Journal of the Society of Automotive Engineers Malaysia
Volume 3, Issue 3, pp 320-332, September 2019
e-ISSN 2550-2239 & ISSN 2600-8092

Calculating the Brake-Application Time of AEB System by Considering Maximum Deceleration Rate during a Primary Accident in Penang's Urban Road

M. F. H. Rani[1,2], S. Abu Bakar[*1,2], M. S. M. Hashim[1,2], A. Harun[1,3], Z. M. Razlan[1,2], W. K. Wan[1,2], I. Zunaidi[1,2], I. Ibrahim[1,2], M. Afendi[1,2], N. E. Efi[1,2], M. Dalib[4] and S. S. Mat Rudin[5]

[1]Motorsports Technology Research Unit (MoTECH), Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
[2]School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
[3]School of Microelectronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
[4]Road Transport Department of Malaysia, 62100 Putrajaya, Malaysia
[5]Penang Traffic Enforcement and Investigation Department, 10760 Pulau Pinang, Malaysia

[*]*Corresponding author: shahriman@unimap.edu.my*

ORIGINAL ARTICLE *Open Access*

Article History:

Received
20 Oct 2018

Received in revised form
22 Jun 2019

Accepted
24 Jun 2019

Available online
1 Sep 2019

Abstract – *An experimental study of the brake-application time of Autonomous Emergency Braking (AEB) system considering the primary accident in an urban area was proposed. Since the functionality of the brake-application time is varied between manufacturers and models, the brake-application time of AEB system must be verified based on driving behaviour in Malaysia. A primary accident was simulated to acquire vehicle deceleration rate in real condition by driving an ego vehicle at a different set of vehicle speeds. The study is focussed on the urban roads in the north region of West Malaysia, i.e. Penang. As a benchmark in this study, the brake-application time (2.6 s) introduced by Mercedes-Benz in the PRE-SAFE® Brakes technology was referred. A new braking permission time was proposed by calculating a minimum deceleration distance and Time-to-Collison (TTC) confirmation time required to brake based on maximum deceleration when a primary accident was simulated. It was found that the brake-application time recommended for the AEB system, specifically AEB City conveys the real driving condition of Penang when a primary accident happens in the urban area. To have a smooth braking and an optimum braking performance during a primary accident, the Forward Collision Warning (FCW) should be activated at TTC ≤ 4.6 s. The partial braking (PB) should be activated automatically when the TTC is approximately 2.9 s. While the automated full braking (FB) phase should begin when the TTC reaches 1.1 s.*

Keywords: Autonomous Emergency Braking (AEB), Time-to-Collision (TTC), brake-application time, road accident, deceleration rate

Journal homepage: www.jsaem.saemalaysia.org.my

1.0 INTRODUCTION

Road accident statistics 2017 recorded by Traffic Investigation and Enforcement Department of the Royal Malaysia Police shows that there is 533,875 total number of reported accidents in Malaysia (RMP, 2018). Majority of accidents especially rear-end collision are caused either by a delay of braking time or insufficient braking force (Dawson et al., 2018). A driver may fail to brake successfully if there is a distraction on the road that causes a driver to drive inattentively (van Huysduynen et al., 2018). For instance, a critical situation such as primary accident may happen in the blink of an eye (Rani et al., 2018). Any unexpected or sudden braking by the driver ahead is difficult to predict due to poor visibility (Saffarian et al., 2015). A brake response time during a critical situation plays an important role too towards the brake-capacity (Ruscio et al., 2015). As most people are not used to dealing with such a critical situation, they may not apply enough braking force to avoid a collision. Besides, some of them do not brake at all because there is limited time to react.

Nowadays, car manufacturers are promoting safer cars equipped with Autonomous Emergency Braking (AEB) system to help the driver in avoiding imminent road accident or in mitigating the severity of collision (Euro NCAP, 2018). The AEB system acts independently of the driver's action to avoid or mitigate the accident, which will intervene only in a critical situation and try to avoid the accident by applying the brakes. The system comes in three categories specified for low speed (AEB City), for high speed (AEB Interurban) and vulnerable road users (VRUs) – i.e. pedestrians and cyclists (Euro NCAP, 2018). Figure 1 illustrates the basic operations of the AEB system, which mainly consists of the remote sensing technology, the Engine Control Unit (ECU) and the Electronic Stability Control (ESC).

The brake-application phase can be defined as illustrated in Figure 2. The AEB system is designed to prevent rear-end collision and sense potential hazards ahead of the vehicle through remote sensing technologies such as radar, LIDAR and cameras (ANCAP, 2012). The information is combined with what the vehicle knows of its travel speed and trajectory through an Engine Control Unit (ECU) to determine whether a critical situation is emerging or not. When a vehicle approaches the hazard, the system will warn the driver with audio and display warnings (Shimazaki et al., 2018). At the same time, the brakes will also be partially charged. If there is no action by the driver in a set of time and a collision is still expected, a full braking will be applied.

