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Optimum Alert For In-Vehicle Safety Technologies

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ABSTRACT: Vehicle safety technologies have played a critical role in protecting vehicle drivers for several decades. Auditory signals, for example, convey relevant data to the driver without interfering with the driving task. Vehicle auditory alerts help ensure the safest driving experience possible by providing warnings, thereby reducing road accidents caused by reckless or careless driving. Nonetheless, auditory alerts have long been a source of contention in vehicle safety features due to driver annoyance and false-alarm issues. This study aims to investigate drivers' awareness and perceptions of in-vehicle safety technology and auditory alerts, and how these factors affect drivers' reactions to the driving environment. A structured questionnaire was designed and distributed to 150 licensed drivers to collect data on their exposure to safety features, perceived usefulness and urgency of alerts, and preferred auditory characteristics. Descriptive and comparative analyses were conducted to evaluate drivers' perceptions alongside benchmark data from Original Equipment Manufacturers (OEMs). Results show that 87% of respondents are aware of major in-vehicle safety technologies, yet 48.7% perceive them as potentially distracting while driving. Findings also identify 1000 Hz at 65 dB as the preferred auditory frequencies for safety alerts based on user responses. This study provides insights for policymakers, manufacturers, and safety stakeholders to enhance the design, acceptance, and effectiveness of in-vehicle auditory warning systems.

ABSTRAK: Teknologi keselamatan kenderaan memainkan peranan penting dalam melindungi pemandu melalui ciri amaran seperti isyarat auditori yang menyampaikan maklumat keselamatan tanpa mengganggu tugas pemanduan. Walaupun amaran auditori dapat membantu mengurangkan risiko kemalangan jalan raya, isu seperti gangguan kepada pemandu dan amaran palsu masih menjadi cabaran utama. Kajian ini meneliti tahap kesedaran dan persepsi pemandu terhadap teknologi keselamatan dalam kenderaan serta amaran auditori, termasuk kesannya terhadap tindak balas pemandu dalam persekitaran pemanduan. Data diperoleh melalui soal selidik berstruktur yang melibatkan 150 pemandu berlesen, merangkumi pendedahan terhadap ciri keselamatan, persepsi kegunaan, tahap kecemasan amaran dan pilihan ciri auditori. Analisis deskriptif dan perbandingan turut dijalankan berdasarkan data penanda aras daripada Original Equipment Manufacturers (OEM). Dapatan menunjukkan bahawa 87% responden menyedari kewujudan teknologi keselamatan utama dalam kenderaan, namun 48.7% menganggapnya berpotensi mengganggu pemanduan. Kajian ini juga mengenal pasti bahawa frekuensi 1000 Hz pada 65 dB merupakan ciri auditori yang paling digemari untuk amaran keselamatan. Dapatan ini dapat membantu pembuat dasar, pengeluar kenderaan dan pihak berkepentingan meningkatkan reka bentuk, penerimaan dan keberkesanan sistem amaran auditori dalam kenderaan.

KEYWORDS: *Vehicle Safety, In-Vehicle Technology, Auditory Alert, Awareness and Perception, Optimum Sound Characteristics.*

1. INTRODUCTION

Advances in technology have accelerated in recent years, with the automotive sector undergoing significant transformations in line with the emergence of the Fourth Industrial Revolution (IR 4.0). This transformation encompasses various aspects of industrial processes, including design, manufacturing, management, and vehicle maintenance. Automakers and Original Equipment Manufacturers (OEMs) are rapidly adapting their business models to align with Industry 4.0 principles to remain relevant and competitive in the global automotive industry. At the same time, they are also trying to convince customers to adopt innovative car technology. Vehicle safety technologies, for example, are used to alert and warn drivers of potentially hazardous circumstances.

According to the World Health Organization (WHO) in its Global Status Report on Road Safety 2018 [12], the number of road accident fatalities has increased gradually over the years, reaching 1.35 million in 2016. With the significant number of yearly fatalities and injuries caused by traffic accidents, the United Nations (UN) emphasized two goals in the 2030 Agenda for Sustainable Development: 1) a 50% decrease in worldwide road traffic fatalities and injuries by 2030; and 2) a safe, economical, and sustainable transportation system for all by 2030 [13]. These goals align with the WHO's Global Plan for the Decade of Action for Road Safety 2011-2020 [14].

In the Decade of Action for Road Safety [14], WHO suggested five road safety pillars: road safety management, safer mobility and roads, safer cars, safer road users, and post-crash management. All countries must enhance road safety holistically and implement effective interventions. Human error, vehicle and equipment failures, and road environmental conditions were identified as the leading causes of road fatalities in studies by Hamid et al. and Mohammed et al. [16, 17].

Advances in technology and information about vehicle safety systems have opened new opportunities to reduce traffic accidents and increase drivers' awareness of their surroundings. As a result, automakers also put more effort into creating new vehicles with advanced safety features [22]. However, each vehicle manufacturer refers to the technology by a different name, even though it operates in the same manner. Vehicle safety technology may communicate with the driver through various modalities, including visual, auditory, and haptic alerts. The combination of visual and auditory alerts is more effective, providing the driver with better situational awareness than the visual modality alone [23-26].

Consequently, automakers and OEMs must adhere to crashworthiness safety performance evaluation criteria and operational safety technology requirements. Furthermore, according to the ASEAN NCAP Labelling Guideline for Manufacturers (applicable only in Malaysia), all automakers and OEMs must incorporate vehicle safety technology, i.e., airbags, Anti-Lock Braking System (ABS), Electronic Stability Control (ESC), Blind-Spot Detection, Lane Keep Assist, Lane Departure Warning, Forward Collision Warning, Seat Belt Reminder (SBR) and Autonomous Emergency Braking (AEB) [18].

Driver-assistance systems that warn of potential collisions have become standard features in modern vehicles. Today's advanced automotive technologies rely on a network of sensors and cameras to identify nearby vehicles and other obstacles. When the likelihood of a collision surpasses a defined safety threshold, the system issues a warning to alert the driver. Research has shown that the effectiveness of these alerts can be undermined by frequent false alarms and mismatches between the perceived urgency of a warning and the actual severity of the situation [1, 2].

Perceived urgency strongly influences how quickly a driver responds, but increasing urgency often makes alerts more annoying, creating a well-recognized trade-off between urgency and annoyance [3, 4]. The context in which the signal is perceived, on the other hand, affects this relationship [5]. According to some studies, the characteristics of auditory alerts result in varying degrees of urgency [6, 7]. The emotional state of the driver (i.e., alert, fatigue, etc.), the driver's age, driving experience, driving conditions (i.e., driving during busy traffic hours or at nighttime with minimal traffic), physical design, innovation, and auditory features (i.e., design of the alarms) all contribute to the irritation of the warning systems [8, 9].

