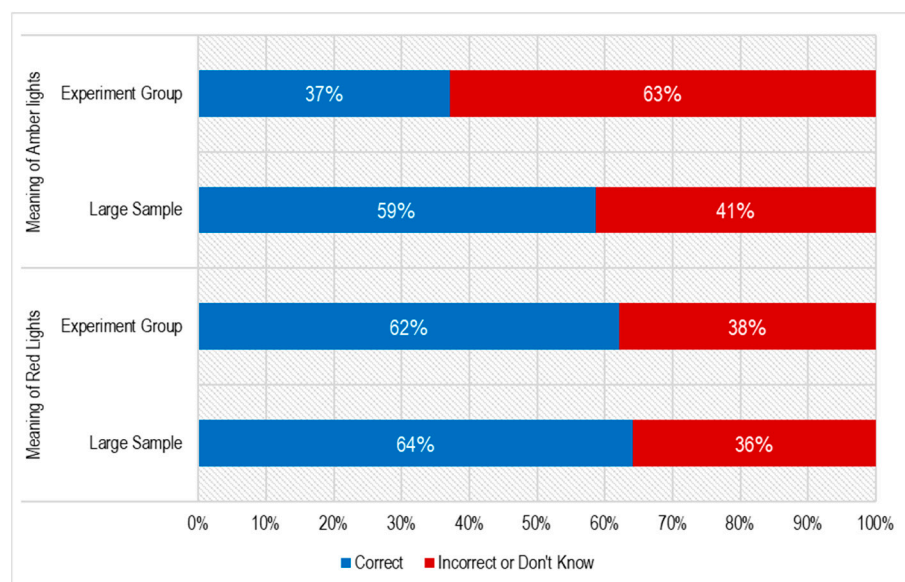


Figure 5. Understanding of lighting systems.

In the experimental group pre-experimental questionnaire, a test of knowledge revealed a barely acceptable majority of responses being correct, with an overall result of just 53% of correct responses and 47% incorrect. Considering the importance of this driving situation, we revealed a lack of understanding of both the functions of the lights and the actual law when it comes to school buses in Korea.

4.2. Survey

As described above, for each concept we evaluated them based on respondents' (1) behavior, (2) perceived understanding, and (3) actual understanding.

4.2.1. Behavior

The results show that the projected "No Overtaking" concept was the most effective in changing behavior since 77% of respondents indicated that they would stop in this case, followed by the horizontal light projection (69%), and projected "Temporarily Stop" (65%).

Other concepts were less effective than the existing red lights, including the VMS options, refer to Table 4.

Table 4. Results of Survey 2, Behavior.

	Type	Temporarily Stop before Proceed Carefully	Drive (Overtake) Cautiously	Drive (Overtake) as Usual
C	Projected “No Overtaking”	77%	21%	2%
B	Horizontal Light Projected	69%	27%	4%
D	Projected “Temporarily Stop”	65%	30%	5%
A	Existing Red Flashing Lights	63%	32%	5%
E2	“Children Getting on and Off” on VMS	62%	32%	6%
C	Projected “No Overtaking” (non-adjacent multi-lane) *	40%	6%	34%
A	Existing Yellow Lights **	38%	57%	5%
E2	“Child Protection Zone” on VMS **	0%	84%	16%

* In the case of multi-lanes, non-adjacent lanes to the bus are not required to stop, which is why in this case most respondents chose to “Drive (overtake) as usual”. ** The existing “Child Protection Zone” language and yellow lights do not mean that children are being loaded or unloaded, and therefore, many respondents rationally indicated they would not stop in these situations.

4.2.2. Perceived Understanding

Our results show that text-based lighting concepts, including VMS, score higher than non-textual-based communication. The last three well-understood lighting solutions were the existing red lights, a projected horizontal light, and the existing yellow lights all of which have no text-based component. Statistical tests demonstrate that VMS and road projections were more effective than the existing red lights, but the projected horizontal light was not, refer to (Table 5).

Table 5. Results of statistical *t*-test—compared to red lights.

	Type	Mean	Std. Dev.	<i>p</i> -Value	Hypothesis
A	Existing Red Lights	2.89	1.25	-	-
D	Projected “Temporarily Stop”	3.14	1.25	**	More effective, significant
C	Projected “No Overtaking”	3.29	1.27	***	More effective, significant
B	Projected Horizontal Light	2.82	1.29	n.s.	Not significant
E2	“Children Getting on and Off” on VMS	3.44	1.22	***	More effective, significant
E1	“Child Protection Zone” on VMS	3.24	1.15	***	More effective, significant

$p < 0.001$ ***, $p < 0.01$ **, n.s. = not significant.

