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ASSESSMENT OF AUTONOMOUS EMERGENCY BRAKING (AEB) PEDESTRIAN SYSTEM IMPACT ON 2016 – 2020 MALAYSIAN ANIMAL-CROSSINGS ACCIDENTS DATA

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ABSTRACT

The trend of animal-vehicle collision (AVCs) occurrences over the past years demonstrates increasing numbers, and this call for a proper mitigation plan by appropriate authority bodies. Autonomous Emergency Braking (AEB) pedestrian system - proven effective in collision prevention and mitigation for vehicle-pedestrian collision – can potentially expand its original functionality to AVCs avoidance. This study presents a new data assessment method to predict the impact of AEB pedestrian system implementation on vehicles to reduce AVCs cases from 2016 to 2020. In general, a new scoring system is introduced whereby fitment rating points of 1, 0.5 and 0 are given to describe successful crash avoidance, crash mitigation with reduced damage and failed crash avoidance. Several noteworthy findings were discovered in assessing impact data from five significant AEB-AVCs. The effectiveness of AEB is found to be correlated with camera detection, system working speed range, frequent collision time, human casualties, and heavy vehicles. In general, the results indicate overall positive consequences of AEB implementation to reduce AVCs, providing concrete reasoning for standardising AEB pedestrian systems in all manufactured road-legal vehicles for upcoming years.

Keywords: *Animal-vehicle collisions, autonomous emergency braking pedestrian system, animal crossing accident data, data assessment, impact data analysis, accident data*

INTRODUCTION

The global automotive industry with high paced gravitation towards autonomous driving capability in pursuit of absolute zero safety circumstances in daily commuting lives irrespective of any form of the road structure and traffic congestion scale while preserving flawless driver and passenger experience and comfortability throughout the journey. Despite the challenges in developing all-inclusive Advanced Driver Assistance System (ADAS) with high precision detection and system response in alleviating such hectic situations with the safety of the driver and passengers engaged as its top priority, there are still uncertain form factors that require further consideration in expanding the system capability to prolong its functionality and relevancy in long term perspective. Aside from generalised vehicle-to-vehicle (VTV) and pedestrian-to-vehicle (PTV) collision test scenario settings for system optimisation and enhancement aspects, animals should be in considered as part of the increasing trends of simulation and experimental setup for any subsystem to ADAS for total mitigation over potential AVCs. AEB pedestrian system is the primary mitigation system designed for frontal collision course avoidance, and such a complex system integrated into ADAS has to adapt to a more diverse object detection algorithm for a higher probability of collision prevention over the uncertain profile of target object obstructed in front of the approaching vehicle.

Overview of Animal Crossing Accidents

According to police records and data collected between 1985 and 1991, there was a notable increase of 69% in Animal-Vehicle Collisions (AVCs) on state-maintained highways [1]. This finding underscores the significant concern that AVCs posed for road safety during the specified period. However, it is worth noting that the study focused exclusively on a specific state roadway with high traffic volume, while the safety and maintenance aspects of rural areas, which often harbour uncertain conditions, were largely unexplored. It is imperative to draw attention to the alarming levels of AVCs in these rural regions.

The data examined in this study predates the current era of globalisation, which is characterised by heightened automotive utilisation and the intricate interconnection of urban and rural districts through complex town planning and road construction. If appropriate measures are not taken into account, the pace at which AVCs occur in these areas could far exceed expectations.

A subsequent investigation was undertaken to gain a more comprehensive understanding of the AVC problem. This investigation utilised a substantial-scale database encompassing both urban and rural roadways from 1990 to 2008. The analysis of this dataset revealed an escalating pattern of fatal AVCs concerning the rate of vehicle miles travelled (VMT). Additionally, non-fatal AVCs displayed a remarkable growth trend. These findings underscore the significant impact of AVCs on reducing road accidents and preventing casualties [2].

A comprehensive investigation conducted by the Malaysian Institute of Road Safety Research (MIROS) examined the occurrence of AVCs over 10 years. The data for this study was obtained from reliable online sources, focusing on reputable news outlets. The distressing findings revealed an average of 20 deaths per year attributed to AVCs. It is important to note that this analysis method relied solely on trusted public sources, specifically online newspaper columns reporting on AVC incidents. Official authorities' reports on AVCs were not included, and it is possible that underreported cases were not captured due to negligence regarding the nature of AVC accidents in comparison to collisions involving vehicles and pedestrians [3].

These figures highlight the urgent need to implement an AEB pedestrian system in Malaysia's road infrastructure. Moreover, the detection mechanisms of this system should be enhanced to include animal-specific specifications, considering the frequent involvement of certain animal species in AVC incidents on Malaysian roads.

