Journal of the Society of Automotive Engineers Malaysia
Volume 4, Issue 2, pp 221-228, May 2020
e-ISSN 2550-2239 & ISSN 2600-8092

Evaluation of Adult Occupant Protection on Body Region using Analytical Hierarchy Process: Side Impact Test

N. S. Suhaimi, E. H. Sukadarin*, H. A. Aziz, H. Osman, M. N. Noordin and I. Shafiee

Occupational Safety and Health Program, Faculty of Engineering Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Pahang, Malaysia

*Corresponding author: ezrin@ump.edu.my

ORIGINAL ARTICLE — *Open Access*

Article History:

Received
15 Mar 2019

Received in revised form
10 Feb 2020

Accepted
12 Feb 2020

Available online
1 May 2020

Abstract – *ASEAN NCAP is a well-known automobile safety rating program in evaluating new cars for performance against various safety threats on the road. For the Southeast Asian countries, Adult Occupant Protection (AOP), Child Occupant Protection (COP) and Safety Assist Technology (SAT) are domains used in the ASEAN NCAP assessment. In a recent rating protocol, the AOP domain contributes 50 percent of the overall rating system with a maximum 36 points from three main elements consisting of Offset Frontal Test (OFT), Side Impact Test (SIT) and Head Protection Technology (HPT). Frontal crashes resulted in a severe injury that comes from contact with frontal components and ejection; however, side crashes are also reported to have high rates of serious injury and fatality as compared to other crash types. However, in the ASEAN NCAP assessment programme, to what extent side impact test helps to reduce the severity of injury to the car driver and passenger when the collision happened need to be explored. Therefore, the injury of body region on the side impact due to AOP failure were evaluated and reported in this paper to strengthen this program where the recommendation for performing side impact test could be proposed to ensure successful performance. The elements on the side impact test were extracted and decomposed from the existing structure. Next, input from the expert panels of various related backgrounds regarding the injury of body region on side impact test was gathered and evaluated using the Analytical Hierarchy Process (AHP). The result shows that the head, neck, and chest have the highest rank, followed by an abdomen with a Consistency Ratio (CR) of 0.0079. The finding of this paper will help to evaluate the existing side impact test in the AOP assessment.*

Keywords: ASEAN NCAP, side impact test, Analytical Hierarchy Process (AHP)

1.0 INTRODUCTION

Frontal-side crashes resulted in the greatest risk of injury to vehicle occupants which comes from contact with frontal components and ejection. However, side crashes are also reported to have a high risk of serious injury and fatality rates as compared to other crash types. The automobile occupants have substantial space in the front and rear, but the sides have relatively little space to absorb impact forces while limiting occupant compartment intrusion. The previous study reported one in three vehicle occupants involved in side crashes are injured and one in one hundred is fatally injured (Ray et al., 1998); an Australian study also revealed that side crashes account for 25 percent of all injury crashes and 40 percent of serious injury crashes where an occupant was either hospitalized or killed (Fildes et al., 1995). Nevertheless, a current study also reported almost the same proportion of side crashes impact. According to the National Highway Traffic Safety Administration (NHTSA), about 637,000 occupants were injured by side crashes in 2007 (28 % of all injured occupants). According to an accident investigation report, most of the side crashes involve roadside objects like trees and road barricades while poles cause the most severe impacts. This also supported by a review of fatality data analysis by Fildes et al., (1995), where two-thirds from 32 % of fatalities in side crashes are caused by multi-vehicle crashes and the rest due to the impact with a fixed object on the roadside. Hence, it is briefly concluded by improving roadside hardware as well as automobile occupant protection with better side crashes performance is an important element in planning for road safety improvement.

