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Auditory Alert for In-Vehicle Safety Technologies: A Review

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Abstract – *Safety technology has evolved rapidly in the past few years to become much more driver-aware and automatic. Many of these technologies build upon one another in a good, better, best pattern to provide the safest possible driving experience. It is expected that this system can eliminate or mitigate road accidents due to reckless and careless driving. However, safety or driver-assistance features are no substitute for the driver's responsibility to operate safely. A survey revealed that the warning alarms were turned off by 70% of drivers due to annoying audio characteristics. It is vital to consider frustration linked to an alarm, where it can affect the driver's behavior. It is recommended to identify optimum chime sound characteristics for the driver's alert and respond appropriately to improve the effectiveness of the auditory signal. In this paper, a review on the identification of the type of warning modality, frequency setting, and warning priority for vehicle safety features technology from the selected vehicle manufacturers are explained.*

Keywords: Vehicle safety, chimes related technology, auditory alert, perception, awareness

1.0 INTRODUCTION

The standard new vehicle manufacturer provides warning systems that alert drivers to possible circumstances of accidents. Advance automotive technology offers various sensors and cameras for vehicle identification and other obstacles. When an obstacle is detected, collision's probability exceeds a certain safety level; a warning shall be issued. Auditory alarms send notifications to ensure drivers receive the notice. The ability of drivers to respond accurately and effectively to time-critical messages mainly depends primarily on how quickly they perceive the message's context. This intervention has the potential for successfully rising both the frequency and the rate of incidence. Travel assistances that offer drivers voice guidance and infotainment systems work well at all the critical tasks and have several additional features to make road travel more comfortable and convenient.

The previous study found that frequent false alarms and the variance between an alert's perceived urgency and the actual urgency of a situation where two factors influencing warning effectiveness (Meredith & Edworthy, 1995, Edworthy et al., 2000). The perceived urgency may also affect the duration of the alert response. An effective auditory alert system should be visible; drivers should be aware of it, perceive urgency and provide drivers with the correct information. In general, there is a relationship between perceived urgency and annoyance, such that as a signal becomes more urgent, it is also perceived as more annoying (Marshall et al., 2007, Baldwin, 2011). The context in which the signal is interpreted, however, affects this relationship. (Wiese & Lee, 2004).

Related to circumstances where high urgency seems appropriate compared to situations where it is less relevant to receive a very urgent signal, more urgent signals are viewed as less distracting. (Marshall et al., 2007). Some research shows that the parameters of auditory alarms lead to various degrees of urgency. (Hellier et al., 1993, 1995; Haas & Edworthy, 1996). The results also suggest that drivers can also appear to irritate and likely disregard warning acceptance. The physical design, emotional, innovation (Kryter, 1985), and acoustic characteristics of the alarms are involved in the warning systems' annoyance. A survey revealed that 70% of drivers were switched off the warning warnings due to annoying audio characteristics (Block et al., 1999).

Characteristics of the sound acoustic systematically influence annoyance, but little research has addressed annoyance associated with alerts in the driving domain. Therefore, it is crucial to consider irritation linked with an alert to influence the driver's behavior. Table 1 shows previous systematic studies on acoustic sounds for vehicle safety.

Table 1: Systematic studies on auditory sounds for vehicle safety

Title/ Author	System	Method	Sound		Major Finding	Critical Review
			Loudness	Frequency		
The Effectiveness of Auditory Forward Collision Warning System (Wu *et al.*, 2018)	Collision Warning System	MiniSim driving simulators	Alert: 75 dB Ambient noise: <60 dB or 15 dB above maximum ambient noise levels	Fundamental frequency: 150-680Hz	• Providing warning alerts reduced the crash rate by up to 50% • Alert with a high level of fundamental frequency setting had the highest collision rate • Alert with high urgency of duty cycle gives the lowest collision rate	• This research focuses on how characteristics of different auditory alerts affect driver avoidance behavior as well as avoidance success when the driver is distracted • The visual alert system was not included

