Journal of the Society of Automotive Engineers Malaysia
Volume 5, Issue 1, pp 57-63, January 2021
e-ISSN 2550-2239 & ISSN 2600-8092

Cost-Benefit Analysis of Autonomous Emergency Braking (AEB) System for Pedestrian: A Review

N. F. Fitri[1], N. K. Khamis[1], S. Koetniyom[2], M. S. Solah[3], M. H. Johari[3], Z. M. Jawi[3], K. A. A. Kassim[3] and M. R. A. Mansor[*1]

[1]Department of Mechanical and Manufacturing Engineering, Universiti Kebangsaan Malaysia (UKM), 43600 Bandar Baru Bangi, Malaysia
[2]The Sirindhorn International TGGS, King Mongkut's University of Technology North Bangkok (KMUTNB), Thailand
[3]Malaysian Institute of Road Safety Research (MIROS), 43000 Kajang Selangor, Malaysia

[*]*Corresponding author: radzi@ukm.edu.my*

REVIEW ***Open Access***

Article History:

Received
18 Aug 2020

Accepted
1 Nov 2020

Available online
1 Jan 2021

Abstract – *Many possible actions can be taken to improve road safety, thus reducing the number of fatalities and injuries. These include improving the enforcement of existing rules, improving infrastructure, improving driver behavior, and introducing safety technologies in vehicles. Annually in Malaysia, around 500 pedestrians are killed in road traffic crashes. Around 40% of these are hit by the front of a car. Third largest contributor group in terms of fatality. Autonomous Emergency Braking (AEB) systems fitted to cars for pedestrians have been predicted to offer substantial benefits. The rapid development of pedestrian safety is in progress worldwide. With forward-looking sensor systems entering the vehicle fleet, the possibility to detect pedestrians in advance opens new possibilities to injury mitigation. Cost-Benefit Analysis (CBA) is to be done on the implementation of the AEB Pedestrian system in ASEAN countries. An estimation of potential benefit for ASEAN is to be done and to do so, a suitable methodology is required. Limitations to the method will be reduced by performing adequate sensitivity analysis on major data such as cost.*

Keywords: Braking system, Cost-Benefit Analysis (CBA), Autonomous Emergency Brake (AEB)

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

1.0 INTRODUCTION

The Autonomous Emergency Braking (AEB) is a safety feature that automatically takes control of a car's emergency brakes in situations where it detects an object or a pedestrian to prevent a collision from happening. The few sub-types of AEB are the AEB City (which focuses on potential crashes happening at low speeds), AEB Inter-Urban (which focuses on potential crashes at higher speeds), and AEB Pedestrian (which focuses on the detection of pedestrians).

The New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP) has included test protocol for AEB City and AEB Inter-Urban; however, for AEB City, only Car-to-Car Rear Stationary (CCRs) is taken into consideration and AEB Pedestrian is yet to be included in the roadmap. The concern in this study is whether AEB Pedestrian should be considered as a compulsory inclusion because pedestrian fatalities in Malaysia are averaging approximately more than 500 deaths every year (which is about 7% of all road deaths in Malaysia) (Solah et al., 2016).

An economic cost-benefit analysis of these technologies, by introducing a priority list will be established to inform and guide decision-makers on the most beneficial steps to take in the future to reduce the number of accidents and/or the severity of accidents in ASEAN. Each technology has to be evaluated via a common approach to ensure a more accurate finding. Economic Cost-Benefit Analysis (CBA) is the preferred method for evaluating the performance of vehicle safety technologies. The results of an economic cost-benefit assessment can however not stand alone, as not all effects are included in the assessment, and the quantification and valuation of effects are uncertain. In this analysis, a method of estimating the potential benefit and an additional benefit-cost ratio will be analyzed to determine the suitability.

2.0 METHODOLOGY

To attain a suitable method for CBA, research on previous similar works must be searched for to provide a good base for research. The papers that involve an economic assessment of an automotive safety technology shall be used to compare methodologies. The research paper will first have its data requirements listed in a table. The data requirements are gathered and extracting every data used for major steps in the research. Similar data in a local scope will be looked for and proposed in this paper. The research papers will be assessed on two factors, level of complexity and availability of local data. The level of complexity will be compared subjectively depending on the steps involved. Data availability will also be assessed based on the availability of local data such as general accident data in Malaysia, Singapore, and other ASEAN countries.