Nevertheless, before the in-depth study is made to upgrade these elements, the roadside safety community must establish uniformity on how side impact test should be performed and which body region are most affected in side crash that needs to be emphasized to ensure successful performance. Various methods of performing side crash test had been conducted by research organizations and agencies in evaluating side impact test where the criteria of evaluation were based on their specific goals. Side impact test conducted by automobile manufacturing community is to improve the performance of vehicles as well as for the effective occupant’s protection implementation while for the roadside safety research is to develop roadside safety hardware that performs well in side crashes events (Ray et al., 1998). Among factors that affected incident and severity in side crashes, vehicle design including occupant restraints is the most easily modified in the short term although road design while traffic control and the monitoring of older drivers may also prove effective in reducing side crashes in the longer term (Chipman, 2004). Therefore, side impact test for occupant’s protection is an important factor to be considered when evaluating new automobile designs for performance against various safety threats to reduce global road accident. In the New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP), the Adult Occupant Protection (AOP) is one of the domains used which contributes 50 % of the overall rating system consisting of Offset Frontal Test (OFT), Side Impact Test (SIT) and Head Protection Technology (HPT). The side impact test in this domain covered head/neck, chest/abdomen and pelvis/leg of the body region. In general, the test procedures and evaluations criteria are greatly important to ensure information exchange can help researchers and developers to find solutions quickly and efficiently.

Laberge-Nadeau et al. (2009) reported in his paper that the Passenger Compartment Damage (PCD) in side crashes could increase the risk of injury to head, neck, chest, thorax, pelvis, and abdomen. Besides, observations at the crash scene by trauma surgeons or emergency clinicians discovered aortic injury and diaphragmatic rupture are types of injuries commonly present in side crashes (Fitzharris et al., 2004). The fatalities in side crashes mostly caused by the traumatic rupture of the thoracic aorta (TRA) where 10 to 20 percent of injuries are to lower extremities (Bertrand et al., 2008). The main purpose of conducting a side impact test is to assess the risk of injury to automobile occupants in the event of side crashes and subsequently develop techniques for minimizing the risk. The side impact test predicts the likelihood of major thoracic or upper abdominal injury during side crashes for car star rating (Figler et al., 2014). With the full use of professional knowledge and experience, a study was conducted to validate results from the simulated side test impact. This information on injury patterns in side crashes highlights some important concepts for the improvement, especially for the occupant's protection design. Thus, this paper reported the occupant's injury of body region due to AOP failure in side crashes based on input from the expert panels of various related backgrounds. The information was gathered and evaluated using the Analytical Hierarchy Process (AHP).

2.0 EVALUATION OF AOP USING AHP

McLellan et al., (1996) study the patterns of injury to vehicle occupants in side crashes by conducting an observation on 141 patients hospitalized after side crashes. It was discovered head, internal soft tissues and pelvic fractures were significantly common while injuries to the face and fractures of the arms and legs were less common in this event. A study reported by Ray et al., (1998) identified three parts of the body region to be evaluated in side impact test using dummy which are thoracic, head and pelvic. A similar study has been conducted by Teoh and Lund (2011), to evaluate the side impact test rating system in predicting real-world occupant death risk in side crashes. The injury measures in this study are computed for the head/neck, torso, and pelvis/leg by taken from fifth-percentile female test dummies. For this study, the information on body region injury of side crashes due to AOP failure was based on the input from the expert panels of various related background. The information was gathered and evaluated using AHP in prioritizing the body region injuries to quantify the performance of side impact tests in ASEAN NCAP.

Analytical Hierarchy Process (AHP) is a multi-criterion decision-making (MCDM) methodology based on a hierarchical structure that performs decision trade-off between multiple objectives in a hierarchical structure. AHP was introduced in 1980 by Thomas L. Saaty and makes it a popular technique for solving the MCDM problem (Saaty, 1980). The general step of the methodology is conducting expert panel discussion comprises of automobile manufacturing engineers, lecturers, research scientist and technologist who directly involves with the research and development in automobile crashes, constructing body region hierarchy based on input from expert panels, performing pairwise comparison matrix, calculating weights ranking and undergo consistency test and analysing the results

2.1 Problem Decomposition

Problem decomposition is very important in decision making. The best and most organized way to decompose a problem is by structuring it into a hierarchical form that starts at the top or first level with a goal or problem statement and ends with the alternatives to be evaluated. Between these two levels are the top-down related elements that describe the system.