Psychophysical evaluation of auditory signals in passenger vehicles (Chi *et al.*, 2016).	Door opening warning, parking sensor	N/A	48 -71 dB(A)	500 – 1000 Hz	• For door open warning, the most preferred is that intermittent sounds with a fading intensity waveform and a dominant frequency between 500 and 1000 Hz • For parking sensor, the most preferred is a sound with the dominant fundamental frequency between 500 and 2000 Hz	• To study the suitable sound for vehicle warning signal to gain further insight into human sound preference
Auditory Interfaces in Automated Driving: An International Survey (Bazilinskyy & Winter, 2015)	Parking Assistant (PA) Forward Collision Warning System (FCWS) Futuristic Augmented Sound System (FS)	N/A	N/A	N/A	• Existing auditory displays (PA and FCWS) received a favorable rating from respondents, but FS was perceived as annoying because of lack of experience with the system • Younger participants saw PA and FCWS as annoying but perceived FS as less annoying and helpful • The most preferred way to support transition control is auditory instruction performed by the female voice	• The study conduct survey to investigates human opinion on existing auditory displays and preferred feedback types – the quality of the system study based on helpfulness and annoyance • The survey was conducted without a visual aid in addition to auditory feedback, vehicle type limited for automated vehicle
Auditory Alerts in Vehicles: Effects of Alert Characteristics and Ambient Noise Conditions on Perceived Meaning and Detectability	Auditory Alerts in Vehicles	Realtime Technologies desktop driving simulator	65dBA, 75dBA, 78dBA, 84dBA	Base frequency: 300Hz, ≥1000Hz, >1500Hz	• Driver perception of the auditory signals was influenced by both the nature of the signal and the ambient noise background • Many sounds that were easily detected and perceived as urgent in a relatively quiet vehicle interior were much less likely to be detected or perceived as urgent in a louder vehicle interior (e.g. with windows open)	• Two complementary studies were conducted based on a critical parameter that perceived urgency of the listeners and the effect of ambient noise on auditory signal detection and perception
In-Car Sound Analysis and Driving Speed Estimation Using Sounds with Different Frequencies as Cues	In-car sound analysis	Virtools Dev3.0 simulation software	N/A	100 Hz, 200 Hz, 400 Hz, 800 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 8000 Hz, and 16,000 Hz	• Drivers can better decide how much risk they want to take with better speed knowledge • Drivers estimated their speed best when the driving speed was 90km/h • Overestimated when driving slowly and overestimated when driving above 100km/h	• This study attempted to explore human speed perception through in-car sound and find useful sound elements by separating sounds into different frequencies

Looming Sounds Enhance Orientation Sensitivity for Visual Stimuli on the Same Side as Such Sounds	N/A	Gabor patches composed on difference orientation	Looming sound: 55-75 dB SPL Receding sound: 75-55 dB SPL Static sound: 65 dB SPL	N/A	• Looming sounds can influence and facilitate visual processing by rapidly increasing the excitability of the visual cortex • Compared to receding and static sounds, looming organized sounds are effective, even though no visual is provided.	• The study show relation on how auditory stimulation can affect visual processing, and human responsiveness towards looming, receding, and static sounds
Distracting Effects of Auditory Warnings on Experienced Drivers (Fagerlönn, 2010)	In-Vehicle Information Systems	VTI Driving Simulator III	Warning sounds: 80 dB(A) and 85 dB(A) Background noise: 64 dB(A)	Low urgency warning: G3 High urgency warning: Cluster of tones B4, C5, D5, C6, B6	• Drivers rated urgent signals as significantly more annoying and startling – causing them to brake harder. • Professional truck drivers with more experienced rated high urgency warnings as less annoying and less affected by the urgent sound	• The study investigates how urgent auditory warning signal impact experienced truck drivers' affective state and their response to unpredictable events.
Acceptability and Potential Effectiveness of Enhanced Seat Belt Reminder System Features (Lerner et al., 2007)	Enhanced Seat Belt Reminder System	Visual displays installed on dashboard with text and icon	Main speaker with normal volume (driver side): 78± dBA Seat belt retractor speaker – loud volume: 90±	Slow beep: 1 Hz, Fast beep: 3Hz Slow chime: 0.83 Hz, Fast chime: 2.5 Hz Practice sound: 1.2 Hz	• Participants least likely to wear seat belts tended to find reminder displays relatively more annoying and relatively less effective in eliciting seat belt use • Visual displays and auditory (speech and sounds) displays are more effective than the visual display alone	• The study focuses on the investigation on acceptability/ annoyance level of reminder system, potential effectiveness, and attention-getting ability of seat belt reminder to induced respondent to buckle up
Alerts for In-Vehicle Information Systems: Annoyance, Urgency, and Appropriateness (Marshall et al., 2007)	In- Vehicle Information System (collision avoidance, navigation & e-mail)	N/A	Experiments 1 & 2: 64DbA Experiment 3: 68dBA	Experiment 1 & 3: fundamental frequency = 150Hz; Experiment 2: Prominent frequency = 2500Hz	• Intensity, sharpness, and harmonic ratio had a strong effect on annoyance, similar to the impact of onset, offset, and harmonic series • Perceived urgency and annoyance depend on both the auditory characteristics of the alert and the context	• Participants did not perform any driving activity • Participants only imagined how the system might interact with their driving