4.2.3. Actual Understanding

Finally, we measured actual understanding by asking respondents what they believed the intended meaning of each lighting system was. We found that VMS was generally the most understood. Statistical tests show differences between the existing lights and the proposed advanced lighting solutions. Among all concepts, only the VMS had a statistically significant better understanding of the existing lighting concepts, with the projected horizontal light being even less understood, refer to Table 6 below.

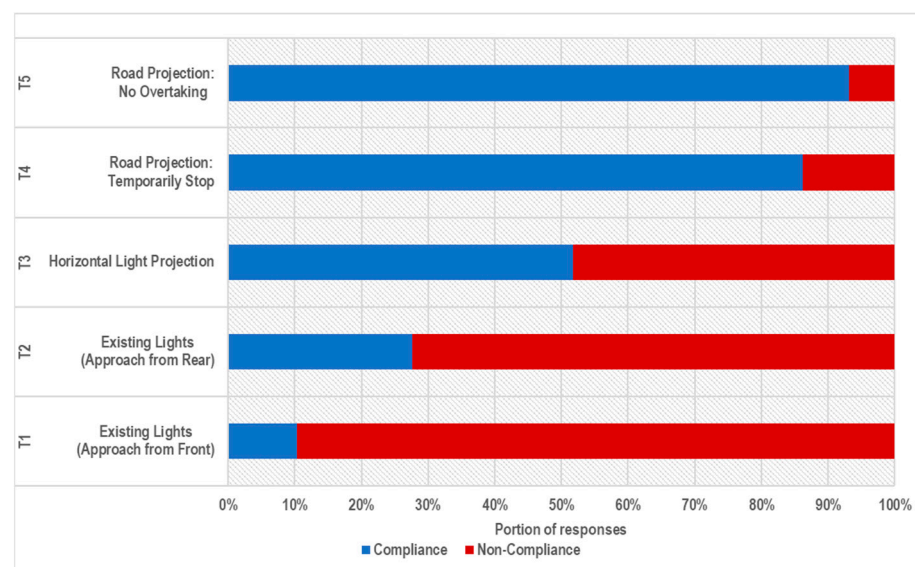
Table 6. Results of statistical *chi square*-test—compared to red lights.

	Type	Observed	Expected	<i>p</i> -Value	Hypothesis
A	Existing Lights (combined)	240	-	-	-
D	Projected “Temporarily Stop”	86	94	n.s.	Not significant
C	Projected “No Overtaking”	264	281	n.s.	Not significant
B	Projected Horizontal Light	61	94	***	Significant, lower understanding
E2	“Children Getting on and Off” on VMS	130	94	***	Significant, better understanding
E1	“Child Protection Zone” on VMS	135	94	***	Significant, better understanding

$p < 0.001$ ***, n.s. = not significant.

4.3. Experiments (and Post-Experiment Survey)

While in the survey, approximately 60% of respondents indicated they would stop for a school bus with its red lights flashing, the experimental results show that compliance was much lower than this, as just 29% of participants stopped when they approached from the rear of the school bus and just 10% of participants stopped when they approached the school bus in the opposite lane (from the front), refer to Figure 6 below.

**Figure 6.** Results of driving experiments (enhanced lighting systems and comparison to the results with existing lights).

After completing the circuit with enhanced lighting concepts in place three more times, compliance was improved considerably. While less than 30% of participants complied with the rule in the existing light settings, the rate of compliance increased to 52% in the case of the horizontal light projection, 86%, with a road projection indicating “Temporarily Stop”, and 93% with a road projection indicating “No Overtaking”. VMS was not tested in driving experiments.

Post-Experiment and Logistic Regression

After the experiments were complete, participants were asked through a questionnaire whether they thought the road projections they experienced were effective in increasing compliance with the rules. More than 80% of the participants agreed that the road projections were effective overall; however, less than 60% of the participants agreed that horizontal light projection was effective. On a 1–5 Likert scale, the average response for the statement “I agree that the lighting system was effective” was 3.69 (± 1.2) for the horizontal light projection, 4.48 (± 1.0) for a road projecting indicating “Temporarily Stop”, and 4.59 (± 1.0) for a road projection indicating “No Overtaking”. In casual post-interview interviews, several participants mentioned that they were unclear of the meaning of the

horizontal light projection and that the text-based solutions were clearer. Some participants also mentioned that they would have found the horizontal light projection to be more effective if it also included text instructions.