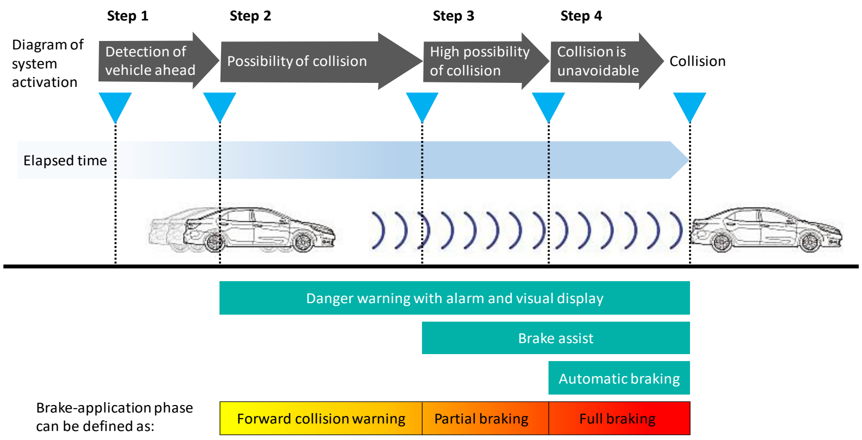

Figure 1: Brake-application phase based on stages of AEB system function to avoid rear-end collision (SAIPA, 2018)

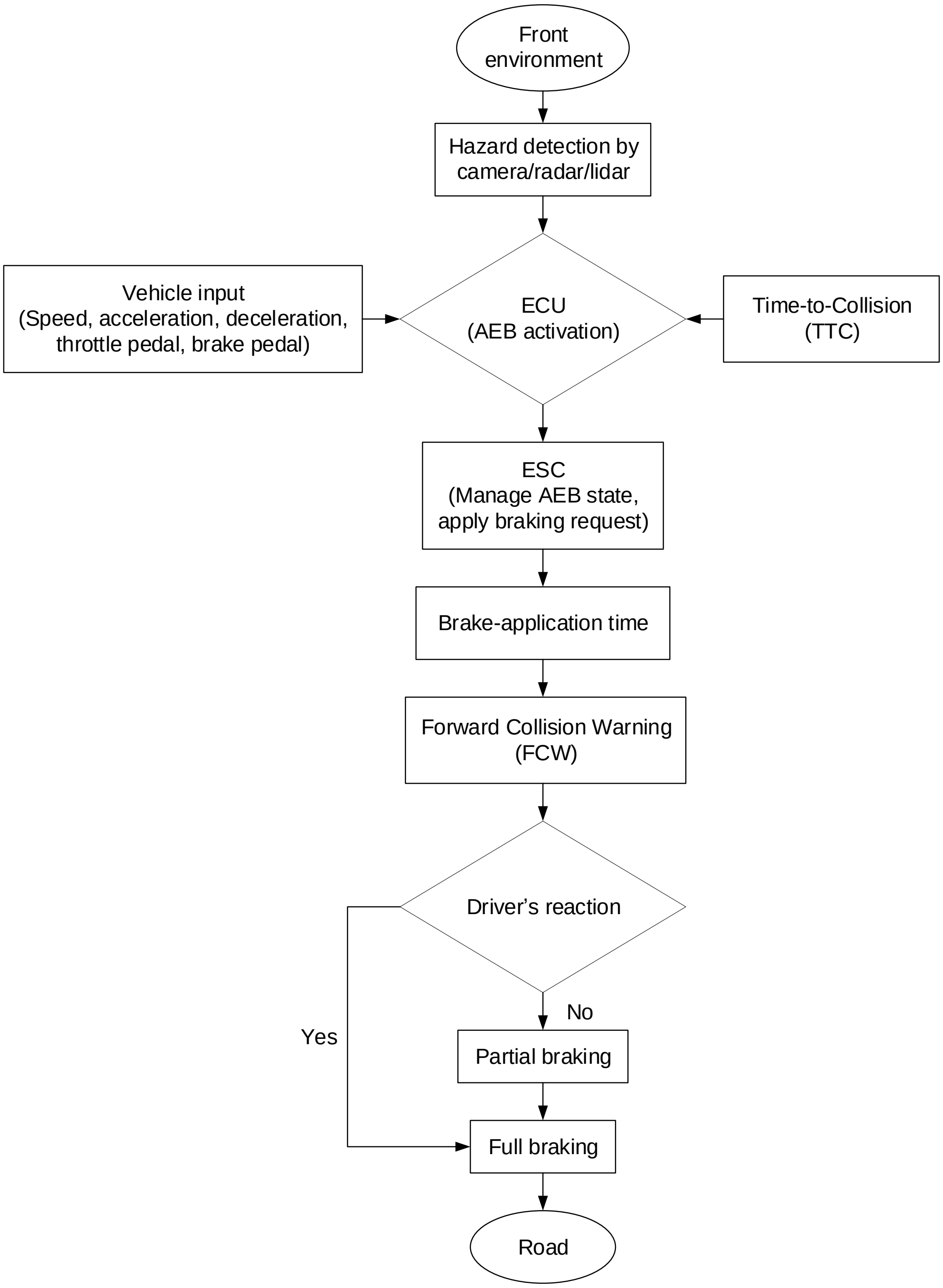

Figure 2: Basic operations of the AEB system (Caspar et al., 2017)

1.2 Problem Statement

In general, the AEB system can improve safety in two ways. Firstly, this system helps drivers to avoid accidents by identifying critical situations early and warn the drivers. Secondly, the system reduces the severity of crashes if the accident cannot be avoided by lowering the speed of collision (Cicchino, 2017). Both aspects are closely related to the brake-application time, which vary between manufacturers and models. As illustrated in Figure 3, the brake-application time determines the activation phase of Forward Collision Warning (FCW), partial braking (PB) and full braking (FB).