The Effectiveness of Enhanced Seat Belt Reminder Systems (Freedman et al., 2007)	Enhanced Seat Belt Reminder (ESBR) System	ESBR icon & text	N/A	N/A	• The presence of ESBR systems would increase driver seat belt use by an estimated 3.2 percentage points, and passenger seat belt use by 3 percentage points	• The objective of this study was to determine the effect of ESBRs in non-commercial passenger cars, pickups, SUVs, and passenger vans on seat belt use rates relative to the same vehicles without ESBRs
Auditory Alerts for In-Vehicle Information Systems: The Effects of Temporal Conflict and Sound Parameters on Driver Attitudes and Performance (Wiese & Lee, 2007)	Car auditory warnings alert	Vection Research Simulator (VRS)	Ambient sound: 54dBA	N/A	• Concurrent performance of two tasks often leads to poorer performance of one or both tasks, depending on each task's levels and types of requirements and their priorities • Highly urgent sounds tended to speed drivers' accelerator release, but the annoyance associated with highly urgent sounds increased workload	• The study focuses on conflicted sound from auditory car warnings alert and In-vehicle information system received to driver

Based on these findings, it can be inferred that automotive safety technology has increasingly advanced to become even more driver-aware and automatic in the past few years. In an excellent great, best model, all of these innovations build on each other to provide the safest driving environment possible. The simplest (good) technology provides audible alerts and the advanced high-end (best) technologies available in upper models incorporate sensors and software in some circumstances to monitor, navigate, and drive/stop the vehicle. As a result of reckless and careless driving, this device is intended to eliminate or mitigate road accidents. However, safety or driver-assistance features are no substitute for the driver's responsibility to safely operate the vehicle. The driver should remain attentive to traffic, surroundings, and road conditions at all times. Therefore, this study aims to establish a chime sound database for vehicle safety features for the Malaysian car that could help assess the driver's awareness and perception of possible hazards on different audible vehicle alerts and work in harmony with other vehicle sounds. The sound characteristics must be defined and tabulated, including the type of warning modality, the frequency setting, and the selected vehicle manufacturer's warning priority.

2.0 METHODOLOGY

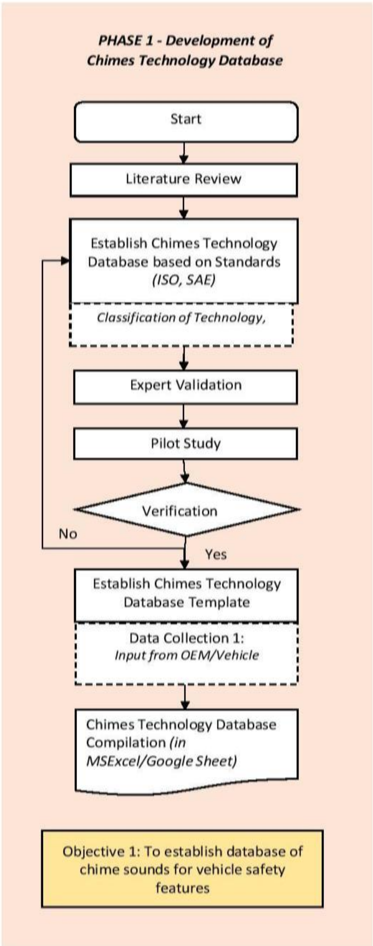

Figure 1: Methodology flowchart

The development of the chimes technology database starts with a literature review on existing vehicle safety technologies that provide audio alerts with the International Organization for Standardization (ISO, 2011) and Society of Automotive Engineering (SAE) standards for each technology (SAE, 2015; 2020). Next, market survey analysis is conducted based on the Malaysian Automotive Association (MAA, 2013; 2019). Five highest-rank vehicle brands were selected to be added to the database table. The vehicle models were classified based on the compact, family, multi-purpose vehicle (MPV), and sport utility vehicle (SUV). Once the chimes technology database template is ready, it will be distributed to the Original Equipment Manufacturer (OEM)/Vehicle Manufacturer for data collection. Methodology for Phase 1: Development of Chimes Technology Database as illustrated in Figure 1.