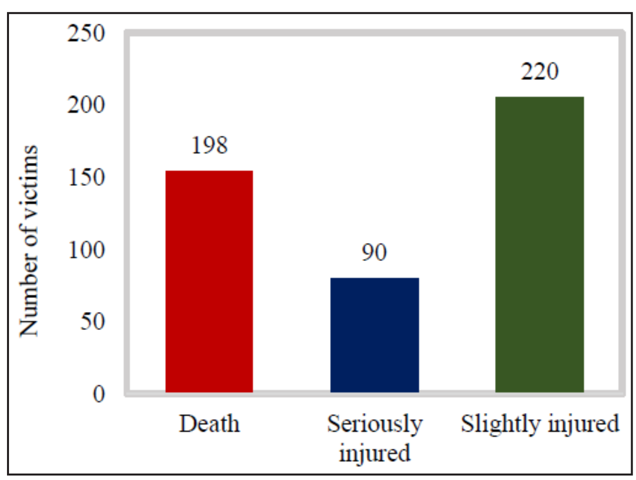

Figure 1 AVCs casualties recorded for 10 years period on Malaysia roads [3]

However, there are significant research challenges in addressing AVCs with respect to the existing automotive detection systems integrated into autonomous emergency braking, which form part of ADAS. These challenges limit the scope for improving AVC mitigation systems safely and effectively. Specifically, the current detection systems face limitations in accurately discerning animal characteristics such as shape, size, and colour variation. Furthermore, factors such as the high occurrence of AVCs during nighttime and varying climate conditions can significantly influence detection accuracy. To achieve comprehensive prevention of AVCs, it is crucial to develop cost-effective technological solutions to implement and maintain while also providing superior accuracy in vision-based animal detection [4].

Overview of AEB Pedestrian System

AEB plays a critical role in ensuring the absolute prevention of frontal collisions by reacting 2 to 4 times faster than a driver's response [5]. The current AEB pedestrian system, as described in a review article, employs a camera-radar fusion device as its detection mechanism. Different automotive manufacturers configure the radar with varying short or long longitudinal ranges. To enhance driver awareness, the system provides audiovisual warnings with varying levels of visibility and loudness as the distance between the host vehicle and the target object decreases.

In developing an effective AEB system, crucial parameters revolve around the Time-to-Collision (TTC) reaction time, which has been standardised globally to advance the overall system. A recommended stopping measurement of a 1-meter distance between the approaching vehicle and the target object is taken for collision avoidance. When the AEB mitigation system is activated, the vehicle's speed is reduced by 10% from its pre-detection travel speed toward the potential collision course [6]. This assessment study indicates the considerable potential for developing an ideal and practical AEB system, regardless of the variations in objects that come into contact with the host vehicle during split-second collision scenarios, with the detection mechanism serving as the core component. A recent study focused on a specific configuration of the AEB pedestrian system's sensor, which acts as the detection mechanism. It revealed that manipulating the sensor range has minimal impact on pedestrian detection but significantly affects the TTC, increasing the reaction time by 1 second through a wider field-of-view (FOV) sensor composition [8]. The higher TTC rate allows for faster assessment and mitigation of potential collisions by the AEB pedestrian system. This highlights the technological advancements in AEB pedestrian systems, which have proven functional and can reduce vehicle collisions over the years. However, achieving similar accomplishments in the context of AVCs necessitates proper research and development efforts focused on animal detection systems.

The objective of this study is to assess the impact of AEB pedestrian systems on road accidents in Malaysia between 2016 and 2020. The study aims to analyse two distinct databases to examine the probability of AEB pedestrian systems as a part of overall Advanced Driver Assistance Systems (ADAS) in mitigating accidents involving AVCs. The goal is to determine if AEB pedestrian systems can be a life-saving solution and reduce the current trends of AVCs on Malaysian roads.

METHODOLOGY

Main Process Flowchart of AEB-AVCs Data Assessment

The study involves five phases, which encompass data analysis and the construction of a new AEB assessment system that is applied to the AVC data. The details of the phases are shown in Figure 2.

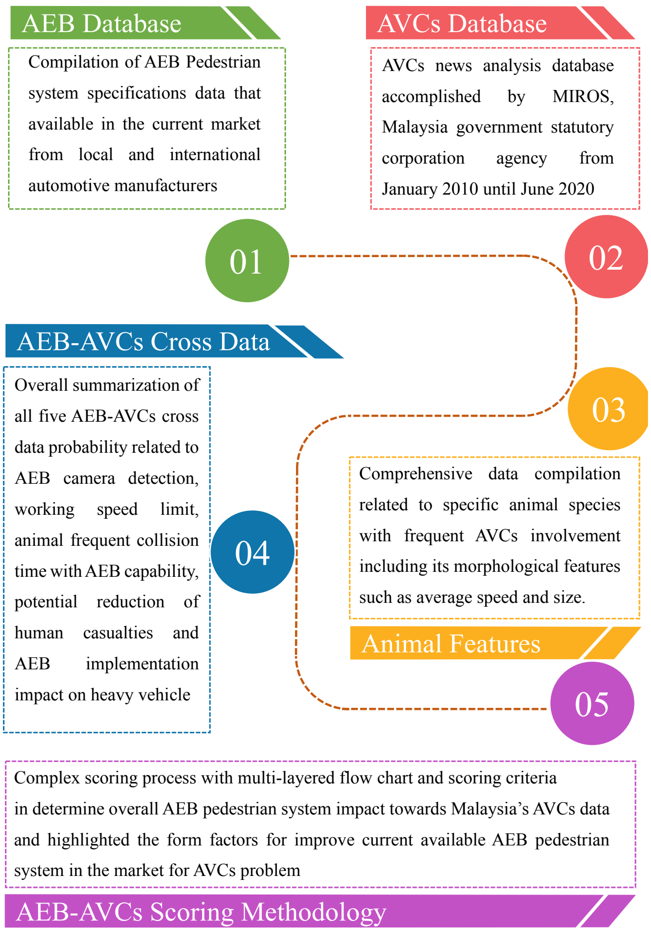

Figure 2 Five phases of AEB-AVCs data assessment for significant findings and finalised conclusion

In-Depth Description Of Major Process Flowchart

AEB Database

The collection of AEB pedestrian system specifications for the database relied on online resources obtained through internet searches. These resources were utilised to gather reliable information necessary to fulfil the requirements of the AEB database. Most of the information was sourced from trusted automotive manufacturers, specifically from their comprehensive owner's manuals, which allowed for comparing AEB pedestrian system technologies.