2.2 Pairwise Comparison Matrix

In pairwise comparison, two components are compared concerning the upper-level control criteria using a scale of relative importance. Identify value of Aij, which indicates the importance of i-th element (left) compared to the j-th element (top) as shown in Table 1. The scaling factor is based on the guideline by Saaty (1980) (Table 2). It is important to note that assigning scale to the elements is subjective thus the assessor's knowledge, experience, and judgement is crucial. AHP summarizes these judgments by ensuring their consistency. *TimbangTara* software is used for weight calculation (Othman et al., 2012).

Table 1: Pairwise comparison matrix

A	**j=1**	**j=2**	**j=3**
i=1	1	A_{12}	A_{13}
i=2	$1/A_{12}$	1	A_{23}
i=3	$1/A_{13}$	$1/A_{23}$	1

Table 2: The fundamental scale of absolute number by Saaty (1980)

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak	Between Equal and Moderate
3	Moderate Importance	Experience and judgement slightly favour one activity over another
4	Moderate Plus	Between Moderate and Strong
5	Strong Importance	Experience and judgement strongly favour one activity over another
6	Strong Plus	Between Strong and Very Strong
7	Very strong or Demonstrated Importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	Between Very Strong and Extreme
9	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation

2.3 Weight Ranking and Consistency Test

The priority value is calculated using Eq. (1– 4). Using Eq. (1), the sum of reciprocal of column j (paired criterion) is calculated:

$$Aw = nw \tag{1}$$

Where A is pairwise comparison matrix; n is the order of the matrix i.e., the number of factors compared.

The normalized relative weights are calculated using Eq. (2) by dividing each element in a column by the sum of its respective column.

$$A'w' = \lambda_{max}'w' \tag{2}$$

where λ_{max} is the largest eigenvalue of A'.

The priorities are calculated using Eq. (3) and (4),

$$w_i = \frac{1}{\lambda_{max}} \sum_{j=1}^{n} a_{ij} \; w_j, \;\; i = 1, 2 \ldots . n \tag{3}$$

Where w_i is the weight to be determined by solving the Eq. (3), these final numbers show an approximation of the relative priorities for the elements being compared concerning its upper-level criteria (eigenvector). Next, check the consistency of judgment by using Principle Eigen Value, λ. Eigenvalue is obtained from the summation of products between each element of eigenvector and the sum of the reciprocal matrix column. The Consistency Index (CI) is defined as:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{4}$$

To overcome the order dependency of CI, the value of CI is then compared with the appropriate CI which is known as Random Consistency Index (RI) as shown in Table 3 (Aguarón & Moreno-Jiménez, 2003). The term is defined as the expected value of the CI corresponding to the order of matrices. Then, Consistency Ratio (CR) is proposed to compare between the CI and the RI using the following formula:

$$CR = \frac{CI}{RI} \tag{5}$$

If the value of CR is smaller than or equal to 10 %, the inconsistency is acceptable. If the CR is greater than 10 %, the comparison matrix must be repeated.

Table 3: Random consistency index, RI (Aguarón & Moreno-Jiménez, 2003)

N	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
RI(*n*)	0.525	0.882	1.115	1.252	1.341	1.404	1.452	1.484	1.513	1.555	1.570
K(*n*)	3.147	3.526	3.717	3.755	3.755	3.744	3.733	3.709	3.698	3.685	3.674

3.0 RESULTS AND DISCUSSION

Figure 1 shows the hierarchical problem decomposition of AOP evaluation for side impact. The analysis goal is to identify which body area that most affected (severe) when a side crash accident happened. The expert discussion is considering conditions as follows: (1) the car driver and the front passenger are using the seat belt; and (2) the car driver is healthy and free from any medication.

The next step is to construct a pairwise comparison. The comparison process can be aided using a series of questions that relate the relationship of the compared elements and the control criterion. So, the participated experts are lead to answer series of questions that relate to the driver and front passenger's body region during a car accident. For example, in this case, the question was raised "How much severe are chest injury compared to the head and neck when side crash happened". Thorough discussions have been carried out before the answer to each question can be finalized. The pairwise comparison and the judgment matrix from the expert input are tabulated in Figure 2 and Table 4 respectively.