2.1 In-vehicle Safety Technology

Advance progress in technology and information of the vehicle safety system has opened up new possibilities that help mitigate traffic accidents and increase driver's alert on the surrounding. Vehicle manufacturers were also paying more effort and attention to designing a new vehicle equipped with a high level of vehicle safety features (Moravčík & Jaśkiewicz, 2018). There is a range of automotive safety technology available on the market, but they are referred to in different ways by each vehicle manufacturer. Vehicle safety technology can communicate with the driver through other modalities – visual, auditory, haptic alert, and combination of visual and auditory are more effective and provide better surrounding awareness to the driver compare to visual modality alone (Lerner et al., 2007; Liu & Jhuang, 2012; Sabic & Chen, 2017; Wang et al., 2019). For this study, the technologies are selected based on the availability of auditory alert modality in any Advanced Driver Assistance System (ADAS) and other Intelligent Transport System (ITS). Based on the European Automobile Manufacturers' Association (ACEA) Code of Practice for ADAS development, the driver behind the wheel's primary driving task is maneuvering/guiding, and secondary tasks are stabilisation and navigation. The ADAS features are designed to support the driver with the primary task and assist with at least one secondary task (ACEA, 2009).

Vehicle safety technologies are categorized into two basic categories – active and passive safety systems. The passive safety feature is a system that protects vehicle occupants and does not do anything unless it is called to action during the time of impact (Goernig, 2007; Page et al., 2009). This passive safety feature such as seat belts, airbags, and vehicle deformation zone becomes active only during an accident. It helps reduce the risk of injury and mitigate the crash's impact (ACEA, 2019). The active safety feature is defined as a safety system that will continuously monitor vehicle performance and surroundings. At the same time, actively assist the drivers during the pre-impact of the crash and mitigate any potential danger (Liu et al., 2008, ACEA, 2019). The feature of active safety system will help the drivers in four stages, which are: (i) the perception enhancement system that increases the perception of drivers using sensors, (ii) driving warning system that monitors and detect potential hazard, (iii) assistant driving starts functioning when the driver does not respond to the warning system given, and (iv) the autonomous driving system which takes over the driving without human interference.

On the other note, National Highway Traffic Safety Administration (NHTSA) classify Driver's Assistance Technologies into four categories: (i) brake and collision avoidance, (ii) backup and parking assist, (iii) lane and side assist, and (iv) maintaining safe distance (NHTSA, 2018). Moravčík & Jaśkiewicz (2016) in their study has differentiated the intelligent vehicle safety technologies based on its application over time of impact: (i) system provides continuous support to the driver's activity, (ii) system that active at the moment of impact, and (iii) system that active after the crash impact. Given that there is a different category of vehicle safety technology, hence for better understanding and avoiding confusion, in this study, 17 vehicle safety technologies with auditory alert are selected and categorized into five sections as illustrated in Table 2.

Table 2: Classification of vehicle safety technology (with auditory alert)

Category	Vehicle Safety Technology (with Auditory Alert)
Collision Warning	Reverse Collision Warning, Forward/Pre-Collision Warning, Pedestrian Detection Warning, Lane Departure Warning (LDW), Lane Change Decision Aid System (LCDAS)/Blind Spot Monitoring (BSM), Rear Cross Traffic Alert (RCTA)/Cross Traffic Monitor
Collision Intervention (Braking)	Pre-collision Braking, Collision Mitigation Brake System (CMBS)/Autonomous Emergency Braking (AEB)
Parking Assistance	Parking Assistance System/Parking Sensor System
Driving Control Assistance	Adaptive Cruise Control (ACC)/Front Departure Alert (FDA), Lane Keeping Assistance System (LKAS)/ Lane Tracing Assist (LTA)
Other Safety Reminder Technology	Seat Belt Reminder (SBR), Door Ajar/Door Left Open Warning System, Child Presence Detection (CPD), Master Warning System, Pedal Misoperation Control, Tyre Pressure Warning System