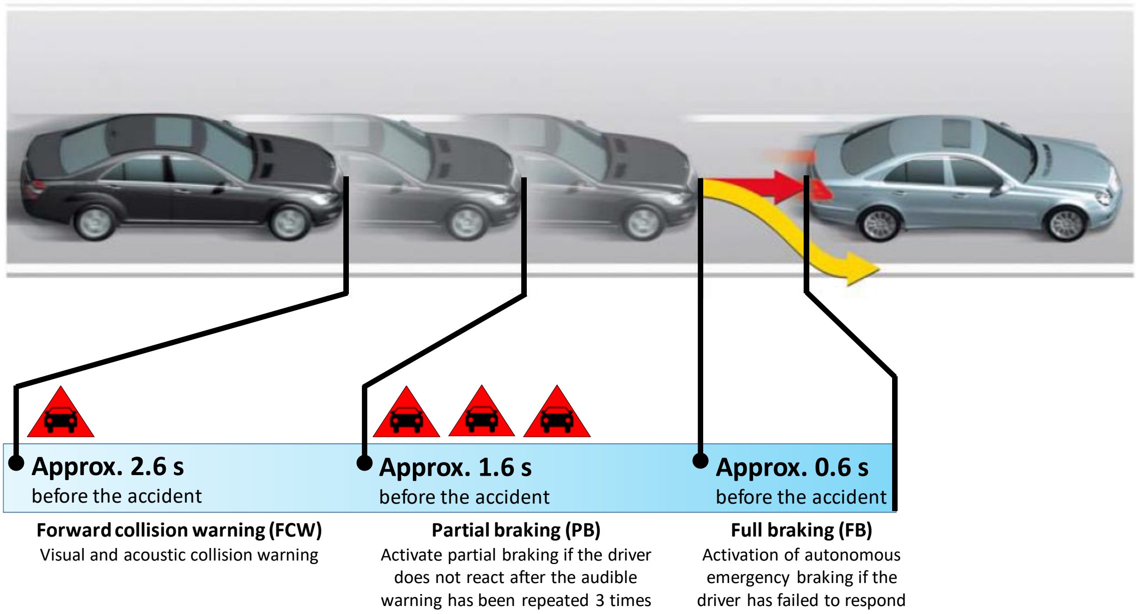

Figure 3: Brake-application time provided by PRE-SAFE® Brakes technology in typical rear-end collision situation (Grover et al., 2008)

Since the system is not fully mature in Malaysia, further investigation on the brake-application time is necessary (Md Isa et al., 2015). The emergence element of interest on the road such as primary accident causes the drivers to be distracted. Without forward collision warning, a driver may fail to brake not only at the right the time, but also without sufficient capacity. The AEB system has been promoted worldwide about a decade ago and has become one of the biggest innovations in car safety technology since the seat belts (ANCAP, 2012). Matthew Avery from Thatcham Research (vehicle safety technology) believes that other than the seat belts, the AEB should be a legal requirement too for vehicles (Simon, 2018). The safety technology system can reduce crashes by 40%, saving lives, preventing injuries and accidents. It is estimated that it could prevent thousands of fatalities and casualties over a decade (McCarthy, 2018).

Through ASEAN NCAP's initiative (Abu Kassim, 2018), a roadmap has been outlined in preparing the readiness of safety technology for the ASEAN market, which includes the AEB system. However, an AEB system, which does not reflect the driving condition of Malaysia will not be able to exhibit accurate brake performance on actual primary accident. Therefore, a study is required to determine the suitable brake-application time of AEB system in Malaysia that considers the maximum vehicle deceleration rate during a primary accident in an urban area. Simulation of a primary accident in one of the urban roads of Penang is conducted to acquire the maximum vehicle deceleration rate. The value will be used to propose a brake-application time by calculating the minimum deceleration distance and Time-to-Collision (TTC) confirmation time required to brake. This paper is mainly focussed to propose the brake-application time for AEB system specifically AEB City by considering a primary accident in urban areas.

2.0 EXPERIMENTAL SETUP AND METHODOLOGY

Previously, the brake-application time in AEB system was determined by the TTC risk index (Lin et al., 2015). It can be defined as the ratio of relative distance, S_{rel} and relative velocity, V_{rel} as shown in Eq. (1). In this paper, the maximum deceleration rate during a primary accident is considered to predict the brake-application time. In order to obtain the maximum deceleration rate, simulation of a primary accident is conducted in the selected urban road of Penang. The details of the data collection will be discussed further in the next section.