Originally, the intention was to extract information from benchmarking data provided by authorised benchmarking organisations accessible through their website portals. However, an alternative approach was adopted due to unresponsive replies and time constraints for completing the research paper.

The AEB pedestrian system database focused on three main technical specifications: the detection devices, which included cameras and radars, and the braking composition type, which represented the braking mechanism. These key points formed the basis for collecting data, which was further expanded to include more detailed information such as VTV and PTV speed detection, the speed range for optimal braking, and the AEB activation speed range. The collected information needed to be relevant for integrating with the system technology and AVCs database, as presented in Table 2, with the aim of highlighting the potential reduction in AVCs cases through the assistance of AEB pedestrian systems.

Table 1 Selected OEM Model for AEB-AVCs impact database assessment

No	OEM Model (Origin)	Segment
1	A (Local)	Sedan A-segment
2	B (International)	Sedan C-segment
3	C (International	Sedan D-segment
4	D (Local)	Hatchback B-segment
5	E (International	Hatchback B segment
6	F (Local)	SUV B
7	G (Local)	SUV B
8	H (International)	SUV C

AVCs Database

The limited availability of deer-related crash volume data poses a challenge to investigating deer-vehicle collisions (DVCs) and formulating strategic mitigation plans. Despite successful measures such as the implementation of fencing to prevent wildlife involvement in AVCs, the lack of representation of deer-related crash volumes can hinder the flow of research in identifying DVC hotspots. Therefore, it is crucial to ensure the inclusion of a substantial amount of reliable and relevant data sources to enhance the likelihood of successful outcomes in this research [9].

Table 2 AEB pedestrian system specification details from respective OEM models

OEM Model	Height Specifications (mm)	Horizontal Camera Angle	Vertical Camera Angle	Working Speed Activation (km/h)	Relative Vehicle Speed range (km/h)	Relative Pedestrian Speed range (km/h)
A	1525	± 50°	up 27° down 21°	4 - 80	4 - 100	4 - 50
B	1435	± 20°	± 4°	10 - 80	30 - 180	10 - 60
C	1452	± 52°	N/A	5 - 80	5 - 80	10 - 60
D	1515	± 40°	± 20°	4 - 80	4 - 80	4 - 50
E	1555	± 52°	N/A	5 - 60	5 - 80	5 - 60
F	1635	± 50°	up 27° down 21°	4 - 120	4 - 120	4 - 60
G	1609	± 52°	± 19°	4 - 70	4 - 150	4 - 70
H	1704	± 50°	± 28°	6.4 - 64	30 - 200	30 - 80

The AVCs database published in a journal by MIROS [3] provides comprehensive coverage of AVC occurrences on Malaysian roads over a period of 10 years. This database incorporates multiple investigational aspects, demonstrating the diversity and reliability of the information analysed. It serves as a primary reference for conducting cross-data assessments between AEB pedestrian systems and AVCs. While the database offers several notable findings that contribute to the general knowledge of AVCs, only four specific datasets have been identified for integration with the AEB pedestrian system specification database. These four datasets hold particular relevance to the research paper and are as follows:

1. Types of roadways in Malaysia with their perspective speed limits

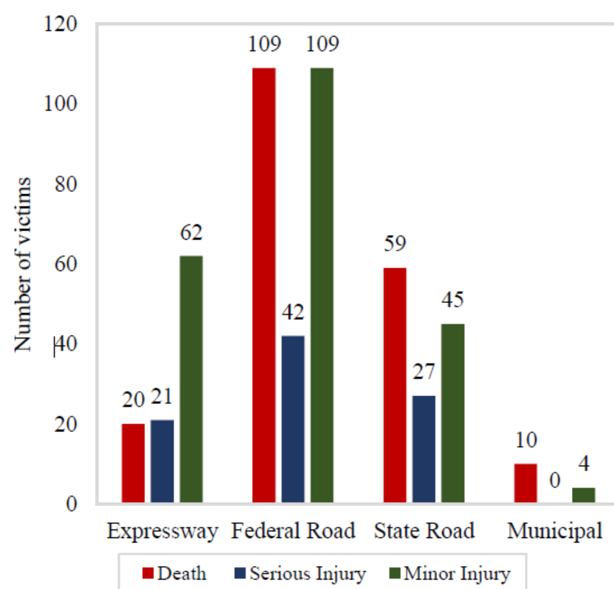

Figure 3 Victims reported based on types of roads

Table 3 Speed limits regulation based on types of roads

Types of roadways	Speed limits (km/h)
Expressway	110
Federal/State Road	90
Municipal	60

The statistical interpretation of speed limitations on specific roadways, in conjunction with the working speed range for activation of AEB pedestrian systems and the relative pedestrian speed range, serves as a cross-reference for animal detection. These aspects are further discussed in the general assumptions of the AEB-AVCs cross-database analysis.