A good urgency alert helps drivers understand warnings and respond appropriately, as they are more likely to respond to high-urgency alerts. Despite this, high-urgency alerts tend to reduce response efficacy due to increased false alarms [10, 11]. Previous studies consistently show that poorly designed auditory alerts can irritate drivers, leading some to ignore or turn off safety warnings altogether. When the pulse repetition rate, the fundamental frequency, and several repeats operate in unison, this substantially affects driving behavior [6].

Edworthy & Hellier [28] identified four attributes of the ideal auditory alert: easily localizable in space, not susceptible to masking by other sounds, not a source of interference for other communications (e.g., speech), and user-friendly and easily manageable. Nevertheless, the auditory alert has long been a contentious topic in vehicle safety technology, primarily due to driver annoyance and false-alarm issues. A survey conducted by Block et al. [29] reported that 70% of drivers turned off the warning alarms due to annoyance with the audio characteristics. Sayed et al. [30] revealed that drivers often feel startled and annoyed when warning alarms are triggered during non-emergency situations that do not require immediate intervention. Similarly, a J.D. Power consumer survey [31] found that many drivers found such warning alerts to be bothersome, leading some to turn off the alert system entirely. This tendency raises serious concerns regarding the effective implementation of vehicle safety technologies.

Malaysia is an essential context for this research because it has one of the highest motorization rates in Southeast Asia. Hence, the Malaysian Institute of Road Safety Research (MIROS), in collaboration with the New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP), has implemented several programs, including developing related guidelines/protocols to improve road safety, raise vehicle safety standards, and promote safer vehicles. For example, the Malaysian Ministry of Transport is constructing a framework for the Malaysian Road Safety Plan 2021-2030 [15].

Thus, this study aims to investigate drivers' awareness and perceptions of vehicle safety technologies with auditory alerts. Towards the end of this study, the awareness and perceptions of Malaysian drivers regarding existing vehicle safety technologies with auditory alerts are discussed, and the preferred frequency level of auditory alerts is mapped to align with the selected OEMs' alert frequency settings.

In this study, the technologies were chosen based on the auditory-alert modality in Advanced Driver Assistance Systems (ADAS) and other Intelligent Transport Systems (ITS).

Based on the European Automobile Manufacturers' Association (ACEA) Code of Practice for ADAS development, drivers have two primary tasks: maneuvering or guiding the vehicle, and stabilizing and navigating. Hence, the ADAS features are designed to support the driver in their primary task and to assist with at least either stabilization or navigation. [27].

The National Highway Traffic Safety Administration (NHTSA) categorizes driver assistance technologies into four main groups: (i) braking and collision avoidance, (ii) backup and parking assistance, (iii) lane and side assistance, and (iv) systems for maintaining a safe following distance [32]. Moravčík and Jaśkiewicz [33] further distinguish intelligent vehicle safety technologies according to their operational timing relative to a crash event: (i) systems that continuously support the driver's actions, (ii) systems that activate at the moment of impact, and (iii) systems that function after a collision. To facilitate understanding, Table 1 organizes 12 vehicle safety technologies that incorporate auditory alerts into five distinct categories.

Table 1. Classification of vehicle safety technology (with auditory alert).

Category	**Vehicle Safety Technology (with Auditory Alert)**
Collision Warning	Pre-Collision Warning (Forward & Reverse), Pedestrian Detection Warning (PDW), Lane Departure Warning (LDW), Blind Spot Monitoring (BSM), Rear Cross Traffic Alert (RCTA)
Collision Intervention (Braking)	Collision Mitigation Brake System (CMBS)
Parking Assistance	Parking Assistance Technology
Driving Control Assistance	Adaptive Cruise Control (ACC), Lane Keeping Assistance System (LKAS)
Other Safety Reminder Technology	Seat Belt Reminder (SBR), Door Ajar/Door Left Open Warning System, Tire Pressure Warning System

In this study, the technologies were organized by their functional support to drivers: collision warning, collision intervention, driving control assistance, parking assistance, and safety reminder systems [32, 34-35]. Collision warning features detect potential hazards around the vehicle, while collision intervention systems apply braking or acceleration to prevent or mitigate impact. Driving control assistance helps maintain safe distances and lane position; parking assistance guides low-speed maneuvers, and safety reminder technologies provide persistent alerts until corrective action is taken.

2. METHODOLOGY

The methodology of this study comprises three phases. Phase 1 focuses on developing a comprehensive database of chime technologies [36, 37]. Phase 2 examines drivers' awareness and perceptions of vehicle safety technologies that employ auditory alerts. Phase 3 aims to identify the optimal sound characteristics that promote effective driver responses in real-world driving environments. An overview of these three phases is shown in Figure 1.