3.0 RESULTS AND DISCUSSION

3.1 Cost-Benefit Analysis on Safety Technologies

The basis for selecting a suitable methodology starts with choosing research that has the same objective for CBA of AEB Pedestrian or correlation such as CBA on safety technologies. These criteria serve to ensure proper comparison of CBA methods. Three research papers were shortlisted and compared in detail. The three research papers are:

1. Preliminary CBA for Safety Assist Technologies in ASEAN NCAP – Rationalizing the impact to road safety for Malaysia's case (Jawi et al., 2014) – from here will be referred to as **Method A.**

2. Cost-benefit assessment and prioritization of vehicle safety technologies (European Commission, 2006) – from here will be referred to as **Method B.**

3. Estimate of potential benefit for Europe of fitting Autonomous Emergency Braking (AEB) systems for pedestrian protection to passenger cars (Edwards et al., 2014) – from here will be referred to as **Method C.**

3.2 Data Requirement

3.2.1 Data Requirement for Method A

Safety Assist Technologies (SATs) have been incorporated in ASEAN NCAP's car safety rating scheme. Cars entering the Southeast Asian market will be assessed using this safety rating scheme and to achieve a maximum rating (5-star), the car should have Electronic Stability Control (ESC) and Seat Belt Reminder (SBR) available. Any car equipped with the aforementioned technologies is eligible for a 5-star rating without the technology's effectiveness being assessed. Nevertheless, because this SAT performance is not field-tested, this study demonstrates the benefits of having this SAT through CBA. Economic CBA will help demonstrate the importance of SAT's role in preventing road accidents or reducing the severity of injuries. Due to the limitations of the data, this initial CBA will only focus on the Malaysian scenario and rests on the published sources and the author's greatest estimates. CBA on the Anti-Lock Braking System (ABS), which is the foundation for ESC technology, is also included in the paper. This is done in preparation for the introduction of the technology in future rating schemes to accelerate the vision of making the ABS a fitting benchmark in every passenger car in the South East Asian market.

Table 1: Data requirements for Method A

Step	Data Used	Proposed Data Source
Cost/Car Registered	Total registered vehicles on the road in 2020	• Malaysia Automotive Association (MAA) – Sales & Production Statistics • News article, April 2020, 31.2 million
	Number of road crashes	• MIROS Annual Report
	Number of damage-only crashes	• MIROS Annual Report
	Cost per crash	• Malaysian value of statistical life for fatal injury in road accident: A conjoint analysis approach (Yusof et al., 2013)
Cost-Benefit Ratio	Influence of technology	• Relevant literature
	Effectiveness of technology	• Relevant literature
	One-off cost (Installation)	• Relevant literature
	Discount rate	• Estimation (e.g.: 7% for 10 years)

Opening results show that each technology – ESC, SBR, and ABS – seems cost-effective (benefit/cost ratio > 3) or most likely cost-effective (1 < benefit/cost ratio < 3) ratio in Malaysia's road safety conditions (Jawi et al., 2014). The study also used the methodology founded from the study (Paine, 2002). In limited data conditions, the methods used in this study are suitable for AEB cost analysis. Improvements can be done by reviewing the installation costs to obtain more accurate results of the analysis. Potential benefits will be given in Ringgit per vehicle (Jawi et al., 2014). The proposed CBA requires a certain number of data where it differs for each approach. The suitability of a certain method depends on the availability of the data in the local scope (ASEAN).

3.2.2 Data Requirement for Method B

Based on a study conducted (European Commission, 2006), there is a suitable CBA method used to assess various vehicle safety technologies. The cost-benefit assessment compares the cost of fitting safety technologies in all new vehicles with benefits for society when doing so in terms of reduction in the number of deaths, severe injuries, and minor injuries. The estimated cost of the safety system is based on information collected from existing literature. Estimated impact on the death count, severe injuries, and slight injuries are based on: (1) Existing studies; (2) Accident data (mainly CARE database); (3) Estimated technological effectiveness in terms of reducing the risk of collisions and/or severity of injuries in the event of a crash occurring; and (4) Scenario for implementation (market penetrating in the Do-Something scenario). The difference between the methodology used in this method and the method used by Jawi et al. (2014) is in terms of the benefits it obtains. The benefits gained in this method are the benefits gained in total, as opposed to the benefits obtained per vehicle as in the study done by Jawi et al. (2014). However, to gain total benefits, the method used in this study requires the calculation of the percentage of vehicles equipped with AEB technology as well as the level of use of such technologies in the market in the coming years.