OEM Model	Pickup Truck Model	OEM Model Height Specifications (mm)	Pickup Truck Model Height Specifications (mm)
A	Toyota Hilux	1525	1865
B	Toyota Hilux	1435	1865
C	Nissan Navara	1452	1825
D	Toyota Hilux	1515	1865
E	Nissan Navara	1555	1825
F	Toyota Hilux	1635	1865
G	Toyota Hilux	1609	1865
H	Toyota Hilux	1704	1865

2. AVCs collision time

The effectiveness of AEB pedestrian systems in relation to AVCs and collision time has encountered several challenges. The reliability and limitations of the AEB detection mechanism depend on the light intensity of the environment, in addition to the positioning of fundamental lighting components at the front edge of the vehicle. Other external factors, such as sudden changes in climate and road conditions, also contribute to the system's limitations. These factors are carefully considered and incorporated into the general assumptions for the AEB-AVCs scoring datasheet.

Table 4 Most significant AVCs time collision taken from its 2 lowest, 2 middle and 2 highest AVCs cases reported

AVCs Collision Time	Casualties number
Early Afternoon (12 p.m. – 2 p.m.)	6
Mid Afternoon (2 p.m. – 4 p.m.)	8
Late Night (4 a.m. – 6 a.m.)	22
Early Evening (6 p.m. – 8 p.m.)	36
Early Morning (6 a.m. – 8 a.m.)	42
Mid Evening (8 p.m. – 12 a.m.)	45

3. Potential AVCs human casualties' reduction

Among the reported cases in the car category, a total of 508 AVC cases involved 225 victims with identifiable evidence of casualties. Out of these, 64 cases resulted in death (28.44%), 35 cases in serious injuries (15.56%), and 126 cases in slight injuries (56%). On average, there were 6 deaths, 4 serious injuries, and 12 slight injuries per year. Therefore, based on the assessment of this cross-data probability analysis, it is estimated that there were 30 deaths, 20 serious injuries, and 60 slight injuries from 2016 to 2020. These numbers are evaluated to determine the potential reduction in human casualties when AEB systems are implemented within a five-year timeframe. Impact of AEB system implementation for heavy vehicles towards AVCs.

Another aspect of the cross-data assessment focuses on the impact of high-end technological evasive mechanisms, specifically the integration of AEB pedestrian systems in four-wheel drive pickup trucks. This assessment explores the implementation of similar AEB systems in respective original equipment manufacturer (OEM) pickup truck models, or alternatively, the Toyota Hilux is selected as a replacement if the OEM model does not offer a pickup truck vehicle. This selection is based on the statistical data indicating that the Toyota Hilux is the highest-selling off-road vehicle in Malaysia.

Animal Features

The investigation of AVCs in relation to the impact of AEB pedestrian systems necessitated the consideration of animal morphological aspects, which are crucial for cross-data assessment between AEB systems and

AVCs. A comprehensive animal kingdom information bank was used as a database, focusing on the animal species involved in recorded AVCs on Malaysian roads. The specific characteristics of these animal species included their bodily measurements, such as height and length, based on standard average dimensions, including differences between males and females. The selection of animal species was based on their significant representation in the AVCs data.

The height and length specifications for each animal species were compiled using a similar procedure employed in gathering reliable information for the AEB database. The accuracy and reliability of cattle wither height information was ensured through a specific research study conducted on cattle reproduction and breed characteristics in Malaysia [10]. For other animal species, average dimensions were used, considering the diverse breeds within each species. It is important to note that the total length (head to body) of four-legged animals did not include the length of their respective tails. Wither height referred to the position from the shoulder blade to the hooves of the four-legged animals. Generally, female species have smaller structures than their male counterparts, with the size difference typically around one-third of the scale, depending on the specific animal type. Based on the AVCs data, the dominating animal kingdom involved in the study was categorised into three classifications: livestock, including cattle, water buffalo, and chicken; wildlife, including pigs, monkeys, and snakes; and pet and stray animals, including dogs and cats.

AEB-AVCs Cross Data

In total, five sets of AEB-AVCs cross-impact data are applicable for an overall assessment, providing evidence of the potential of AEB pedestrian systems to avoid collisions between vehicles and animals. Each set of data contributes to the final findings related to reducing AVCs and casualties through the assistance of AEB systems. The technical procedures and framework used to assess the data, which vary for each AEB-AVCs cross-impact set, are critical for decision-making and determining the effectiveness of different AEB pedestrian system technologies.

AEB-AVCs General Assumptions

1. The distance between the animal species and the approaching vehicle is measured from the animal's body profile to the front grille component of the vehicle and set at 20 meters.
2. The animal species is positioned perpendicular to the direction of the approaching vehicle.
3. The animal species remains static and is located at the leftmost side of the road on the road with more than two lanes.