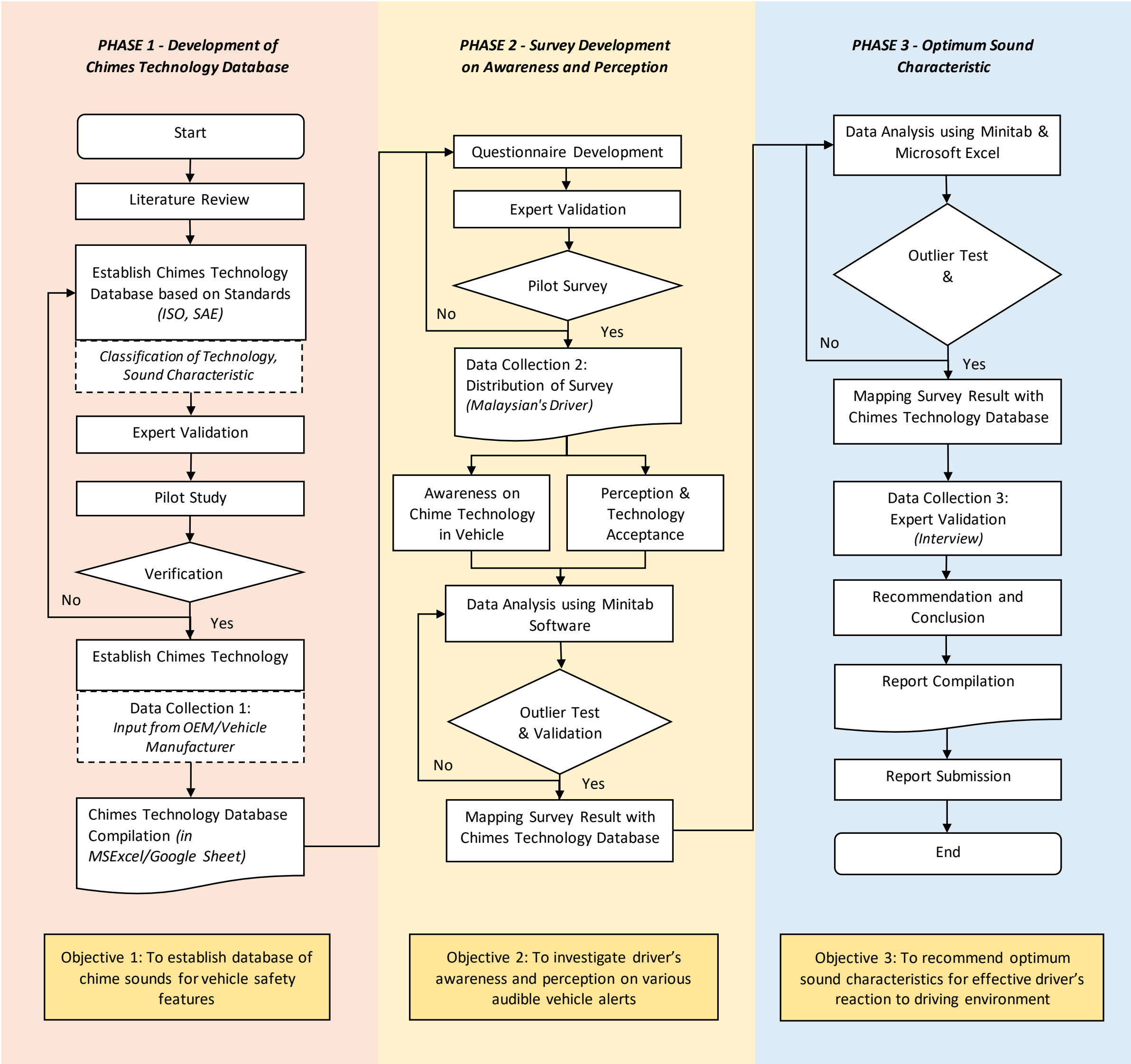

Figure 1. Research methodology flowchart.

2.1. Phase 1: Development of the Chime Technology Database

The chime technology database for this study was developed using proprietary information provided directly by selected OEMs, thus offering authentic insight into the in-vehicle alert systems used in the market. Each OEM was provided with a structured template to specify the details of its in-vehicle auditory alerts, including audio files, dominant frequency characteristics, sound pressure levels, and associated safety functions. In cases where OEMs were unable to share actual alert files due to confidentiality constraints, the researchers generated supplementary auditory samples based on the dominant frequencies recommended in ISO 15006, ensuring consistency across datasets. All collected and generated information was then compiled into a standardized database, which acted as the baseline reference for subsequent analyses of driver preferences.

The development of the chime technology database began with a comprehensive literature review of existing vehicle safety systems that utilize auditory alerts. This review took into account the sound characteristics recommended by the International Organization for Standardization (ISO) [38] and the standards established by the Society of Automotive Engineers (SAE) for each respective technology [34, 35]. Subsequently, a market survey was conducted using data from the Malaysian Automotive Association [39–45] to provide an overview of Malaysia's top five vehicle brands and their total sales.

The survey revealed that Perodua led the Malaysian market in vehicle sales, followed by Proton, Honda, Toyota, and Nissan [39–45]. This result was used to identify potential OEMs or vehicle manufacturers for data collection on chime technology. Based on this OEM's selection, a standardized database template was distributed to the selected OEMs, requesting detailed information on the vehicle safety technologies in their models that incorporate audible alerts. Each OEM was asked to specify the type of warning modality, provide corresponding audio files, and submit relevant user manuals. The collected inputs were consolidated into a comprehensive database of Chime technology.

2.2. Phase 2: Survey Development on Awareness and Perception

In Phase 2 of this study, a survey approach was employed to assess Malaysian drivers' awareness, perceptions, and acceptance of in-vehicle chime technologies. Before data collection, the survey was validated by experts from the Malaysian Institute of Road Safety Research (MIROS) with at least 10 years of experience to ensure it covered critical aspects and identified any missing components.

The survey was developed using Google Forms and is divided into four parts. Part A: Demographics covers demographic characteristics such as age, nationality, driving experience, car ownership, and type of vehicle driven, including its model year. Part B: Driver's Awareness of In-Vehicle Safety Technology with Auditory Alert focuses on awareness of the chime technology, in which the respondents need to answer the vehicle buying factor, awareness of vehicle safety technology available in their car, drivers' interaction with the technology, and the importance of vehicle safety technologies with auditory alert. In Part C: Driver's Perception of In-Vehicle Safety Technology with Auditory Alert, respondents must rate their perceptions of vehicle safety technology in terms of ease of use, usefulness, and the auditory alert's safety and effectiveness using the Likert scale. Lastly, in Part D: Audio Test, respondents need to select their preferences for perceiving urgency and annoyance for each audio alert.

The auditory alerts used in the survey were configured with distinct characteristics, including frequency, intermittent cycles, and sound pressure levels. They were created using NCH's Tone Generator software. Meanwhile, WavePad Audio Editing software was used to compile the audio files. The audio frequencies used in this study comprised three levels: 500 Hz, 1000 Hz, and 1500 Hz, with corresponding sound pressure levels (SPLs) set at 65 dB, 70 dB, 75 dB, and 80 dB. Additionally, the intermittent sound cycles used in this study were set at 500 ms, 1000 ms, and 2000 ms.

Prior to the main data collection, a pilot test was conducted to ensure that the auditory alert characteristics met the desired specifications and to estimate the time required for respondents to complete the survey. To verify the accuracy of the desired sound pressure levels, a calibrated sound level meter was used.

A probability sampling method was adopted in this study to obtain a representative sample of the population. This is to ensure equal selection probabilities and thereby reduce sampling bias [46]. Based on the sample size calculation method outlined in [47], at least 120 respondents were required. The survey was designed with a 10% margin of error, a 90% confidence level, and a 50% distribution across each category. Only Malaysian drivers with driving experience are allowed to participate as respondents. They were categorized into four age groups: 18 to 24 years old, 25 to 39 years old, 40 to 54 years old, and 55 years old and above [48].

2.3. Phase 3: Optimum Sound Characteristic

This phase aims to identify and map the preferred frequency levels for auditory alerts and align them with the frequency settings provided by the selected OEMs. In this study, the sound characteristics identified from the driver survey were compared with the OEM-provided auditory frequency settings. Dominant frequencies were extracted from the OEM audio samples using Python software, following the frequency guidelines specified in ISO 15006 [38]. The extracted frequencies were then mapped to the warning-priority levels corresponding to different crash-event stages, based on the established classifications [49]. The alert priority was determined according to the sequence of crash events, ranging from everyday driving to emerging or critical situations [49]. Four priority levels were defined, as shown in Table 2, to reflect increasing urgency: Notification, Low, Medium, and High. The chime technology database was subsequently utilized to determine the most suitable frequency range for auditory alerts; hence, it was the basis for recommending optimal sound characteristics that promote effective driver response.

Table 2. Specification of audio warning priority.