The proposed AEB system applies full braking when the $TTC \leq TTC_{min}$, by comparing the TTC collision-risk index and a new risk index that considers a maximum deceleration rate during the primary accident, TTC_{min}. Eq. (2) depicts the equation for calculating the TTC_{min}. As shown in Eq. (3), the minimum deceleration distance, S_{min} is calculated based on the velocity of ego vehicle, v_i at deceleration time, t = i. The maximum deceleration rate, a_{max} is calculated by assuming a vehicle is decelerating at a constant rate as summarized in Eq. (4). When a vehicle is running and approaching a primary accident, if Eq. (5) is satisfied, the AEB system can function to avoid a collision by applying full braking to the vehicle. Figure 4 provides a flowchart for the proposed brake-application time in the AEB system, which is considering a maximum deceleration rate during the primary accident in an urban road of Penang.

$$TTC = \frac{S_{rel}}{V_{rel}} \tag{1}$$

$$TTC_{min} = \frac{S_{min}}{V_{rel}} \tag{2}$$

$$S_{min} = v_i\, t + \frac{1}{2} a_{max} t^2 \tag{3}$$

$$a_{max} = \frac{v_{i+1} - v_{i-1}}{2} \tag{4}$$

$$TTC \leq TTC_{min} \tag{5}$$

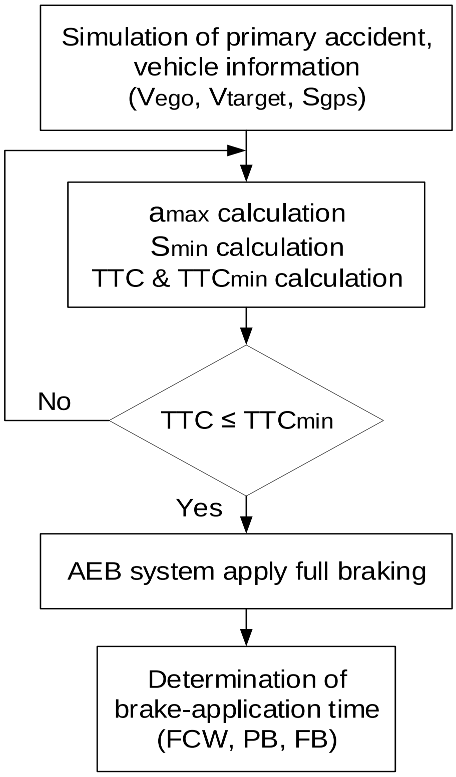

Figure 4: Flowchart of the proposed brake-application time study in the AEB system by considering the maximum deceleration rate during the primary accident

2.1 Route Selection

Figure 5 shows the selected road as the location of the experiment, which is Jalan Butterworth – Taiping (through Prai area). In order to represent an urban road in Malaysia, the road was selected due to its highest traffic flow in Penang. According to Road Traffic Volume Malaysia (RTVM) version 2016 (KKR, 2017), the Level of Service (LOS) of the selected road is considered to be LOS F, which experiences extreme congestion during peak hour. In addition, the route was found to be one of the most frequent crash locations in Penang, which is good to study the driving behaviour of Malaysians when a primary accident happens. The route comes in a dual carriageway and possesses sufficient length for data collection.

2.2 Data Collection

A general car was used as the ego vehicle. Before conducting the data collection, the brakes and tyres of ego vehicle were checked to be in good condition. The maximum deceleration rate was acquired by establishing a scenario of a primary accident as illustrated in Figure 6. By adapting the chase car method in the previous study (Galgamuwa et al., 2015), the ego vehicle will start chasing the target vehicle about 1 km before reaching the accident location. For every data collection, the two-second rule must be obeyed by the driver when pursuing the target car (Murphy, 2017). This precaution is important to ensure there is sudden braking before reaching the accident location.

At the same time, the speed-time data of ego vehicle was recorded by using on-board diagnostics (OBD) GPS scanner. When reaching 200 m before the accident location, a deceleration mode of the target vehicle is expected to start. The ego vehicle will imitate the behaviour of the target vehicle to acquire the maximum deceleration rate during the simulation of an accident. The test distance in determining the vehicles deceleration rate was set to be 200 m in accordance with the radar sensors capability for both short and long-range applications (Grover et al., 2008).