Table 5 Required animal specification dataset for AEB-AVCs impact assessment

Animal Species	General Height Specifications (cm)	Male (cm)	Female (cm)	General Length Specifications (cm)	Male (cm)	Female (cm)
Cattle	100 (wither)	127.42 ± 4.42	107.66 ± 0.78	N/A	162.56 ± 4.64	147.39 ± 0.55
Water Buffalo	150-190 (wither)	129-133	120-127	240-270	N/A	N/A
Chicken	70	30-45	30-45	70	30-45	30-45
Wild Boar	80	80	55	150	150	110
Monkey	11.7 - 100	56-72	55-62	11.7 - 100	56-72	55-62
Snake	30 (upright head position)	30	30	100-700	360-550	N/A
Dog	38 - 49	20-112	13-107	N/A	N/A	N/A
Cat	23-30	27	23	46	44	41

Table 6 Mathematical conversion data for length and height comparison with animal features

Vehicle Model (Camera)	Horizontal Angle Formula (^{0})	Length from Midpoint (m)	Vertical Angle Formula (^{0})	Height from Top Center (m)
A	tan (0.873)	23.84	tan (0.367)	7.68
B	tan (0.349)	7.28	tan (0.07)	1.4
C	tan (0.906)	25.52	N/A	N/A
D	tan (0.698)	16.76	tan (0.349)	7.28
E	tan (0.906)	25.52	N/A	N/A
F	tan (0.873)	23.84	tan (0.367)	7.68
G	tan (0.906)	25.52	tan (0.332)	6.88
H	tan (0.873)	23.84	tan (0.489)	10.64

4. The approaching relative vehicle speed falls within the effective range of the AEB system for the respective vehicle model, set at its peak range, with an average speed of 60 kph.
5. The road scenario involves a straight, flat interstate freeway with two lanes and a proper median strip, well-lit and highlighted with white road lines.
6. The driving time is in the early morning, from 6 a.m. to 8 a.m., with a clear and bright sunrise without any cloud formation.
7. The host vehicle has undergone regular maintenance, and no modifications have been made to the authentic automotive parts involved in the AEB pedestrian system. (This assumption does not apply to AEB-Animal Collision Time data assessment).

These general assumptions establish standard limitations for assessing all five sets of AEB-AVCs cross-impact data. Only the AEB-Animal Camera Detection, AEB-AVCs Human Casualties, and AEB-AVCs Heavy Vehicle Implementation data adhere to these original guidelines for scoring assumption settings. Other data sets require modifications due to the inherent variability in the assessed factors and to balance other influencing variables within the overall scoring methodology.

AEB-Animal Camera Detection

The AEB-Animal Camera Detection, set of data involves mathematical evaluation and focuses on the crucial components of the AEB pedestrian system, specifically the detection mechanism through the horizontal and vertical angles of the camera in response to the animal's body dimensions, including its height and length measurements. Given the initial assumptions, the evaluation is divided into two segments, each contributing to the scoring criteria. Both segments share the condition that a 5-meter distance has been set for AEB detection scoring.

The first segment involves converting horizontal angle data, representing the camera's horizontal field of view. The horizontal data is extracted from the vehicle, and the limitations of the camera's horizontal view are calculated using the Pythagorean theorem. This allows for detecting the animal's length based on the distance between the vehicle's camera and the animal's perpendicular body position. The horizontal camera action is taken at the midpoint of the animal's positioning. The second segment converts vertical angle data, representing the camera's vertical field of view. The vertical data is extracted from the vehicle, and the constraints of the camera lens's vertical angle are analysed using similar theorem evaluations. This enables the detection of the animal's height based on the distance between the camera and the animal. The vertical camera detection starts from the top of the animal's body and moves downwards.

AEB-Animal Working Speed Limit

The AEB-AVCs assessment followed general assumptions, with the exception of a modification in point (d) concerning the effective range of AEB systems for respective vehicle models, considering the approaching relative vehicle speed within the legal speed limits of Malaysian roads. The assessment covered the following road scenarios:

1. Straight highways with three lanes and a divider, well-lit and marked with white road lines.
2. Straight federal highways with three lanes and a median strip, well-lit and marked with white road lines.
3. Straight interstate freeways are similar to federal highways but have two lanes.
4. Straight municipal roads, similar to the previous scenario, but with one lane in each direction and no proper divider, only white road lines.

This assessment relied on a hypothetical relationship between the Malaysia road speed limits and the working speed range of AEB activation, considering the detection range of relative pedestrian speed.

AEB-Animal Collision Time

The AEB-AVCs assessment followed general assumptions, with the exception of modifications in points (e) and (f), which accounted for variations in street lighting and driving time. The assessment considered the following periods and weather conditions:

1. Early morning (6 a.m. to 8 a.m.), bright sunrise with no cloud formation.
2. Early afternoon to mid-afternoon (12 p.m. to 4 p.m.), high sun positioning with subtle cloud formation.
3. Early evening (6 p.m. to 8 p.m.), early sunset with a darker pale orange surrounding indicating nighttime approaching.
4. Mid-evening to late night (8 p.m. to 10 p.m., 4 a.m. to 6 a.m.), nighttime conditions with clear sky, full moon, and starry night, without rain.

Considering the intensity of light or real-time collision data extracted from MIROS news analysis, the dependability of AEB systems on operational lighting intensity during both daytime and nighttime, along with headlamp assistance and streetlights, significantly affected detection and braking initiation. Operational limitations were found in the owner's manuals of all vehicle models and included the following:

1. High exposure to sunlight over a period of time could interrupt system performance (Daytime Limiter 1, D1).
2. Sudden changes in light intensity, such as entering a tunnel or experiencing weather changes, affect system functionality (Daytime Limiter 2, D2).
3. Lack of disclosed specific values for adequate light intensity, with vehicle models mentioning dark and dim environments, including the subtle taillights of preceding vehicles and low intensity of the vehicle's own headlamps (Nighttime Limiter 1, N1).
4. Modifications to the headlamp and fog lamp could inhibit the AEB system's overall performance (Nighttime Limiter 2, N2).