Audio Warning Priority (Hz)	Notification	Medium
	Low	501-800
	Medium	501-800
	Medium	501-800

The data collected from Malaysian drivers were processed and analyzed using Microsoft Excel and Minitab Version 20. Excel was used to sort the raw survey data, filter out outliers, and identify the key characteristics of the audio test (frequency, sound pressure level, and intermittent cycle). Minitab software was used to conduct statistical analyses, encompassing descriptive statistics such as means and standard deviations [50]. Data collection sessions were conducted at several locations across the Klang Valley using smartphones, sound level meters, and Bluetooth-enabled vehicles. During each audio test, the sound samples were played from a smartphone connected to the car's audio system via Bluetooth.

3. Result and Discussion

3.1. Phase 1: Development of the Chime Technology Database

Significant differences in the availability of chime-enabled safety technologies across vehicle classes and specification levels were found in the initial desktop study. In general, higher-specification vehicle models were equipped with multiple auditory-based systems, such as collision warning, collision intervention, driver assistance, and safety reminder technologies. On the other hand, limited auditory alert systems were offered in lower-specification models, with some relying solely on the dashboard's visual indicators. This variation highlights an implementation gap that may affect drivers' exposure to important auditory warnings, given that road-crash risk is equally distributed across all vehicle types.

The desktop study also discovered that most OEMs operate within the recommended dominant frequency range of 500–1500 Hz, although several high-frequency alerts exceeded 3000 Hz. Such high frequencies may contribute to driver annoyance, consistent with previous human-machine interaction (HMI) literature. Additionally, OEMs were found to differ substantially in their warning-priority tuning, with some applying high-urgency tones even for non-critical alerts. This observation aligns with the findings of Sayed et al. [30], who reported that drivers are often startled and annoyed by the warning alarm triggered in non-emergency situations. These findings highlight the pertinence of aligning auditory alert design with urgency–annoyance principles to minimize distraction and enhance user acceptance of in-vehicle safety technologies.

Auditory alerts in in-vehicle safety systems serve an essential communication role in the human–machine interface, guiding and conveying information to drivers while effectively capturing their attention during maneuvering vehicles. As indicated by the Guideline for Safety of In-Vehicle Information Systems and the Human Factors Design Guidance for Driver–Vehicle Interfaces [51, 52], the recommended sound pressure levels are 50–90 dB(A), with an ideal minimum of 75 dB(A) and frequencies between 500–2500 Hz, including at least two dominant frequencies within 500–1500 Hz. This range aligns with the most sensitive region of the human hearing range. Sounds above 90 dB(A) or above 3000 Hz should be avoided because they may startle or irritate drivers. Nevertheless, alerts should also be at least 15 dB(A) higher than ambient noise to remain detectable. Alert urgency corresponds to the stage of a potential collision and is typically grouped into three levels: low (response needed within 10–120 s), medium (2–10 s), and high (0–2 s) [49]. In general, research consistently shows that alerts with higher frequencies, greater intensity, and shorter intervals are perceived as more urgent [49, 51, 53].

Table 3 presents the database of chime-related technologies collected from five OEMs. The database indicates that all OEMs provide Seat Belt Reminder (SBR) and pre-collision Warning systems, while low-specification models from several brands rely solely on visual indicators. Of the 17 safety technologies examined, only Child Presence Detection (CPD) was absent across all OEMs. For other features such as the Master Warning System, Pedal Misoperation Control, and Tire Pressure Warning System, most OEMs provided only visual indicators without accompanying chime alerts.

Several OEMs also employed the same auditory alerts across multiple safety functions. For example, the Collision Mitigation Braking System (CMBS) in OEM-03 and OEM-04 used the same alert tone for several collision-related features, including Reverse Collision Warning, Forward/Pre-Collision Warning, Pedestrian Detection Warning, and Pre-Collision Braking. Only a few technologies, such as the Master Warning System in OEM-02 and the Tire Pressure Warning System in OEM-04, integrated both visual and auditory cues, while most relied exclusively on dashboard icons.

Dominant frequencies from the available chime samples were extracted using Python, following the recommendations in ISO 15006 [38]. These frequencies were subsequently categorized into several warning-priority levels, as presented in Table 2. The analysis revealed significant variation in frequency settings across OEMs, likely influenced by factors such as the vehicle model, recording conditions, and background noise in the submitted audio files.

Overall, OEM-04 predominantly used high-priority frequencies (1600–2400 Hz) across most technologies while remaining within the limits prescribed by ISO 15006. In contrast, OEM-03 used lower-priority tones around 800 Hz for many alerts, except for Adaptive Cruise Control (ACC), Seat Belt Reminder (SBR), and Pedal Misoperation Control. Notably, the Pedal Misoperation Control alert used a 3200 Hz tone, which exceeds the recommended comfort range for human hearing. This finding is consistent with the design recommendations reported by Campbell et al. [51] and Stevens et al. [52], who emphasized that high-frequency tones can contribute to driver discomfort and annoyance. In summary, while the OEM frequency settings generally align with recommended practices, the observed variations highlight the need for further research on Malaysian drivers' acceptance of these auditory alerts.

Table 3. Database of chimes-related technology.

			Vehicle Brand				
			OEM-01	OEM-02	OEM-03	OEM-04	OEM-05
Chime Technologies	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 Assistanc	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
		Tire Pressure Warning System	Visual	Visual	Visual	800	Visual

Legend:		
Audio Warning Priority (Hz)	Notification	300-500
	Low	501-800
	Medium	801-1200
	High	1201-3000

3.2. Phase 2: Survey Development on Awareness and Perception

3.2.1. Demographic Data

A total of 150 respondents took part in this survey. In the 18 to 55 age group, the highest percentage is 45.0%, comprising drivers aged 25-39 years with more than 10 years of driving experience. Participants were mostly from the Klang Valley area (93.3%), while the remaining 6.7% resided outside the Klang Valley. Such a result is expected, as the Klang Valley has a higher population density and a higher concentration of vehicle ownership.

The demographic result also indicates that 71.3% of respondents own a car, with 65.1% owning a national brand. On the other hand, 28.7% of the respondents who do not own a car were drivers with less than 5 years of driving experience (36 respondents), followed by 6-10 years (5 respondents) and more than 10 years (2 respondents). In addition, 39.8% of the respondents owned the latest vehicle model (2016-present). Many respondents also owned either a sedan or a compact car (42.6%). The high percentage of national car users reflects Malaysia's current market distribution, thereby reinforcing the relevance of analyzing locally standard vehicle models. Table 4 tabulates the demographic characteristics of the survey participants.

Table 4. Demographic data of the survey participants.