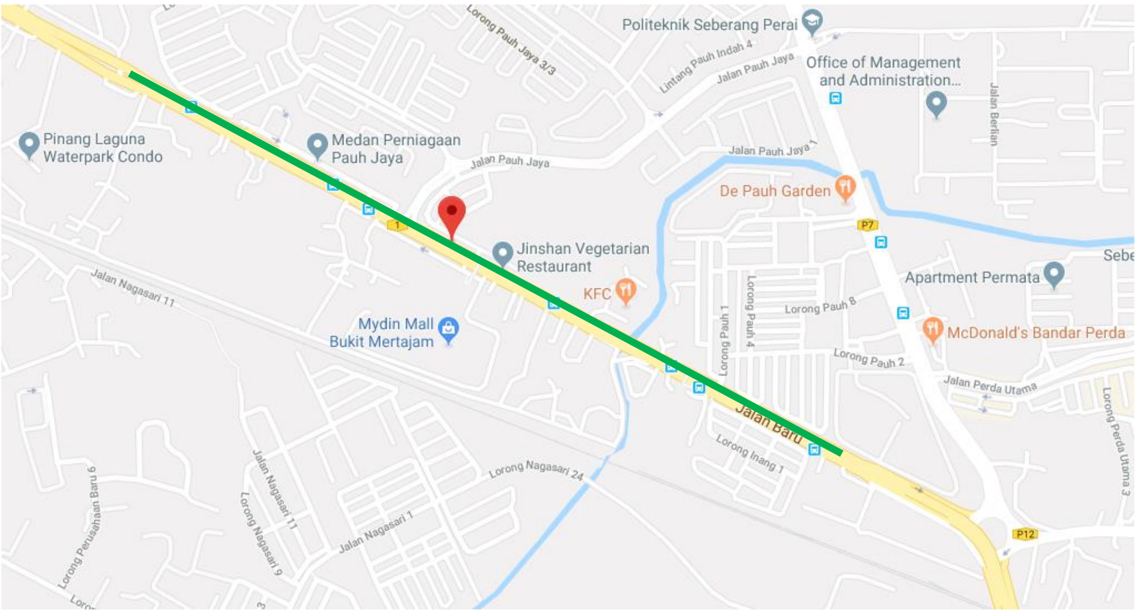

Figure 5: Location of the experiment based on Google Maps (coordinate: 5.370181, 100.414789)

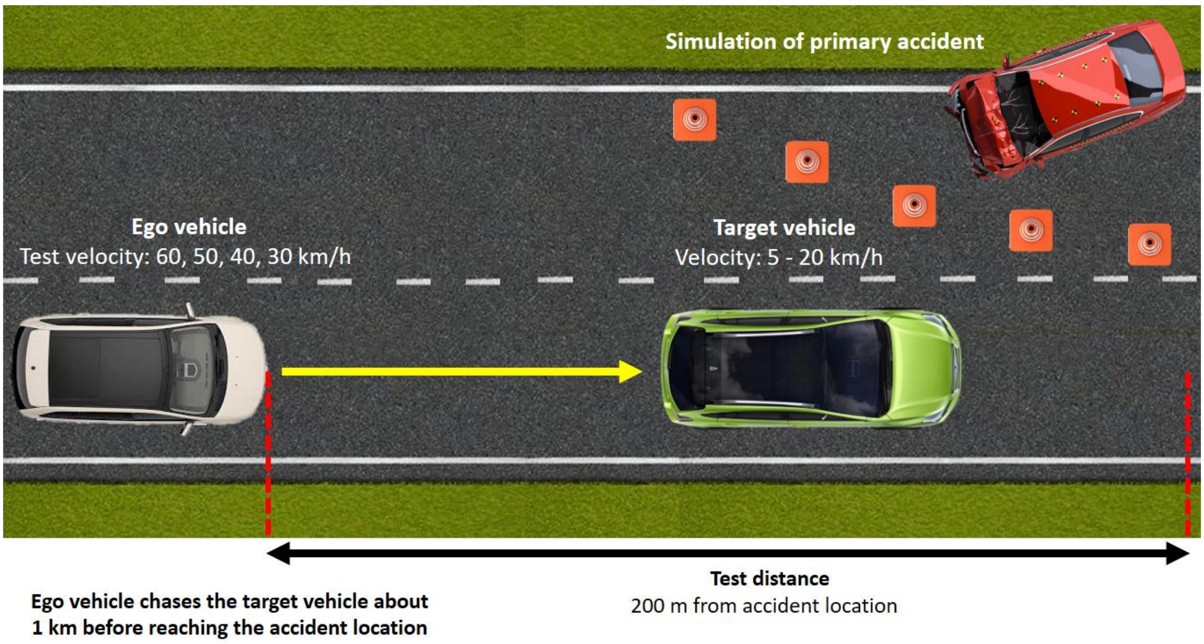

Figure 6: Simulation of the primary accident for data collection

3.0 RESULTS AND DISCUSSION

All the data collection was conducted during off-peak hour condition (morning and evening) to avoid any unwanted casualties and extreme road congestion. A series of ego velocity (60, 50, 40 and 30 km/h) was tested for every sample during the experiment while chasing the target vehicle. Table 1 summarizes the maximum deceleration rate acquired during the simulation of the primary accident. The deceleration rate was found to be inconsistent as it depends on the behaviour of the driver when braking.

Table 1: Maximum deceleration rate acquired during simulation of the primary accident

No. of samples	Maximum deceleration rate (km/h/s)
Sample 1	6.120
Sample 2	3.816
Sample 3	4.968
Sample 4	6.462

Once the maximum deceleration rate was acquired for each sample, the TTC risk index and TTC_{min} risk index were calculated to predict the brake-application time, which consists of time to activate forward collision warning (FCW), time to activate partial braking (PB) and time to activate full braking (FB). Table 2 summarizes the calculated TTC risk index and TTC_{min} risk index for all four samples. The velocity of ego vehicle, v_i has been tested from the range of 30 to 60 km/h. According to the "AEB system – Test Protocol" by Euro NCAP (2015), the AEB City system was tested within the speed ranges of 10 up to 50 km/h only. Since the speed limit of the selected route is 60 km/h, we consider include the velocity of ego vehicle = 60 km/h in predicting the brake-application time. The velocity of the target vehicle, v_f was assumed when the ego vehicle reaching the accident location, which is at the end of the test distance (200 m). During the data collection, the v_f was found to be from 5 to 20 km/h. We believe that the v_f turned out to be random due to the behaviour of drivers when passing by the accident location. Before predicting the brake-application time, the TTC and TTC_{min} for each sample were compared based on Eq. (5). Sample 1, 2 and 3 satisfy the comparison and can be further analysed to propose the brake-application time for AEB system in the urban area. Meanwhile, the last sample, Sample 4 (a_{max} = 6.462 km/h/s), specifically for ego vehicle, v_i = 31.032 km/h, does not satisfy the Eq. (5). Hence, it cannot be further analysed.