For this study, the selected technologies are categorized based on their application in assisting drivers' primary and secondary tasks while driving – collision warning, collision intervention, driving control assistance, parking assistance, and other safety reminder technology (SAE, 2015; NHTSA, 2018; SAE, 2020). The collision warning technologies included systems that will notify and alert the driver when it detects potential collision or objects closed to the vehicle (front, side or rear-end) and given a warning when the driver was unintentionally drifting out of their lane. The collision intervention technologies feature a system that autonomously accelerates or applies the brake if the collision is imminent. The driver control assistance technologies help the driver maintain a safe distance between vehicles, particularly during traffic jams, and keeping the vehicle centered on its lane. The parking assistance features technology equipped with a sensor and camera to guide the driver during a parking maneuver. Apart from ADAS technology, other safety reminder technology will continuously give visual and audible warnings until the driver takes corrective actions.

2.2 Vehicle Market Survey in Malaysia

Market survey analysis is conducted based on the vehicle sales data provided by the Malaysian Automotive Association (MAA, 2013; MAA, 2019) to get an overview of the top five vehicle brand ranking in Malaysia and total vehicle sales in Malaysia. Besides, the purpose of this market survey analysis is to identify the potential Original Equipment Manufacturer (OEM)/Vehicle Manufacturer for data collection of chimes-related technology. Based on MAA Market Review and Outlook 2013 to 2019, the vehicle data sales were analyzed. Perodua conquered the highest sale units of the Malaysia market vehicle, followed by Proton, Honda, Toyota, and Nissan (MAA, 2013; MAA, 2019).

3.0 DATA COLLECTION

3.1 In-vehicle Chimes Related Technology Database Template

This paper presented the development of a database template for in-vehicle chimes-related technologies that are available in Malaysian cars. A database template has been developed using MS Excel and distributed to the selected OEM/Vehicle Manufacturer to gather the information data about these technologies. The OEMs are required to fill in the template with in-vehicle safety technology (with audible alert) available in their vehicle model, provided with warning modality, an audio file, and related manuals.

3.2 In-vehicle Chimes Related Technology According to Vehicle Specifications

Automakers across the world have introduced a new refreshed model each year to upgrades the physical aesthetic design or improved engine performance but to revamp several of their models by featuring advanced safety technology to comply with stricter standard regulatory reforms (Sharma, 2017). This has accelerated automaker’s effort to provide users with safer vehicles equipped with safety features that will prevent or mitigate crashes. Each OEM has different trade names for their in-vehicle safety technology, noting that not all vehicle models or variants for Malaysia’s market are equipped with auditory alerts. The numbers of advanced safety technology included in each model are based on three variants to match with the customer’s budget – full, medium, and low specifications. The full specification model features all electronic driving aids and advanced safety technology. However lowest specification model features only essentials technology. Several studies have highlighted that vehicle with Advanced Driver Assistance System (ADAS) and other Intelligent Transport System (ITS) shows reduction in crash rates compare to the vehicle without the technology (Cafiso & Di Graziano, 2012; Eckert et al., 2013; Khan et. al., 2019; IIHS, 2019). Besides, auditory alerts are the most suitable method to gain a driver’s attention, particularly during an emergency, and where possible, the combination of visual and auditory modality may increase the effectiveness of the in-vehicle safety technology (Stevens et al., 2002).

A desktop study has been conducted to study the availability of vehicle safety technology (with audible alert) included in Malaysian vehicles according to four categories – compact, family/sedan, sport utility vehicle (SUV), and multi-purpose vehicle (MPV). The information is collected from the website, vehicle brochure, manuals, and videos provided by the OEM/Vehicle Manufacturer. From the comparison of in-vehicle chimes related technology according to vehicle specification variants, the availability of in-vehicle chimes related technology in each vehicle model is varied according to the category of car and its specification. Full specification vehicles are equipped with more than two chimes-related technology of collision warning, collision intervention, driver control assistance, parking assistance, and other safety reminder technology. Meanwhile, medium specifications vehicles are equipped with at least two chimes-related technologies from collision warning, collision intervention, parking assistance, and other safety reminder technology.

As for low specification vehicles, the models are included with at least two chimes-related technologies such as Reverse Collision Warning, Seat Belt Reminder, and Master Warning System. Some low-specs models only feature safety technology with a single modality (visual/audio) however accidents don't differentiate between variants. Hence, here's a call for stricter standard regulatory reforms to include more chimes-related technology even in low specification variant vehicles.