Variables		Percentage (%)
Age:	18 – 24 years	33.3
	25 – 39 years	44.7
	40 – 54 years	16.8
	≥ 55 years	5.3
Gender:	Male	52.3
	Female	47.7
Current location:	Klang Valley	93.3
	Outside Klang Valley	6.7
Driving experience :	1 – 5 years	39.3
	6 – 10 years	16.0
	>10 years	44.7
Car's possession:	Yes	71.3
	No	28.7
Car's model	National car	34.9
	Imported car	65.1
Car's model year:	Before 2005	9.3
	2006 – 2010	21.3
	2011 – 2015	29.6
	2016 – Present	39.8
Car's type:	Sedan	42.6
	Compact	42.6
	Multi-Purpose Vehicle (MPV)	10.2
	Sport Utility Vehicle (SUV)	4.6

3.2.2. Driver's Awareness of Various Audible Alerts

Figure 2 illustrates the key factors drivers will consider when purchasing a new vehicle. The top five factors identified were comfort (74%), cost (69.3%), fuel consumption (64.7%), engine performance (64%), and safety technology features (57.3%). These findings suggest that Malaysian drivers are attentive to comfort, affordability, efficient vehicle performance, and safety technologies in their purchasing decisions.

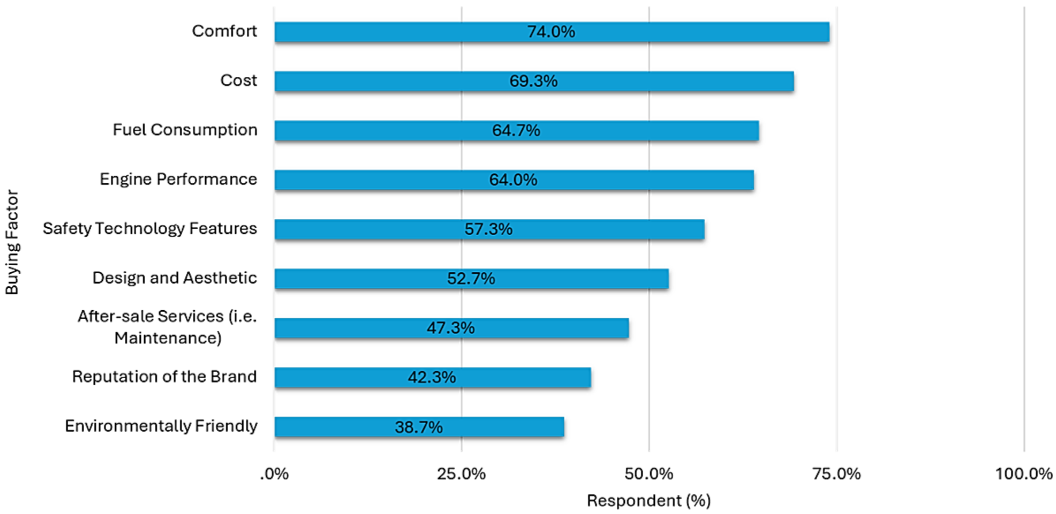

Figure 2. Contributing factors influencing vehicle purchase decisions.

Respondents were also asked about their awareness of existing in-vehicle safety technologies. Overall, 87% of respondents reported familiarity with these technologies, and 92.3% agreed that these systems are useful for preventing crashes, while 94.7% believed that the technologies are helpful during emergencies. However, several respondents admitted that they faced difficulties in differentiating the functions of the safety features and in using them correctly. Similar observations were reported by Kaur et al. [54], who reported that drivers with greater knowledge of vehicle safety systems tend to have stronger safety perceptions. Nonetheless, some drivers still appeared to underestimate these features, believing that their driving skills were sufficient. Conversely, Rohr et al. [55] noted that when drivers understand and use safety systems appropriately, fatalities can be reduced.

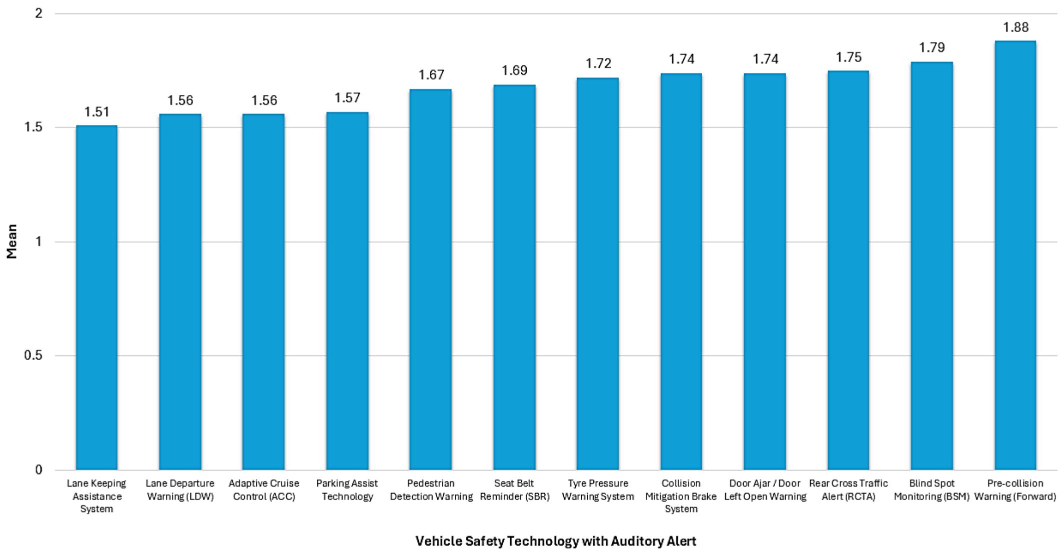

Figure 3. Importance of vehicle safety technology.

Figure 3 presents the perceived importance of 12 vehicle safety technologies among Malaysian drivers. These technologies are consistent with ASEAN NCAP's recommended safety requirements for vehicles in the Malaysian market. Respondents' awareness was evaluated using a three-point scale, where 2 indicated "very important," 1 "somewhat important," and 0 "not important." All technologies recorded mean scores above 1.5, indicating generally high awareness. From this study, it was found that Pre-Collision Warning (1.88, 88%) was rated as the most important, followed by Blind Spot Monitoring (1.79, 80%), Rear Cross Traffic Alert (1.75, 76%), Collision Mitigation Braking System (1.74, 75%), Door Ajar/Left-Open Warning (1.74, 76%), and Seat Belt Reminder (1.69, 72%). These results suggest that Malaysian drivers perceived collision-related and safety-reminder systems as the most important, reflecting their strong concern for crash prevention and emergency response.

In contrast, driving-control assistance technologies such as Lane Keeping Assistance System (LKAS) and Lane Departure Warning (LDW) were rated as less important, with mean scores of 1.51 and 1.56, respectively. These lower ratings may be attributed to less familiarity with semi-autonomous driving features. Overall, the findings indicate a strong presence of awareness among Malaysian drivers of vehicle safety technologies and their performance. This trend aligns with ASEAN NCAP and MIROS' ongoing efforts to mandate essential safety features in new vehicles, thereby increasing consumers' awareness of safety technologies. Variations in vehicle brand, cost, and safety features also appear to influence driver perceptions, with Malaysian drivers prioritizing systems that directly prevent crashes over those that require greater driver adaptation, such as Adaptive Cruise Control (ACC), Parking Assist, LKAS, and LDW.