Table 7 shows the limitation indicators found on each OEM model of AEB pedestrian systems related to light intensity.

Table 7 The limitation indicator found on each OEM model of the AEB pedestrian system related to light intensity

OEM Model	Light intensity limitation indicator
A	N1 and N2
B	D1, D2 and N2
C	D2 and N1
D	N1 and N2
E	D2 and N2
F	N1 and N2
G	D1 and D2
H	N1 and N2

AEB - Animal-Vehicle Collision Human Casualties

This impact data assessment heavily relied on the scoring methodology, requiring cumulative scores from the previous three AEB-AVCs data assessments. The assessment focused on the potential reduction of human casualties in animal-vehicle collisions in Malaysia.

AEB - Animal-Vehicle Collision Heavy Vehicle Implementation

The data evaluation in this section followed a similar analysis style as the AEB-Animal Camera Detection data, providing information on the height and length of the animal species involved. However, the specific focus was on implementing AEB camera specifications for available pickup truck vehicles, either from the OEM's product line or through a neutral choice, such as the Toyota Hilux.

AEB - Animal-Vehicle Collision Scoring Methodology

The scoring system for assessing the impact data of AEB-AVCs had its own standardised values ranging from 0, 0.5, to 1, representing different outcomes. These values were assigned based on the system's ability to detect and avoid collisions between vehicles and animals, considering the specified variables of AVCs data.

AEB - Animal-Vehicle Collision Scoring Value

The scoring indicators were 0, 0.5, and 1, each representing a conclusive outcome. A score of 0 indicated a failure in animal detection, resulting in an unavoidable collision and major damage. A score of 0.5 indicated a failure in collision avoidance, resulting in low levels of damage. A score of 1 indicated successful collision avoidance, with the AEB system detecting the animal and initiating appropriate warning signals and brake pressure to prevent a collision.

AEB - Animal Camera Detection/AEB-AVCs Heavy Vehicle Scoring Criteria

The evaluation of Animal-Vehicle Cross Length Detection and Animal-Vehicle Cross Height Detection involved comparing data from the front vehicle camera's horizontal and vertical angles with animal side profiles. The final scoring criteria were determined based on specific parameters:

1. A score of 0 was given when the animal's length and height were out of range for camera detection (less than 25% of camera angle detection).
2. A score of 0.5 was given when the animal's specifications were within the detection range but could not be accurately defined (intersection between 25% and 75% of camera angle detection).
3. A score of 1 was given when the animal's characteristics were within the detection range, allowing for proper image processing (more than 75% of the camera detection angle).

AEB - Animal Working Speed Limit

The evaluation of Road Types involved comparing available data on speed limits on Malaysian roads. The AEB system's Working Speed Activation Range established the system's effective range, while the Relative Vehicle Speed Range represented the probability of a collision occurring due to the animal's potential to exceed 110 km/h. The Relative Pedestrian Speed Range served as an indicator for successful collision prevention by the AEB system.

1. A score of 0 was given when the vehicle's speed in the respective road types could not avoid a collision, exceeding the maximum relative vehicle speed range.
2. A score of 0.5 was given when the vehicle's speed in designated road types resulted in low damage to internal and external surroundings, driving within the relative vehicle speed range.
3. A score of 1 was given when the vehicle's speed in dedicated road types resulted in zero collisions, indicating successful operation of the AEB system and driving within the relative pedestrian speed range.

AEB - Animal Collision Time

The evaluation of Lighting Intensity involved comparing collision time data during different

Table 8 Final scoring for AEB-Animal camera detection

OEM Model \ Animal type		Livestock	Wildlife	Pet and Strays	Final Score
Sedan	A	1	1	1	1
	B	1	1 except 0.5 for snake	1	1
	C	1	1	1	1
Hatchback	D	1	1	1	1
	E	1	1	1	1
SUV/MPV	F	1	1	1	1
	G	1	1	1	1
	H	1	1	1	1
	Final reduction percentage (%)	100%	100% (94% for snake)	100%	

periods: two bottom-range, two mid-range, and two top-range scenarios. The assessment considered the AEB system's Scope of Reasoning, which had similar limitations across all vehicle models.

1. A score of 0 was given when all data summarisation indicated collisions during both daytime and nighttime.
2. A score of 0.5 was given when at least one of the daytime and nighttime indicators was available for each vehicle model.
3. A score of 1 was given when there were no indications of collisions during daytime and nighttime or when only one of the four indicators from data summarisation was present, similar to the previous scoring criteria.

Special cases for scoring were identified:

When only D1 and D2 were highlighted, it indicated that the AEB system functioned well during nighttime. When only N1 and N2 were highlighted, it indicated that the AEB system was fully operational throughout the daytime journey.

AEB - Animal-Vehicle Collision Human Casualties

The evaluation of potential casualties reduction involved comparing the rates of death, serious injury, and minor injury resulting from animal-vehicle collisions in Malaysia. The previous three final scores from the AEB system's cross-data probability assessment were added, and the resulting value determined the final verdict before scoring the potential casualties reduction.

1. A score of 0 was given when the finalised value fell between 0 and 1 for each vehicle model.
2. A score of 0.5 was given when the finalised value fell between 1 and 2 for each vehicle model.
3. A score of 1 was given when the finalised value fell between 2 and 3 for each vehicle model.