To understand whether the results were statistically significant, logistic regression analyses were undertaken. Four different binary logistic regression models were estimated to test if age, gender, driving experience, tested awareness of traffic laws and the enhanced lighting systems had effects on compliance with the law (i.e., stopping) Table 7 presents the results of the logistic regressions.

Table 7. Logistic regressions analysis results.

	M1/2–Type A		M3–Type B		M4–Type D		M5–Type C	
R ²	0.436		0.478		0.577		0.657	
	β	<i>p</i>	β	<i>p</i>	β	<i>p</i>	β	<i>p</i>
Intercept	−7.7585	*	−7.4969	***	−9.2065	**	−6.5485	*
Gender	−1.3919	n.s.	−	−	−	−	−	−
Age	0.3071	n.s.	−	−	−	−	−	−
Driving Experience	−2.0747	n.s.	−	−	−	−	−	−
Knowledge (Tested)	2.0392	*	1.0251	***	1.2627	**	0.6798	n.s.
Lighting System	N/A	−	2.1109	*	6.9302	**	6.6309	**

p < 0.001 ***, *p* < 0.01 **, *p* < 0.05 *, n.s. = not significant.

The model's goodness-of-fit was assessed using the coefficient of determination (R-squared), while the significance of individual predictor variables was evaluated by using *p*-values. The fitness of models was satisfactory in all cases, as R² values vary from 0.436 to 0.657.

We found that gender, age, and driving experience were not statistically significant in Model M1/2. However, tested knowledge (M1/2, M3, and M4) and the enhanced lighting system (M3, M4, and M5) were statistically significant. These results confirm our hypothesis that a lack of knowledge of the law could be one reason for non-compliance and that enhanced lighting systems could increase compliance. In addition, all models including lighting system parameters (M3, M4, and M5) seem to have the strongest impact on the compliance with law as their coefficients are the largest besides the intercepts.

5. Discussion

The results from the survey and the driving experiments show that Korean drivers have an insufficient understanding of both the traffic rules related to school buses and the function of the existing lighting systems. The ambiguity of the law could be what is causing people to interpret it in different ways and may be one of the reasons for a lack of knowledge and non-compliance. It is also unknown what enforcement, if any, is taken by police officers in Korea. Despite its potential flaws, the law does clearly state that drivers should temporarily stop and ensure safety before proceeding carefully, which is not always followed by the drivers. Approximately 63% of respondents in the survey indicated that they would temporarily stop before proceeding when exposed to the existing red lights, but in driving experiments, we found that only an abysmal 18% of drivers complied.

Our results from surveys and experiments using different types of advanced lighting systems showed that advanced lighting systems were effective in improving compliance with the traffic rules, and this change in drivers' behavior could contribute to the improvement of the safety of children while getting on and off the school buses, a critical point in the journey to school [1,2,4–6,66]. In our surveys, we have shown that additional messaging beyond the existing "Child Protection Zone" and flashing lights are needed to improve behavior and encourage drivers to follow the minimum requirements of the law (to stop before proceeding slowly), which could be as high as 77%. In experiments, when enhanced lighting systems were used, compliance increased to 53% (for horizontal light projection),

86% (for the textual road projection, approach from the front), and 93% (for the textual road projection, approach from the rear). Logistic regression models on the experimental results confirmed that the presence of all three enhanced lighting systems was a statistically significant factor in the increase in compliance with the traffic rules (i.e., stopping).

We found from the survey that a horizontal light bar, which would project a red light across the road without any additional information or text, was ineffective in increasing understanding of the lighting and was even less understood than the existing lights. However, the horizontal light was more effective than existing red lights in changing behavior (in both surveys and experiments). This may be due to drivers taking extra precautions in an unfamiliar situation, which has been shown to make drivers more cautious [67,68]. We also found that VMS was effective in increasing understanding, but not behavior; however, road experiments involving VMS were not available to confirm this from this study. However, when used in combination with a road projection, a VMS may prove to be useful in increasing understanding and could potentially function as an eHMI [32,35] for other uses as well.

While there is some debate as to whether text or iconographic symbols are more effective in road signage, some studies have found that icons or other unfamiliar shapes may take additional time and effort to understand, especially for a first-time experiment [69,70], and that text-based signs provide additional context and clarity [32,71,72]. On the other hand, icon-based signs are more visible from further distances and can therefore reduce reaction time as well as overcome potential language barriers [73–75]. Several participants also mentioned during the interview that had the horizontal light projection also included textual instructions, they would have found it to be more effective. For these reasons, it appears that text-based solutions would be the most effective.