3.2.3. Driver's Perception of Various Audible Alerts

Malaysian drivers' perceived ease of use of in-vehicle safety technologies is demonstrated in Figure 4. Overall, 76% of respondents agreed that these technologies are easy to operate. About 71.3% also found it easy to learn how the systems work, and 70.7% agreed that the interaction with the technology is clear and understandable. In addition, 62.7% felt that using the technologies requires minimal effort. These findings suggest that most Malaysian drivers perceive Advanced Driver Assistance Systems (ADAS) and related safety features as user-friendly. This outcome is consistent with the findings of Wu et al. [56], who emphasized that the effectiveness of such systems depends heavily on how well drivers understand and interact with them. Hence, ensuring a user-friendly design for in-vehicle safety technologies is essential for these technologies to function smoothly.

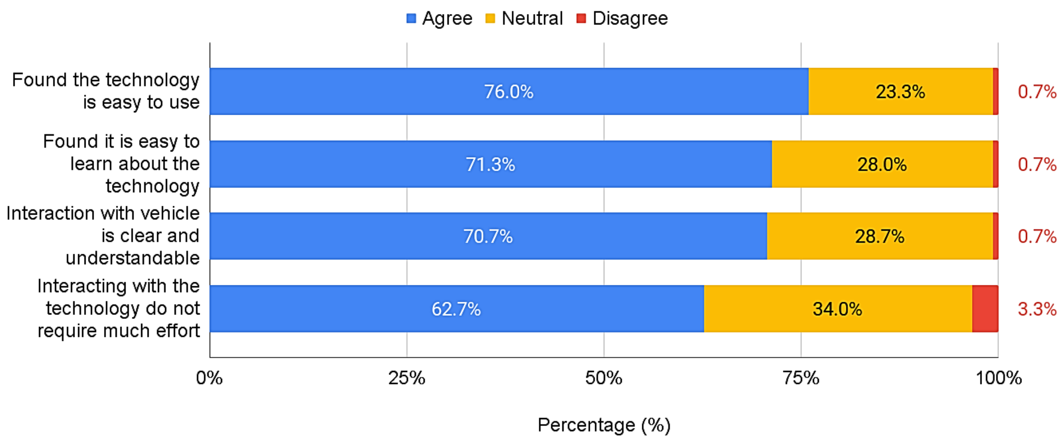

Figure 4. Perceived Ease of Use.

On the other hand, perceived usefulness reflects the extent to which drivers believe these technologies enhance their driving performance. As shown in Figure 5, more than 70% of respondents agreed that the technologies do assist them massively in driving and improving their overall driving performance, while 68% considered the technologies to be practically feasible. This, of course, increases the likelihood that drivers will willingly use the technologies. When drivers view a system as applicable, they are less likely to deactivate it.

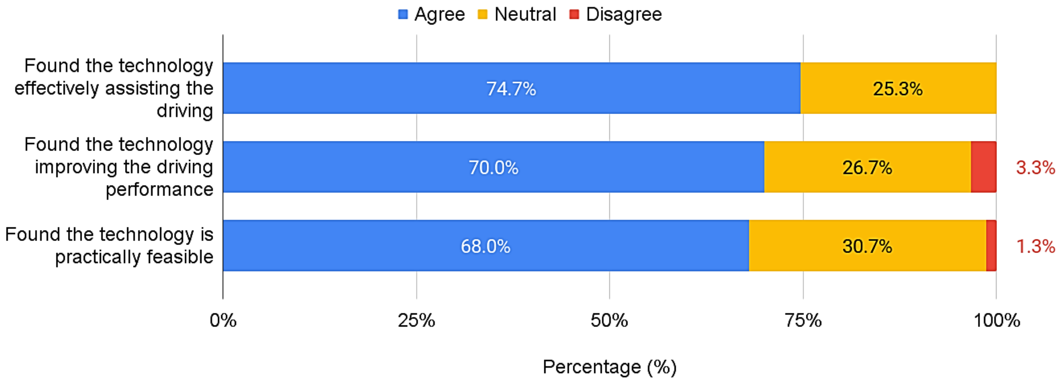

Figure 5. Perceived Usefulness.

The urgency level is defined as the effectiveness with which warnings can influence drivers' behavior in response to upcoming dangerous events. Figure 6 demonstrated that 86.7% of respondents believed that vehicle safety technology increases their driving safety and 68% trusted that the technology could reduce the likelihood of crashes. However, 48.7% of respondents found that the technologies distracted them while driving. The European Commission [57] study on driver distraction highlighted that vehicle safety systems are designed to draw the driver's attention away from other traffic activities. However, the warning alerts and signals must be instructive to the driver without being too overwhelming or causing cognitive distraction.

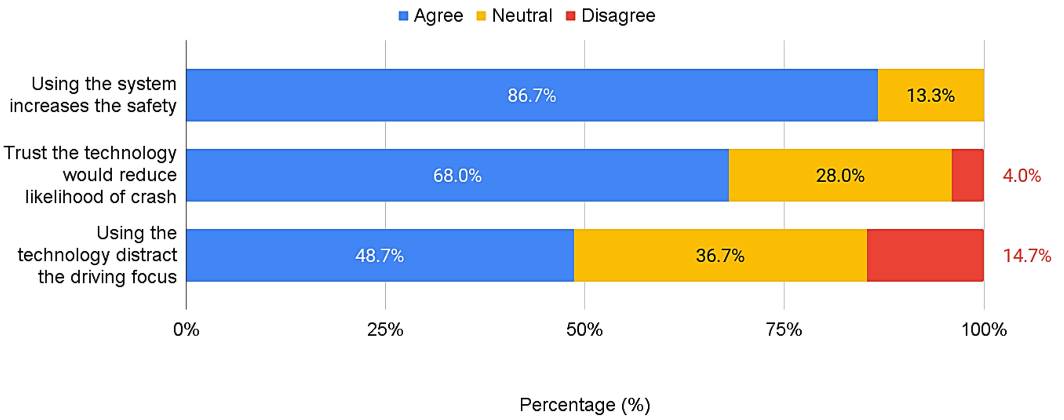

Figure 6. Perceived Safety.

In the audio test conducted in the survey, respondents selected their preferences for the perceived urgency of audio alerts, which encompassed three variables: sound pressure level, fundamental frequency, and an intermittent cycle. Prior to the audio test, the sound level meter was used to ensure that the ambient noise inside the car was 60 dB with the air conditioner and engine running. This study used four different sound pressure levels: 80 dB, 75 dB, 70 dB, and 65 dB. Respondents were asked to choose the preferred sound characteristic across different frequency settings and sound pressure levels. They were then required to rate their perceived annoyance and urgency for each frequency and intermittent cycle.