The brake-application time was proposed by referring to the brake-application time introduced by Mercedes-Benz in the PRE-SAFE® Brakes technology (Grover et al., 2008). The technology provides the warnings in a typical rear-end collision situation into three stages of activation time. The first stage, forward collision warning (FCW) is activated by giving visual and acoustical warnings at 2.6 s before a collision. Secondly, the partial braking starts to activate automatically when the collision time reaches 1.6 s if the driver has not responded even audible warning has been sent. Lastly, the autonomous full braking is applied when the TTC $\leq$ 0.6 s to avoid an accident. Based on this benchmark, the brake-application time is modified based on the proportion of FCW, PB and FB activation time. Table 3 summarizes the proposed brake-application time for AEB system specifically during a primary accident in Penang's urban road.

Table 2: Calculated TTC and TTC_{min} for all four samples

No. of sample	Velocity of ego vehicle, v_i (km/h)	Velocity of target vehicle, v_f (km/h)	TTC (s)	TTC_{min} (s)	Full braking application
Sample 1 a_{max} = 6.120 km/h/s	59.184	14.832	2.706	6.047	Yes
	50.796	10.404	2.476	5.000	Yes
	40.860	9.612	2.560	4.124	Yes
	30.600	8.964	2.773	3.232	Yes
Sample 2 a_{max} = 3.816 km/h/s	59.596	11.232	2.481	9.280	Yes
	50.364	10.548	2.512	7.981	Yes
	39.852	9.972	2.677	6.528	Yes
	30.672	8.928	2.759	5.189	Yes
Sample 3 a_{max} = 4.968 km/h/s	59.145	8.064	2.349	6.764	Yes
	50.976	7.200	2.284	5.855	Yes
	40.680	6.768	2.359	4.775	Yes
	29.016	5.544	2.556	3.478	Yes
Sample 4 a_{max} = 6.462 km/h/s	59.145	20.088	3.072	6.131	Yes
	50.148	18.036	3.114	5.276	Yes
	40.392	17.604	3.511	4.487	Yes
	31.032	16.596	4.156	3.685	No*

*Sample 4 does not satisfy the Eq. (5) and cannot be further analysed to propose the brake-application time.

Table 3: Proposed brake-application time: Activation time of Forward Collision Warning (FCW), partial braking (PB) and full braking (FB) considering a primary accident in Penang's urban road

		Activation time before a collision		
No. of samples	Average TTC_{min} (s)	Forward collision warning (s)	Partial braking (s)	Full braking (s)
Sample 1	4.601	4.6	2.9	1.1
Sample 2	7.245	7.2	4.5	1.7
Sample 3	5.218	5.2	3.2	1.2

To improve the braking performance during a primary accident in urban roads of Penang, the lowest activation time for each stage is considered to be the optimum brake-application time for AEB system. Based on Figure 7, Sample 1 shows a better brake-application time compared to the other samples. By selecting Sample 1 as the brake-application time for AEB system, the forward collision warning (FCW) will be activated at TTC $\leq$ 4.6 s when a vehicle starts detecting hazard such as an accident. After the activation of FCW, there will be 1.7 s of delay time before the activation of the next phase. If the driver has not responded until the TTC $\leq$ 2.9 s, the AEB system should automatically initiate the partial braking for a duration of 1.8 s. Approximately 1.1 s before the collision, the AEB system should activate full braking to avoid the collision. Figure 8 illustrates the estimated delay time before the activation of each brake-application phase. Sample 1 results in the lowest delay time when compared to the other samples.