Lighting systems are only one part of systems that can be used to make roads safer, especially for children. If there truly is a desire to reduce accidents related to school buses, then other important considerations should also be pursued including improving the law, driving culture, awareness campaigns, enforcement, road designs, and vehicle safety. Lighting systems could be considered as the “last defense” of road safety for school buses, and if there was a robust culture of safety and awareness, then advanced lighting systems may not even be required. Compliance with existing law is incredibly low and this is dangerous for children—this issue must be addressed by all sides for any real improvement to be made.

6. Conclusions

In this study, we surveyed 237 participants and conducted field experiments with 29 participants which included pre- and post-experiment surveys and interviews. Participants in surveys and experiments were exposed to scenarios in which a school bus was parked on a road with its lights flashing, indicating that children may be being loaded or unloaded. In addition to the existing lights, several other advanced lighting scenarios were included using various road projections and VMS. Survey results from both groups (experiment participants and large sample) support our hypothesis that Korean drivers do not have a good understanding of the law and lighting systems for school buses, and the results from model estimations confirm that a higher tested score is correlated to an increased compliance in actual driving scenarios.

In surveys and driving experiments, we found that compliance with legal requirements (i.e., stopping) when using the existing lighting system was very low. Subsequently, we found that VMS and three types of road projection were effective in increasing compliance with the law. However, our results have shown that road projections that consist of only a horizontal projection light, without further context or information, would not be effective in increasing understanding of the correct behavior of the law around school buses. Therefore, we conclude that any type of modified messaging for stopped school buses should include explicit textual instructions to other road users. We posit that a road projection system displaying text to drivers could be effective in ensuring compliance with

the law and reducing school-bus-related pedestrian accidents during nighttime hours, or when ambient luminance is low allowing for the detection of the light on the roadway. While our survey also found VMS to be effective at increasing understanding, it did not translate into increased compliance—this has not been confirmed with driving experiments.

The results of this exploratory study give strong evidence that new lighting concepts for school buses could be contemplated in the Korean context, as well as in other jurisdictions experiencing difficulties with non-compliance around school buses. Road projects especially hold much promise for night driving applications while VMS could be used for situations where additional context and information is warranted, with the advantage of being visible during daylight hours.

In Korea and in potentially other countries as well, the current regulations are not enough to entice drivers to stop properly. A multi-faceted approach to tackle this problem is necessary, including simplification and enforcement of the existing laws, education for drivers and children, and enhanced technologies for lighting systems. Based on the positive results of this study, governments could consider mandating these types of lighting systems and developing regulations for them.

Before this is possible, future research should also (1) consider how such projection systems can be safely mounted on vehicles; (2) develop technical specification including projection angles, power requirements, projection distances, VMS size specifications, etc.; (3) determine the distraction potential of these systems; and (4) confirm what combination of textual projection or VMS should be used. Projection systems and novel applications of VMS are emerging automotive lighting systems that have the potential to significantly improve the driving experience for many on-road situations, but at the same time, since they are emerging, there are many questions remaining that must be solved before they can be implemented safely.

Limitations of This Study and Areas for Future Study

For experiments, this study had a relatively small sample of just 29 drivers, and most were male (although this likely parallels the actual makeup of drivers in Korea). Experiments were performed under the same circumstances with the same lighting and weather conditions on the same day; therefore, it is not clear whether different lighting and weather conditions would make a difference to our results. As found in a previous study [23], weather conditions (especially wet road surfaces) could make a difference in visibility. Participants joined the experiments voluntarily, but they were aware their behaviors were observed, and the data were collected. Therefore, they may drive differently than they normally would, although participants were instructed to drive as they normally would.

While we found that text-based projections were most effective, we did not consider a combination of text and iconography, for example, a projection of the horizontal light projection with text displayed on or next to it. Future studies of road projections for school buses, or for other instructive situations, should test text and iconography together. The behavior of other road users, namely motorcycle drivers, should also be tested and observed.

Note that any road projection system would only be effective in conditions where the ambient luminance is low (i.e., at night time) as suggested in previous research [29,30] as it is difficult for the system to detect the projections in a bright environment. Other types of signage or lighting may be explored to improve safety and compliance with the traffic rules during the daytime.

Finally, these experiments used light lamps which were installed in the roadside equipment, rather than installed on the vehicle, for practical reasons. Due to current regulations, in order to be used in the market, the lamps would need to be made smaller and safely attached to the vehicles, and able to project to the front and rear of the vehicle at various angles. It is not clear yet whether the lamps installed on the vehicles are practical or even possible, especially in the case of text-based road projections, which project light into the opposite lane. Under real driving conditions, the projection may be difficult to

achieve. The horizontal light beam (or indeed any projection out the rear of the vehicle) may be the most practical.

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