The audio used for the survey was set at three frequencies: 500 Hz, 1000 Hz, and 1500 Hz, while the intermittent cycle was set at three speeds: 500 ms, 1000 ms, and 1500 ms. The sound pressure level was set at 65 dB to achieve the desired level of perceived annoyance. Meanwhile, the sound pressure level was set to 65 dB and the frequency to 500 Hz, designed to enhance the perception of urgency. The results for the preferred frequency and sound pressure level among Malaysian drivers are illustrated in Figure 7, while the results for perceived annoyance and urgency across different frequencies and intermittent cycles are shown in Figure 8.

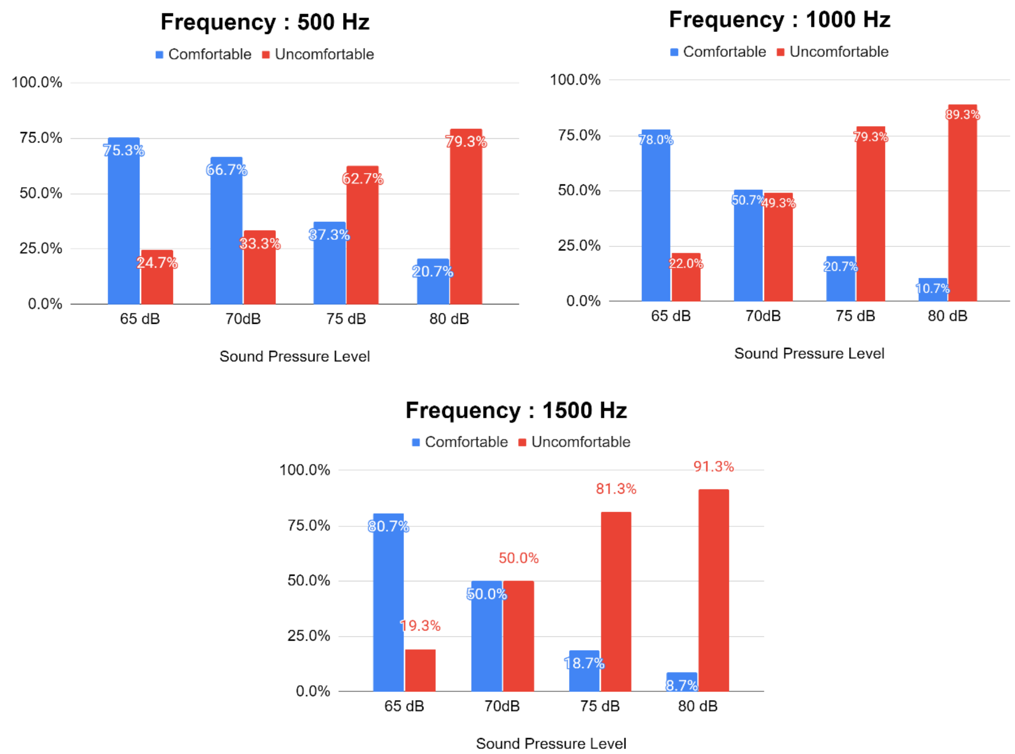

Figure 7. Preferred Sound Pressure Level and Frequency.

Figure 7 shows that respondents became increasingly uncomfortable as both the sound pressure level and frequency increased. At 500 Hz, 75.3% preferred 65 dB, while 79.3% found 80 dB uncomfortable. A small group, mainly aged 25–39 and 40–54, still tolerated 80 dB. Overall, 500 Hz tones were rated as least annoying (30%) and moderately urgent (60%). At 1000 Hz, 78% of respondents again preferred 65 dB as the most comfortable loudness, and this setting was perceived as fairly urgent and noticeably annoying. For 1500 Hz, 80.7% preferred 65 dB, whereas 91.3% judged 80 dB to be uncomfortable or noisy. Only 8.7% of drivers, mostly young drivers (18–24 and 25–39), tolerated 1500 Hz at 80 dB. Differences in comfort levels between younger and older drivers may reflect age-related changes in hearing sensitivity. Younger drivers are also more prone to external distractions, such as music, smartphones, and infotainment systems, as highlighted by the European Commission [57].

Compared with other frequency levels, audio at 1500 Hz was ranked the highest in perceived annoyance; yet 74.7% of respondents felt it was the most urgent (see Figure 8). Moreover, in terms of perceived annoyance and urgency across the different intermittent cycles, respondents rated the 500 ms cycle as the most irritating and the most urgent.

In terms of annoyance, more than 70% of respondents found 1000 ms and 2000 ms intermittent cycles not irritating; however, respondents perceived the 2000 ms cycle as the least urgent alert. Based on our findings, it can be concluded that Malaysian drivers prefer a frequency range of 1000-1500 Hz and a sound pressure level range of 65-70 dB as comfortable for auditory alerts. Furthermore, the 500 ms intermittent cycle is best suited for warning drivers of an urgent alarm, while the 1000 ms cycle is more suitable for recurring warning and reminder alerts.

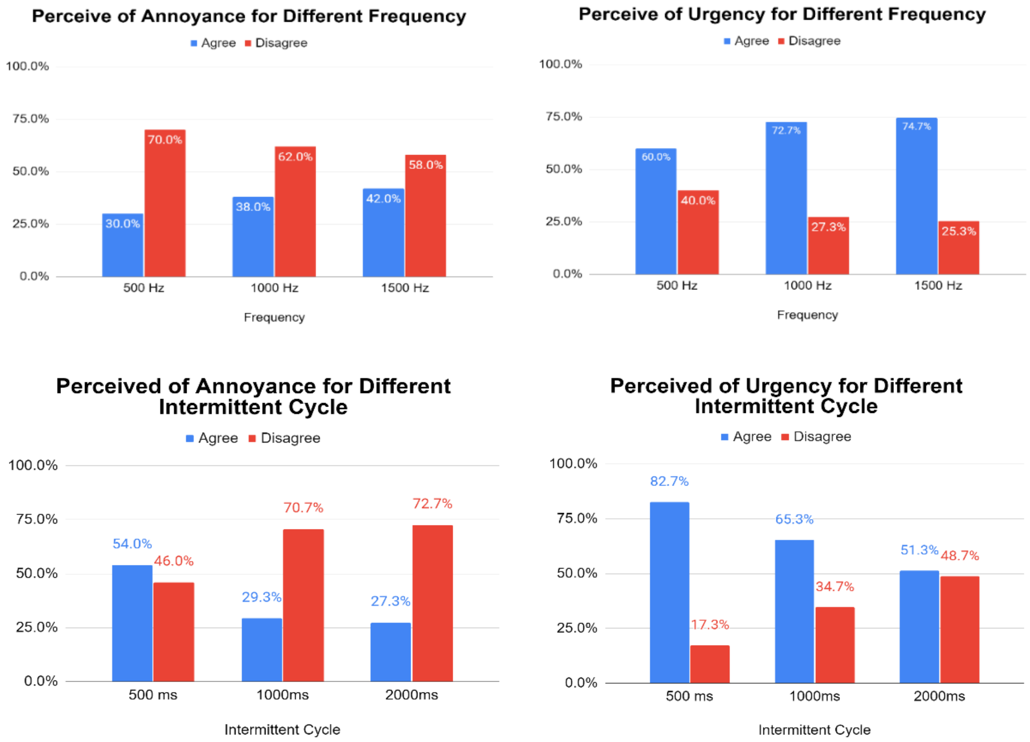

Figure 8. Perceived Annoyance and Urgency for Different Frequencies.