Table 2: Data requirements for Method B

Step	Data Used	Proposed Data Source
Forecasting vehicle stock	Vehicle stock	• Malaysia Automotive Association – Sales & Production Statistics • News article, April 2020, 31.2 million
Forecasting safety situation	Total traffic growth	• -
	Change in crash and casualty rates	• -
Identification of relevant accident	Type of accidents (Collision, road condition, etc.)	• Studying previous literature
Technology Assessment	Effectiveness of Technology	• Studying previous literature
Scenario for Implementation	Level of market deployment in year X	• -
	Level of market deployment in year Y	• Relevant literature
	Change in collision probability	• Relevant literature
	Change in accident severity	• Relevant literature
CBA	Total unit cost per fatality	• Malaysian value of statistical life for fatal injury in road accident: A conjoint analysis approach (Yusof et al., 2013)
	Installation cost	• Estimation based on previous literature

The benefit/cost ratio formula is then used to calculate the ratio for 13/21 technologies. The cost of break-even units has been estimated for four supplemental technologies as there is no strong cost estimate available in the existing literature. If the actual unit costs are lower than the estimated cost of break-even units, technology can be considered as cost-effective. The remaining four technologies did not have any available cost-benefit information and data. The firmness of results has been studied through sensitivity analysis for each technology. The current circumstance that a great number of technologies under consideration seem to be either cost-effective or most likely cost-effective is correlated to the presumptions made.

3.2.2 Data Requirement for Method C

A study was done to estimate the potential benefits of being acquired should the AEB for pedestrians be paired on cars in Europe. The analysis will be done in two steps which involve: (1) the methodology development for estimating benefits for two countries, Great Britain and Germany; and (2) scaling results from both countries to give an indicative approximation for Europe (EU27). Two important measures are crucial in estimating the benefit. The measures include: (1) comparing the impact speed distribution curve in baseline situation (no initiative to encourage AEB fitment, Do-Nothing scenario) and Do-Something scenario (100% fitment in all new cars); and (2) comparing the number of different injury severity to the baseline situation by utilizing the relationship between risk of injury and impact speed distribution to approximate the final risk for each severity level.

There are three categories of AEB development, namely: (1) existing systems; (2) future systems (2-3 years); and (3) reference limit systems are evaluated using the aforementioned methodology. The methodology used in the study required the use of logistical regression to produce speed distribution and injury risk curves. In a study done by Edwards et al. (2014), the logistical regression used was a connection from a study done by (Richards, 2010). The study examined the link between impact speed and risk of fatal injuries using on-the-spot data.

This method used by Edwards et al. (2014) compares the baseline situation where AEB is not installed on any car with a condition in which all cars are equipped with an AEB. Sensitivity analysis was carried out using the experience of commencement of the design of the AEB system for current pedestrians and the prototype of the technology, AsPeCSS project members estimate the value for critical parameters affecting the AEB system performance. This helps to produce a more accurate level of efficiency as it considers the performance of the AEB such as the speed of pedestrian movements and the time of the occurrence (day or night).

Approximation of nominal benefit is then calculated through nominal and sensitivity calculations. The calculations indicated that £119-385 million/year and €63-216 million/year of the nominal benefit of the implementation of AEB Pedestrian can be saved for Great Britain and Germany respectively. The exact value is dependent on the type of AEB System assumed to be in place. Due to the circumstances that might affect the effectiveness of the AEB system (such as road friction and time of day), the sensitivity calculations are done to indicate that the estimated benefits can vary from half to twice the approximated benefit.

The scaling of the calculated benefits was then made to demonstrate the nominal benefit of AEB implementation for Europe. The nominal benefit of AEB implementation was estimated from €1 billion per year to €3.5 billion. To be cost-effective, it was also found that the cost of the technology should be less than ~€80 to ~€280. These findings show a fairly wide range of benefits as these benefits depend on the performance of the AEB which also has a wide range of effectiveness levels as shown in the studies done by the European Commission (2006) and Jawi et al. (2014).

Table 3: Data requirements for Method C

No.	Step	Data used	Detail
1	Estimating casualty benefit	Injury Risk Curves	• Obtained through Linear regression
		Impact speed distribution	• Data is weighted according to STATS19 data
		Baseline calculations	• Number casualties when no AEB is installed
		Nominal and sensitivity calculation	• -
2	Scaling to Europe	Estimate of the number of casualties in Europe	• By categories (fatal, severely injured, slightly injured)
		Estimate of benefit for Europe in terms of casualty prevented	• Expressed in terms of % of total casualties prevented. • Used to estimate benefit for EU by scaling the number for each category
		An estimate of benefit for Europe in terms of monetary value	• Value of reduced occurrence of fatal, severe, and slight injury • Annual benefits estimated in monetary value