The final scoring criteria, based on the general AEB-AVCs scoring values, were as follows:

1. A score of 0 was given when the final accumulated score was lower than the level of casualties for each vehicle model.
2. A score of 0.5 was given when the final accumulated score matched the respective degree of casualties for each vehicle model.
3. A score of 1 was given when the final accumulated score was higher than the level of casualties for each vehicle model.

The final percentage was calculated by dividing the final value by the overall total and multiplying by 100%.

Table 9 Final scoring for AEB-Animal working speed limit

OEM Model \ Speed Limit		Expressway (110 km/h)	Federal Road (90 km/h)	State Road (90 km/h)	Municipal Road (60 km/h)	Final Score
Sedan	A	0	0.5	0.5	0.5	0.5
	B	0.5	0.5	0.5	1	0.5
	C	0	0	0	1	0
Hatch Back	D	0	0	0	0.5	0
	E	0	0	0	1	0
SUV/MPV	F	0.5	0.5	0.5	1	0.5
	G	0.5	0.5	0.5	1	0.5
	H	0.5	0.5	0.5	1	0.5
	Final reduction percentage (%)	25%	31.3%	31.3%	87.5%	

RESULT AND DISCUSSION

Multiple factors require careful attention in reducing the frequency of AVCs after conducting an in-depth analysis of AVC patterns. It has been observed that animal behaviour in daily life and driver attitudes during high-frequency animal crossings can play a crucial role in resolving this unforeseen problem [11]. Various measures can be implemented, such as cost-effective fencing construction, frequent road notification signs for animal crossings, and lower speed limits, to ensure the responsibility of everyone using the road to drive appropriately without endangering other drivers and the environment [11]. This prevention approach is supported by reliable sources investigating the risk factors associated with different types of accidents, indicating that AVCs often occur due to failure to adhere to speed limit regulations, improper fencing positioning, and inadequate lighting conditions [12].

With the significant advancements in ADAS technology, particularly in applying AEB pedestrian systems, there is now an opportunity for immediate mitigation of accidents involving animals using high-precision detection systems and responsive braking mechanisms, regardless of the type of road being used. The application of AEB pedestrian systems can serve as a crucial catalyst for reducing the incidence of AVCs, in addition to the road safety responsibilities of the relevant authorities responsible for road construction and maintenance.

AEB-Animal Camera Detection

The effectiveness of AEB-Animal Camera Detection in mitigating AVCs was evaluated using a scoring system. Table 8 presents the final scores for AEB-Animal Camera Detection for different animal types across various OEM vehicle models. The results indicate that all OEM models achieved a final score of 1, except for model B, which scored 1 for most animal types except for snakes, where it scored 0.5. Overall, implementing AEB pedestrian systems led to a 100% reduction in AVCs, except for snake-related incidents, where a 94% reduction was achieved due to limitations in the camera's ability to detect snakes.

AEB pedestrian systems with advanced camera detection capabilities have proven highly effective in reducing AVCs. The different OEM vehicle models compared regarding their AEB system operational methods exhibited reliable and unmatched performance in detecting sudden target objects, irrespective of whether they were living or non-living obstacles.

AEB-Animal Working Speed Limit

The overall findings reveal a relationship between the working speed range of the AEB pedestrian system in relation to the VTV and PTV speeds allowed on

Table 10 Final scoring for AEB-Animal collision time

OEM Model \ Collision Time	Low frequency		Middle frequency		High frequency		
	12 p.m. – 2 p.m.	2 p.m. – 4 p.m.	4 a.m. – 6 a.m.	6 p.m. – 8 p.m.	6 a.m. – 8 a.m.	8 p.m. – 10 p.m.	Final Score
A	1	1	0.5	0.5	0.5	0.5	0.5
B	0.5	0.5	0.5	0.5	0.5	0.5	0.5
C	0.5	0.5	0.5	0.5	0.5	0.5	0.5
D	1	1	0.5	0.5	0.5	0.5	0.5
E	0.5	0.5	0.5	0.5	0.5	0.5	0.5
F	1	1	0.5	0.5	0.5	0.5	0.5
G	0.5	0.5	1	1	1	1	1
H	1	1	0.5	0.5	0.5	0.5	0.5
Final reduction percentage (%)	75%	75%	56.3%	56.3%	56.3%	56.3%	

Malaysian roadways according to standard rules and regulations. It can be observed that the AEB pedestrian system has a lesser impact at higher speed limits, indicating its true capability in reacting to both vehicles and pedestrians within its lower speed range, despite the system requiring a broader range of activation speeds. The assistance provided by the AEB system in avoiding total crashes achieved an 87.5% success rate only in municipal road areas, while the remaining contribution from its highest PTV speed range did not reach the maximum speed limits, resulting in a score of 0.5.

Among the different vehicle segments, SUV/MPV vehicles dominated, but they only scored 0.5 in total, indicating a failure in crash avoidance with minimal property damage and injury to both the driver and the animal. However, it is noteworthy that the overall interpretation of the results showed relatively unsatisfactory scoring, with three selected vehicle models failing to mitigate AVCs and being susceptible to a high degree of injury suffered by both the driver and the animal.