3.3. Phase 3: Optimum Sound Characteristic

Auditory modalities convey information to the driver, and different alert parameters correspond to different levels of urgency [58]. A driver's perception greatly influences how safety features are interpreted. As noted by Wu & Chan [59], the way information is processed can influence drivers' decision-making. This connection is also reflected in Malaysian consumers' tendency to consider ASEAN NCAP safety ratings when purchasing vehicles. However, as highlighted by Altamirano et al. [60] and other previous studies [19], Malaysian drivers have had limited exposure to Advanced Driver Assistance Systems (ADAS) due to their late introduction into the local market.

Figure 9 illustrates the frequency ranges used by five OEMs. Although most frequencies fall within the acceptable range defined in ISO 15006:2011, several exceed the recommended upper limit. This could potentially increase the likelihood of perceived distraction and annoyance among Malaysian drivers. The survey results further indicate that perceived urgency and comfort vary with frequency and sound pressure level. From the audio test, it was found that the chime configuration rated most favorably by Malaysian drivers was a 1000 Hz tone at 65 dB with an intermittent cycle of approximately 1000 ms. This configuration was perceived as sufficiently urgent for safety-critical scenarios, yet less annoying than higher-frequency tones. Therefore, this study recommends 1000 Hz at 65 dB as the preferred auditory-alert setting for in-vehicle safety systems in Malaysia.

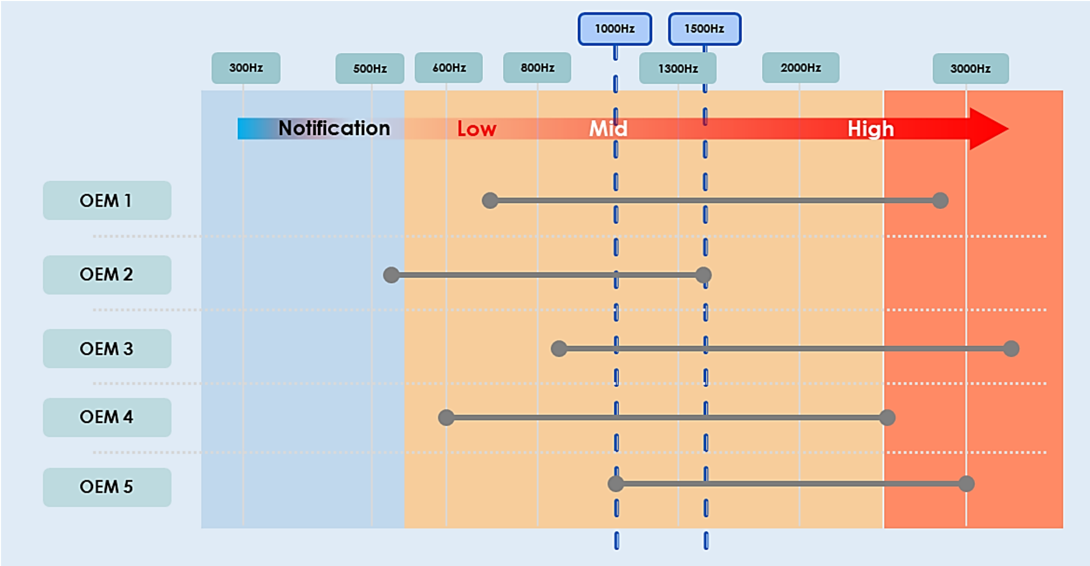

Figure 9. Range of frequency for vehicle safety technology and recommended frequency.

4. CONCLUSION

This study contributes deeper insight into Malaysian drivers' awareness, perceptions, and behavioral responses towards vehicle safety technologies that incorporate auditory alerts. Aside from identifying factors contributing to vehicle purchase decisions, the findings also highlight an overwhelming preference for safety-related technologies. Collision-avoidance safety technologies such as Pre-Collision Warning, Blind Spot Monitoring, Rear Cross Traffic Alert, Collision Mitigation Brake System, Seat Belt Reminder, and Door-Ajar Warnings were perceived as the most critical. On the other hand, lower familiarity with Lane Departure Warning and the Lane Keeping Assistance System reflects the limited awareness by Malaysian drivers of driving-control assistance technologies. This suggests a gap in public understanding of semi-autonomous safety features.

A key contribution of this research is to link driver perception to the technical properties of auditory alerts. The comparison between OEM-supplied frequencies and user preferences showed that although most OEM alerts fall within the ISO 15006:2011 guidelines, several exceed the optimal frequency range and may contribute to distraction or annoyance. The preferred auditory characteristics identified in this study, specifically 1000 Hz at 65 dB, provide an evidence-based reference for technology developers in designing alerts that balance urgency and comfort. These findings have direct implications for OEMs in calibrating warning tones to maintain safety relevance while minimizing distraction.

From a policy perspective, these findings carry implications for Malaysia's road-safety stakeholders. Firstly, ASEAN NCAP could incorporate auditory-alert preference data into the guidelines for local manufacturers. At the same time, OEMs may raise driver acceptance by tuning alert frequencies and sound pressure levels within user-preferred ranges. Furthermore, the Ministry of Transportation Malaysia and ASEAN NCAP may also consider standardizing minimum auditory-alert requirements for lower-specification vehicles to ensure consistent safety performance across vehicle models. Because prolonged exposure to excessively high frequencies can cause discomfort or hearing issues, it is essential to ensure that warning alerts balance urgency (to prompt a timely response) with minimal annoyance (to avoid distraction). Optimizing auditory-alert design in this way may support clearer human–technology interaction and contribute to safer driving experiences in Malaysia.

This study acknowledges certain limitations, particularly its Klang Valley-focused sample and the use of controlled stationary-vehicle testing. The involvement of participants from diverse regions and the investigation of cross-cultural differences in auditory perception should be explored in future research. It would also be beneficial to conduct simulation-based or real-world driving experiments to validate the effectiveness of alerts under dynamic driving conditions.

Despite these limitations, the findings offer meaningful insights for policymakers, manufacturers, and safety stakeholders. Designing auditory alerts that align with local driver preferences while still meeting international standards can enhance local driver acceptance, reduce distraction, and strengthen Malaysia's broader road-safety initiatives under the ASEAN NCAP protocol roadmaps and national safety plans.

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