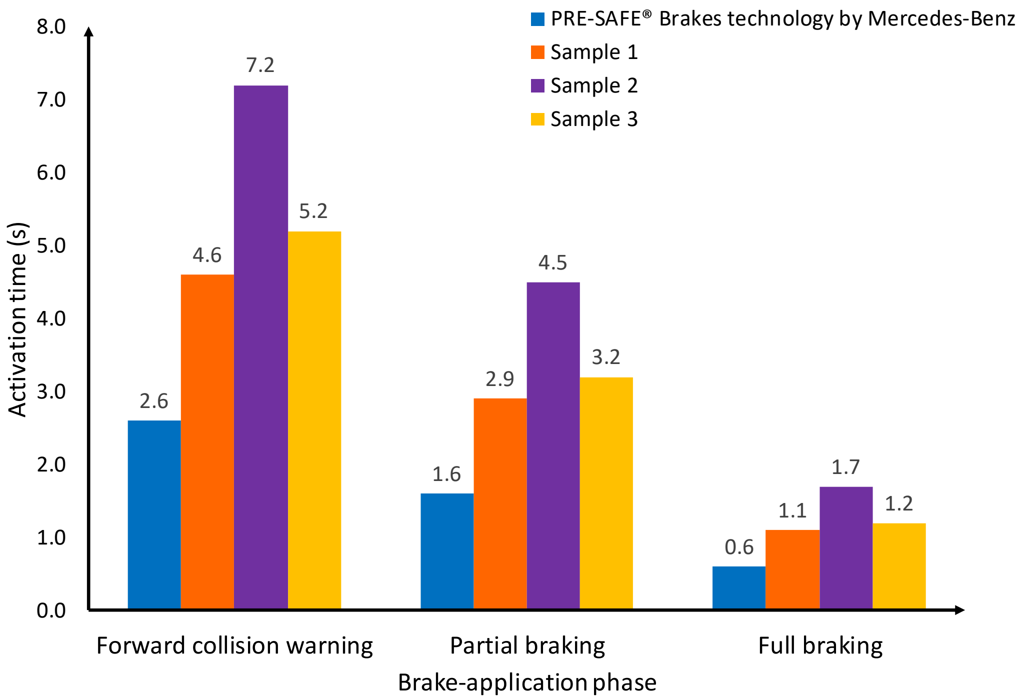

Figure 7: Brake-application time based on the maximum deceleration rate by considering a primary accident in Penang's urban road.

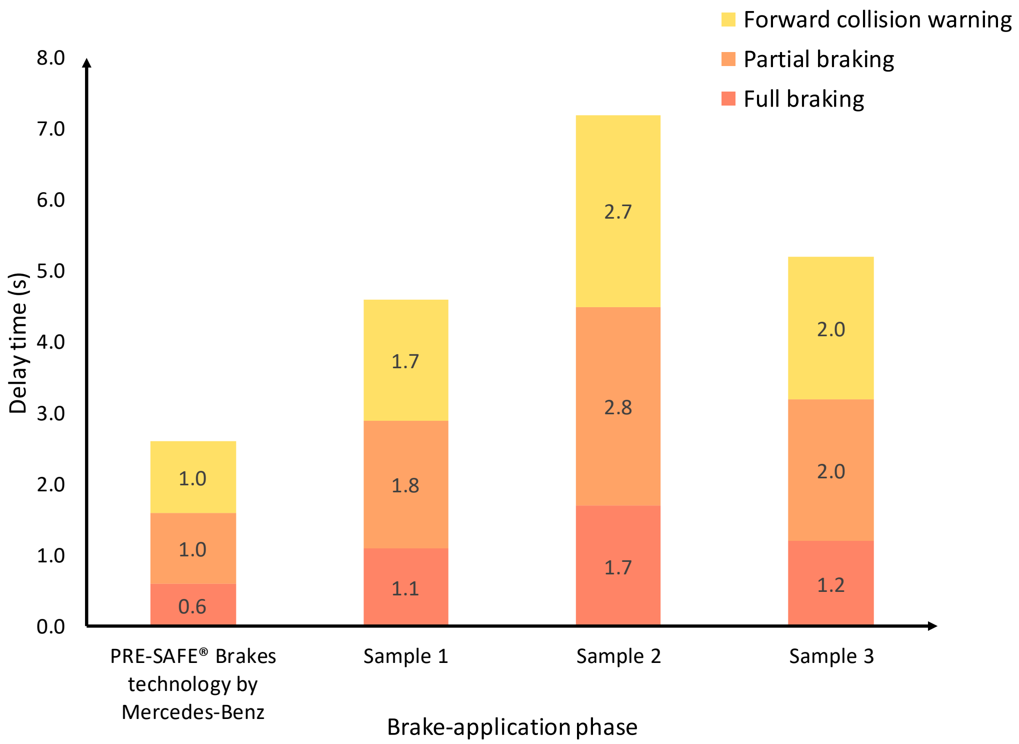

Figure 8: Estimated delay time before activation of the brake-application phase

By considering the maximum deceleration rate, the proposed brake-application time conveys the real driving condition in Penang's urban road when a primary accident just occurred. The proposed brake-application time is expected to contribute to the AEB system, specifically AEB City that work mostly at a lower speed. Further experiments should be conducted by selecting other urban roads in Malaysia to confirm whether the proposed brake-application time is suitable for the whole region of Malaysia. Besides, additional experimental and simulation studies are recommended to verify the effectiveness of the proposed brake-application time for AEB City in Malaysia.

4.0 CONCLUSION

The brake-application time for AEB system, specifically AEB City by considering a primary accident in an urban road of Penang is proposed. A scenario of a primary accident was established to acquire the maximum deceleration rate. The maximum deceleration rate was analysed to determine the minimum deceleration distance and Time-to-Collision (TTC) confirmation time required to brake. Minimum TTC or TTC_{min} must be equal or more than the calculated TTC in order for the AEB system to operate at full braking and avoid a collision. The brake-application time introduced by Mercedes-Benz in the PRE-SAFE® Brakes technology has been benchmarked in proposing the brake-application time for AEB system in urban roads of Malaysia.

By considering the maximum deceleration rate during the occurrence of a primary accident, the proposed brake-application time in this study was found to be 77.0% higher during Forward Collision Warning (FCW) phase, 78.3% during partial braking (PB) phase and 76.4% higher during full braking phase when compared to the PRE-SAFE® Brakes technology. For optimum braking performance and a smooth braking and optimum braking performance during a primary accident, we suggest that the forward collision warning (FCW) should be activated at TTC $\leq$ 4.6 s. The partial braking (PB) should be activated automatically when the TTC is approximately 2.9 s. While the automated full braking (FB) phase should begin when the TTC reaches 1.1 s. Future studies should be carried out to improve the proposed brake-application time by considering other urban roads in Malaysia. More scenarios are suggested to be studied too during the primary accident such as road gradient, road surface and weather conditions.