AEB-Animal Collision Time

From a general perspective, the analysis of the finalised reduction percentages in relation to three different sets of AVCs collision frequencies indicates positive outcomes associated with the performance of the AEB system. These outcomes suggest a potential decline of over 50% in the current majority value of AVCs occurrences during nighttime situations. Furthermore, there is a three-quarters possibility of preventing total collision courses evaluated during peak daytime hours when high traffic movement is expected, regardless of the type of roadways.

Regarding the impact assessment data of the AEB-AVCs relationship, OEM model G stands out with its remarkable capability for detecting low light intensities. This is evident in the scoring marks provided in Table 10, which indicate a zero probability of AVCs incidents occurring at nighttime. However, this model does have a technological limitation during the daytime, as prolonged camera exposure to high temperatures from the interior and exterior of the vehicle can negatively affect the overall operation of the AEB system. On the other hand, the other compared OEM models received identical scoring of 0.5, implying a likelihood of AVCs occurring with a relatively lower intensity of damage experienced by both sides involved in the collision.

AEB-AVCs Human Casualties

The aggregation of the three previous finalised data scorings, represented by each OEM model, has

Table 11 Final scoring for AEB-AVCs Human Casualties

OEM Model \ Casualties type in 2016 - 2020	Death (30)	Seriously Injured (20)	Slightly Injured (60)	Final Score
A	1	1	1	1
B	1	0.5	1	1
C	1	0.5	1	1
D	1	0.5	1	1
E	1	0.5	1	1
F	1	1	1	1
G	1	1	1	1
H	1	1	1	1
Final reduction percentage (%)	100%	75%	100%	

Table 12 Final scoring for AEB-AVCs heavy vehicle implementation

OEM Model (camera) \ Animal type	Pickup Truck Model Conversion	Livestock	Wildlife	Pet and Strays	Final Score
A	Toyota Hilux	1	1	1	1
B	Toyota Hilux	1	0.5	0.5	0.5
C	Nissan Navara	1	1	1	1
D	Toyota Hilux	1	1	1	1
E	Nissan Navara	1	1	1	1
F	Toyota Hilux	1	1	1	1
G	Toyota Hilux	1	1	1	1
H	Toyota Hilux	1	1	1	1
	Final reduction percentage (%)	100%	94%	94%	

assessed the potential reduction in human casualties resulting from AVCs. By implementing the AEB pedestrian system five years ago, based on the AVCs statistical database, it is projected that the possibility of zero deaths, one-fourth of cases categorised as serious injuries, and zero cases of minor injuries could have been achieved.

Various factors, such as the rate of camera detection competency, the system's working speed range relevant to animal detection, and the frequency of AVCs collisions over time, have been considered to evaluate the overall performance of the AEB pedestrian system in protecting human lives. These assessments were conducted considering the different types of roads and time periods, taking into account the randomised occurrence of AVCs incidents in the absence of adequate warning signs and driver responsibility. Consequently, the execution of the AEB pedestrian system has demonstrated its potential as a life-saving solution for AVCs cases. In comparing OEM models, each model achieved a finalised score of 1, indicating their effectiveness in mitigating AVCs incidents.

AEB-AVCs Heavy Vehicle Implementation

Moreover, in addition to the successful performance of the AEB pedestrian system across three prominent vehicle segments, encompassing classical sedan chassis, compact hatchbacks with ample cargo space, and family-oriented SUV/MPV variants, the adaptability of this system must be extensively validated for heavy vehicle types, specifically the pickup truck segment. It is essential to explore the system's capability and performance when dealing with the robust and substantial physical characteristics inherent to pickup trucks.

Although the detection mechanism is primarily affected by the vertical angle variation caused by the height disparity, a similar evaluation of scoring is observed in the initial assessment of AEB-AVCs impact data, which focuses on the camera's technological specifications for providing precise feedback to the AEB pedestrian system in partial braking application, however, the identical limitation identified in the OEM model B also influences the finalised reduction percentage due to the significantly larger dimensions of pickup trucks, rendering the height of each designated animal species beyond the range of detection as per the camera specifications.

CONCLUSION

The potential for the AEB pedestrian system to evolve into a comprehensive ADAS becomes evident when considering the increased complexity and challenging perspectives introduced into the testing scenarios. This includes incorporating randomised longitudinal and lateral collective movements and partial pedestrian occlusion testing setups [13]. The research paper emphasises the need for continued efforts and time-consuming advancements to fully mature the AEB pedestrian system's capabilities, as it has not yet achieved its highest competency in total collision avoidance. Integrating the existing AEB pedestrian system with complex test scenarios is crucial for advancing this technology and can significantly reduce statistical casualty rates, aiming for zero fatalities in AVCs.

Regarding the probability of AVCs experiencing a declining growth pattern, implementing AEB pedestrian system technology undoubtedly contributes to achieving the desired goal of zero reported AVCs. This is accomplished by developing highly precise detection maneuvers and swift adaptive feedback for the vehicle braking system, enabling autonomous braking activation in sequential stages, ranging from partial to full braking force. The assessment of camera detection and sensitivity to lighting conditions, which received high scores across competitive OEM models equipped with their exclusive AEB pedestrian systems, has transformed life-threatening situations into life-saving experiences. While there are limitations regarding the relative VTV and relative PTV speed ranges for timely detection, analysis, and information transmission to the AEB pedestrian system's brain unit, it still offers significant improvements in AVCs cases, prioritising advanced safety protection features in modern driving experiences.

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