3.3 Auditory Alert Characteristic

The presence of auditory alert as part of in-vehicle safety technology offers human-machine interface guidance to convey information and gain the driver's attention during maneuvering the vehicle. Frequency setting, sound pressure level/loudness, and urgency/priority level are important characteristics that play a significant role in ensuring the auditory alert's perceivable and differentiate urgency/priority of the sound (Nees & Walker, 2011; Campbell et. al, 2016). When designing an auditory interface, the primary concern is to create an alert that matches the signal's urgency with the real situation and minimizes the annoyance associated with the alert not to distract the driver.

According to Guideline for Safety of In-Vehicle Information Systems and Human Factors Design Guidance for Driver-Vehicle Interfaces, recommended auditory sound pressure level range under all driving conditions are between 50 to 90db(A), with the ideal minimum acoustic signal is 75dB(A) (Stevens et al., 2002; Campbell et al., 2016). In addition to that, based on ISO 15006:2011, recommended in practice for auditory frequency range should be within 500 to 2500Hz. At least two the dominant frequency of an auditory alert should be within 500 to 1500Hz (International Organization for Standardization, 2011). These frequency ranges fall within the human hearing range that is most sensitive and most likely to be detected. Any auditory alert with a volume higher than 90db(A) and frequency above 3000Hz should be avoided as it may startle or cause annoyance to the drivers (Stevens et al., 2002; Campbell et al., 2016). The auditory warning should be 15dB(A) louder than ambient noise to improve the detectability of the sound in order to prevent competing signals with other sounds inside the vehicle, such as radio, voice, or external noise (Nees & Walker, 2011).

An alert's urgency/priority level is described based on the sequence of crash events from normal driving to emerging/critical situations to crash unavoidable (UNECE, 2011). These warning stages have different countermeasures to avoid potential crashes depending on how the driver perceives the auditory alert. Warning priority is divided into three levels – (i) low-level warning: action within 10s to 120s; (ii) mid-level warning: action within 2s to 10s; and

(iii) high-level warning: action within 0s to 2s (UNECE, 2011). Several studies and guidelines (UNECE, 2011; Campbell et al., 2016; Marshall et al. 2018) suggested that auditory alerts with higher fundamental frequency, higher sound intensity, and shorter intermittent periods are perceived as more urgent.

Table 3: Database of in-vehicle chimes related technology

			Vehicle Brand				
			OEM-01	OEM-02	OEM-03	OEM-04	OEM-05
In-Vehicle Chimes Related Technology	Collision Warning	Reverse Collision Warning (RCW)	Visual	Visual	800	2000	2400
		Forward/Pre-collision Warning	1000	1300	800	2000	2000
		Pedestrian Detection Warning (PDW)	NA	800	800	2000	Visual & Audio
		Lane Departure Warning (LDW)	650	Visual & Haptic	NA	1600	1000
		Lane Change Decision Aid Systems (LCDAS)/ Blind Spot Monitoring (BSM)	650	Visual	NA	Visual	Visual & Audio
		Rear Cross Traffic Alert (RCTA)	NA	Visual	NA	2400	1000 3000
	Collision Intervention	Pre-collision Braking	NA	NA	800	2000	2400
		Autonomous Emergency Braking (AEB)/ Collision Mitigation Braking System (CMBS)	Visual	1300	800	2000	NA
	Driver Control Assistance	Lane Keeping Assistance System (LKAS)/ Lane Tracing Assist (LTA)	Visual	1300	NA	1600	Visual
		Adaptive Cruise Control (ACC)/ Front Departure Alert (FDA)	Visual	Visual	1600	800	Visual & Audio
	Parking Assistance	Parking Assistance System	1500	Visual	Visual	Visual	Visual
	Other Safety Reminder Technology	Seat Belt Reminder	650 2400	500 800	800 3200	600 800	Visual & Audio
		Door Ajar/Door Left Open Alarm	650	Visual	800	800	Visual
		Child Presence Detection (CPD)	NA	NA	NA	NA	NA
		Master Warning System	Visual	500 1000	Visual	Visual	NA
		Pedal Misoperation Control	NA	NA	800 3200	2000	Visual
		Tyre Pressure Warning System	Visual	Visual	Visual	800	Visual

Legend:

Audio Warning Priority (Hz)

300-500	Notification
501-800	Low
801-1200	Medium
1201-3000	High

Table 3 displays a database of in-vehicle chimes related technology collected from five OEMs. Nevertheless, not all OEM/Vehicle Manufacturer participated in this study share technical specifications and auditory alert samples for available technology in their vehicle due to company policy. The data gathered in Table 3 is the combination of data received from the database template given to the OEMs and through the desktop study conducted, as explained in the previous section. Based on OEMs' database template, all five OEMs equipped their vehicle models with Seat Belt Reminder (SBR) and Pre-Collision Warning technologies.