3.3 Summary

Method A is a CBA of safety assist features that are done with the scope focusing on Malaysia. The framework was clearly explained in the research paper which minimizes the risk of wrongful execution. The chosen methodology is as follows (Paine, 2002):

1. Identify each safety feature. Estimate the initial cost of the feature, the possible effect on resale value (giving a net installation cost), and the annual cost of the feature (maintenance or amortized replacement).
2. Identify the group(s) of vehicles to which the safety feature is applicable (in this project the analysis was confined to passenger cars, but it applies equally to other vehicles such as trucks, buses, and motorcycles).
3. Calculate the annual crash risk, in terms of road crash dollars, for fatal, serious injury, minor injury, and non-injury crashes for a single vehicle.
4. Determine the types of crashes potentially influenced by the safety feature. For example, driver airbags are generally only of benefit in a frontal crash. (Assumed to be equally beneficial to driver and passenger for SBR in this study)
5. Estimate the proportion of the influenced crashes that are likely to be saved by the use of the safety feature. This step usually has the greatest uncertainty.
6. Calculate the crash savings, based on steps 3, 4, and 5.
7. Calculate the net annual savings by subtracting the annual (maintenance) cost from the estimated crash savings.
8. Determine appropriate financial values to use in the benefit/cost analysis (7% discount rate and 10-year evaluation period).
9. Calculate the benefit/cost-ratio by applying the Present Value formula (below) to the net annual savings and dividing by the net installation cost:

$$B/C = \frac{\text{PV (Annual crash savings - Annual maintenance, 7\% for 10 years)}}{\text{(Initial cost - Extra resale value)}} \qquad (1)$$

4.0 CONCLUSION

A Cost-Benefit Analysis (CBA) provides a good base for stakeholders and decision-makers to base their decision around. In this study, our end goal was to decide on one methodology for the CBA based on previous practices and research. The two factors that helped segregate the three papers include the level of complexity/difficulty and availability of necessary data. The study was first done by collecting and analyzing previous works related to CBA or estimation of potential benefits regarding automotive safety features. Data requirements for each paper were listed to assess the local data availability. Based on the two deciding factors, it can be seen that method A has the highest suitability as it has low complexity/difficulty and available data. There are limitations to the method chosen and it therefore should be minimized by making the required assumptions carefully. At the end of the execution, CBA and potential benefit per year will be attained after implementing the method.

ACKNOWLEDGEMENTS

This study is supported by ASEAN NCAP Collaborative Holistic Research Project (ANCHOR III – No. A3-C232).

REFERENCES

Edwards, M., Nathanson, A., & Wisch, M. (2014). Estimate of potential benefit for Europe of fitting Autonomous Emergency Braking (AEB) systems for pedestrian protection to passenger cars. Traffic Injury Prevention, 15, S173-S182. doi:10.1080/15389588.2014.931579

European Commission (2006). Cost-benefit assessment and prioritisation of vehicle safety technologies. European Commission Directorate General Energy and Transport, January 2006.

Jawi, Z. M., Ariffin, A. H., Ahmad, Y., Abu Kassim, K. A., Mohamed, N., & Voon, W.S. (2014). Preliminary Cost-Benefit Analysis (CBA) for Safety Assist Technologies in ASEAN NCAP – Rationalizing the impact to road safety for Malaysia's case. Applied Mechanics and Materials, vol. 663, 596-603. doi:10.4028/www.scientific.net/AMM.663.596

Paine, M. (2002). Encouraging the purchase of safer vehicles – Part A (benefits and costs of vehicle safety features). Vehicle Design and Research Pty Ltd. New South Wales, Australia.

Richards, D. C. (2010). Relationship between speed and risk of fatal injury: Pedestrians and car occupants. Transport Research Laboratory, Department for Transport (DfT). Retrieved from http://www.dft.gov.uk/pgr/roadsafety/research/rsrr/theme5/researchreport16/doc/rswp16.doc

Solah, M. S., Deros, B. M., Harun, N. Z., Ariffin, A. H., & Paiman, N. P. (2016). Prevalence of distracted pedestrians while crossing: A study of Malaysia's situation. MATEC Web of Conferences. (Vol. 90, p. 01031). doi:10.1051/matecconf/20179001031

Yusof, M. F. M., Nor, N. G. M., & Mohamad, N. A. (2013). Malaysian value of statistical life for fatal injury in road accident: A conjoint analysis approach. Journal of Society for Transportation and Traffic Studies, 2(2), 30-40.