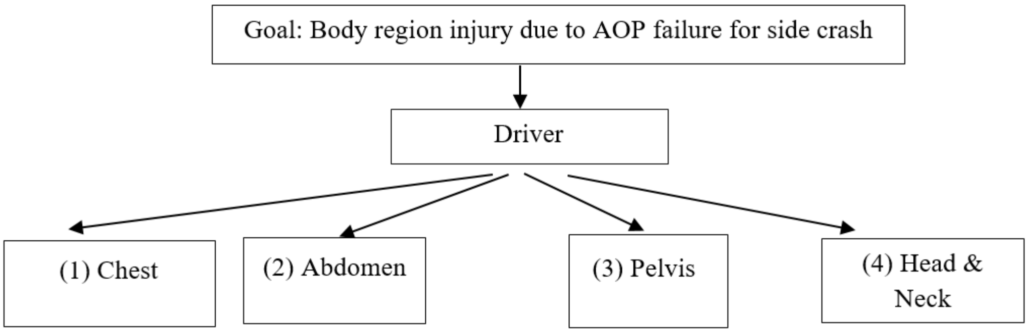

Figure 1: Problem decomposition hierarchy

Figure 2: Pairwise comparison based on expert panel input

Table 4: Judgment matrix

Driver	Chest	Abdomen	Pelvis	Head & neck
Chest	1	2	4	5
Abdomen	½	1	2	3
Pelvis	¼	½	1	2
Head & neck	1/5	1/3	1/2	1

As shown in Table 5, Figures 3 and 4, the weight of the level index shows that the chest will get the most severe body injury chest if the side crash happened with a relative weight of 0.5068. This is followed by the abdomen, pelvis, head, and neck which have a relative weight of 0.2641, 0.1428 and 0.0863 respectively. The consistency ratio of the analysis is 0.0079 which below 10 %, thus the pairwise judgements that have been made can be trusted.

Table 5: Priorities based on body region injury

Body Region	Prioritize
Chest	0.5068
Abdomen	0.2641
Pelvis	0.1428
Head & neck	0.0863

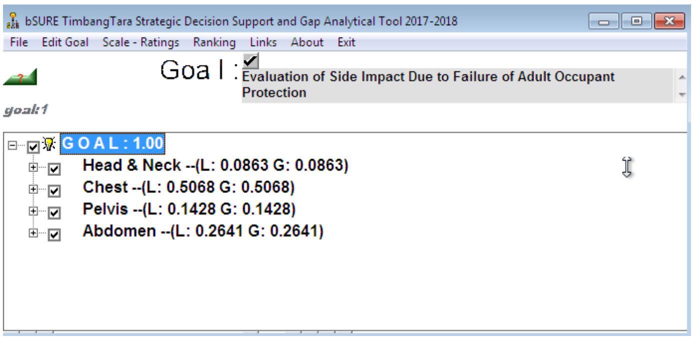

Figure 3: *TimbangTara* output

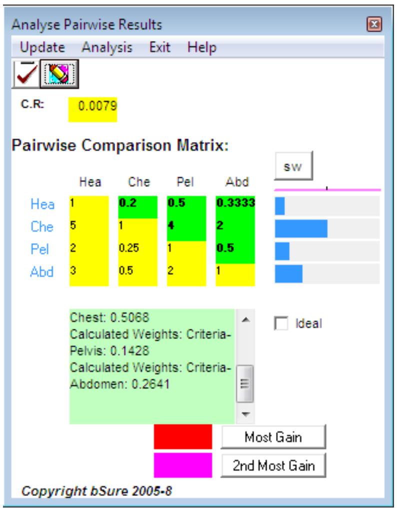

Figure 4: *TimbangTara* output

4.0 CONCLUSION

The results suggest that expert judgements are reasonable and protection of the thorax and upper abdomen following side impact crashes need to be improved. Buckle up seat belt could reduce head injury 20 % lower than unbelted while head or torso protection side airbags lower risk of head and thoracic injury of 75 % and 68 %, respectively, which also reduces the risk of death by 37 % to 45 %.

ACKNOWLEDGEMENTS

This research was supported by Universiti Malaysia Pahang (UMP) and ASEAN NCAP Collaborative Holistic Research (ANCHOR) (UIC181502) grant.

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