However, based on a desktop study, not all vehicle models are provided with a visual modality such as an icon on the dashboard or camera, especially for the lowest specification models. From 17 in-vehicle safety technology selected in this study, only Child Presence Detection technology is not available in all vehicles manufactured by the OEMs.

On the other hand, some OEMs have developed their vehicle safety technologies to complement other technologies and use the same audio warning and frequency settings to alert the driver and automated braking to prevent collisions. For example, Collision Mitigation Braking System (CMBS) for OEM-03 and OEM-04 use the same audio alert and its frequency setting with Reverse Collision Warning (RCW), Forward/Pre-Collison Warning, Pedestrian Collision Warning (PDW), and Pre-Collision Braking. Meanwhile, only the Master Warning System for OEM-02 and Tyre Pressure Warning System for OEM-04 has both visual and auditory alerts, while the other OEMs only feature icon on the vehicle dashboard.

The frequency level is extracted based on at least two dominants frequencies recommended in ISO 15006 (ISO, 2011) by using the Phyton Software. This is to provide an initial examination for the frequency setting of the auditory alert sample collected from OEM to be mapped accordingly with warning priority stages. Table 3 demonstrated that different OEMs have different frequency settings for their in-vehicle chimes-related technology. They differed in frequency setting between each OEM can be due to surrounding ambient conditions, type of vehicle model use, and tool used to record the auditory alert. Some of the samples received from OEMs have background noise.

From the investigation, OEM-04 uses auditory alert with high-frequency warning priority ranging between 1600-2400Hz for most of the in-vehicle safety technologies equipped in their vehicle model except for Adaptive Cruise Control (ACC), Seat Belt Reminder (SBR), and Door Ajar/Door Left Open Alarm. The high-frequency range used by OEM-04 is still within ISO 15006:2011 recommended practice. In comparison, OEM-03 uses a low-frequency warning priority of 800Hz for most of their in-vehicle safety technologies except for ACC, SBR, and Pedal Misoperation Control. The frequency setting and warning priority of SBR and Pedal Misoperation Control ranging from 800Hz (low) to 3200Hz (high) indicate that the driver's immediate action or decision is needed within 0s to 2s to avoid potential crash ahead. However, the high frequency of 3200Hz exceeds the acceptable human hearing range and should be avoided as it may annoy the drivers (Stevens et al., 2002; Campbell et al., 2016). It can be concluded that the frequency setting for all technologies provided by OEM-01 to OEM-05 is within the recommended practice; nonetheless, further study is needed to investigate the perception of Malaysian drivers on these various auditory alert samples.

4.0 CONCLUSION

Urbanization promotes changes in the traffic environment; hence safety is the crucial theme for any vehicle technology development. The driver needs to remain alert with their surroundings, and that can’t be done alone without having effective chimes-related technology to assist. The presence of auditory alert as part of in-vehicle safety technology offer human-machine interface guidance to convey information, gaining the driver’s attention during maneuvering vehicle and improve driver’s response/behavior during the unpredictable event. The auditory warning signal impacts drivers’ behavior and response during unforeseen events based on the literature review. Auditory alerts with high perceived urgency are effective; however, it may startle or produce other negative effects on drivers’ responses such as high collision rate and increased annoyance. The drivers' behavior and ability to avoid a crash also will differ given the sound characteristic provided in their in-vehicle auditory alert system. Frequency setting, sound pressure level/loudness, and urgency/priority level are important characteristics that play a major role in ensuring the auditory alert's perceivable and avoid annoyance sound. This significant information can be used as input to establish the questionnaire development to investigate the driver's awareness and perception of various audible vehicle alerts for Malaysian drivers. Later, from this project, optimum audible warning alerts for vehicle applications will be recommended.

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