ACKNOWLEDGEMENTS

The authors would like to express gratitude and appreciation for the financial support from ASEAN NCAP, under the grant of the ASEAN NCAP Collaboration Holistic Research (ANCHOR).

REFERENCES

Abu Kassim, K.A. (2018). *ASEAN NCAP Roadmap 2021 – 2030*. ASEAN NCAP, Kajang, Malaysia.

ANCAP (2012). *Autonomous Emergency Braking can slash the road toll*. Australasian New Car Assessment Program (ANCAP), ANCAP Media Release, 18th of July, 2012. Retrieved from https://www.ancap.com.au/media-and-gallery/releases/autonomous-emergency-braking-can-slash-the-road-toll-d3ab3c

Caspar, M.E., Dabek, M., & Zeitouni, R. (2017). *Performance comparison between a camera only AEB-FCW and a camera-radar fusion AEB-FCW*. In 25th International Technical Conference on the Enhanced Safety of Vehicles (ESV), National Highway Traffic Safety Administration (NHTSA).

Cicchino, J.B. (2017). Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates. *Accident Analysis & Prevention*, *99*, 142-152.

Dawson, D., Reynolds, A.C., Van Dongen, H.P., & Thomas, M.J. (2018). Determining the likelihood that fatigue was present in a road accident: A theoretical review and suggested accident taxonomy. *Sleep Medicine Reviews*, *42*, 202-210.

Euro NCAP (2015). *AEB systems – Test Protocol*. Euro NCAP, 3000 Leuven, Belgium.

Euro NCAP (2018). *Autonomous Emergency Braking*. Euro NCAP, 3000 Leuven, Belgium. Retrieved from https://www.euroncap.com/en/vehicle-safety/the-rewards-explained/autonomous-emergency-braking/

Galgamuwa, U., Perera, L., & Bandara, S. (2015). Developing a general methodology for driving cycle construction: Comparison of various established driving cycles in the world to propose a general approach. *Journal of Transportation Technologies*, *5*(4), 191-203.

Grover, C., Knight, I., Okoro, F., Simmons, I., Couper, G., Massie, P., & Smith, B. (2008). *Automated Emergency Brake systems: Technical requirements, costs and benefits*. TRL Limited, April 2008.

KKR (2017). *Road Traffic Volume Malaysia (RTVM) 2016*. Ministry of Works, Malaysia (MOW/KKR).

Lin, M., Yoon, J., & Kim, B. (2015). A study and analysis for calculating the brake-application time of AEB systems considering the gradient. *International Journal of Control and Automation*, *8*(6), 283-292.

McCarthy, M. (2018). *Why you should be driving a car with AEB*. SAGA, 20th August, 2018. Retrieved from https://www.saga.co.uk/magazine/motoring/cars/using/why-you-should-be-driving-a-car-with-aeb

Md Isa, M.H., Abu Kassim, K.A., Jawi, Z.M., & Deros, B.M. (2015). *Promotion of active safety technologies in automobile safety ratings*. In Conference of ASEAN Road Safety (CARS) 2015, Kuala Lumpur.

Murphy, P. (2017). *The Two Second Rule*. Australind Driving School, 2017. Retrieved from http://australinddrivingschool.com.au/?p=464

Rani, M.F.H., Bakar, S.A., Hashim, M.S.M., Harun, A., Razlan, Z.M., Wan, W.K., Zunaidi, I., Ibrahim, I., Afendi, M., Efi, N.E., Ahmad, Y., Dalib, M., & Mat Rudin, S.S. (2018). Scene Barrier effects on vehicle deceleration rate during primary accident in a suburban area. *Journal of the Society of Automotive Engineers Malaysia, 2*(3), 315-323.

RMP (2018). *Laporan Perangkaan Kemalangan Jalan Raya Malaysia 2017*. Polis Diraja Malaysia (PDRM/RMP).

Ruscio, D., Ciceri, M.R., & Biassoni, F. (2015). How does a collision warning system shape driver's brake response time? The influence of expectancy and automation complacency on real-life emergency braking. *Accident Analysis & Prevention, 77*, 72-81.

Saffarian, M., de Winter, J.C., & Senders, J.W. (2015). Measuring drivers' visual information needs during braking: A simulator study using a screen-occlusion method. *Transportation Research Part F: Traffic Psychology and Behaviour, 33*, 48-65.

SAIPA (2018). *Vehicle Advanced Technologies*. SAIPA Group. Retrieved from http://www.saipacorp.com/en/researchanddevelopment/advancedtechnology

Shimazaki, K., Ito, T., Fujii, A., & Ishida, T. (2018). The public's understanding of the functionality and limitations of automatic braking in Japan. *IATSS Research*, *42*(4), 221-229.

Simon (2018). *Matthew Avery of Thatcham Research on Vehicle Safety Technology*. Driving for Better Business (DfBB), 27th April, 2018. Retrieved from https://www.drivingforbetterbusiness.com/matthew-avery-of-thatcham-research-on-vehicle-safety-technology/

van Huysduynen, H.H., Terken, J., & Eggen, B. (2018). The relation between self-reported driving style and driving behaviour. A simulator study. *Transportation Research Part F: Traffic Psychology and Behaviour*, *56*, 245-255.