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Applying Analytical Hierarchy Process to Evaluate Adult Occupant Protection on Body Region in ASEAN NCAP Offset Frontal Test Domain

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Abstract – *Adult Occupant Protection (AOP) is a vital area of evaluation in all New Car Assessment Programs (NCAPs) around the globe. The primary objective of these new car assessment programs is to reduce road deaths by focusing on vehicle (pre-crash) safety features. Starting from the year 2017 until 2020, a single rating system has been introduced whereby AOP contributes 50% to the overall rating with a maximum of 36 points; split into three main domains including offset frontal test (OFT), side impact test (SIT) and head protection technology (HPT). However, the extent of OFT protection to car drivers and passengers during a collision still needs to be explored. Therefore, in this study, an evaluation of body region injury due to AOP failure in frontal crash is conducted to validate and support NCAP rating. Analytic hierarchy process (AHP) is put forward on the basis of expert's input from various related fields to evaluate the injury to body regions and OFT protection during an accident based on the current situation. The results show that head, neck and chest indicated the highest severity, followed by knee, femur and lower leg with respect to the Consistency Ratio (CR) of 0.0633. This was in line with the focus of ASEAN NCAP's AOP protocol whereby the three body regions were deemed as the critical parts and required sufficient protection. Based on the findings, it is proven that ASEAN NCAP's consideration of OFT in AOP is well developed and suits the current needs.*

Keywords: Adult Occupant Protection, Offset Frontal Test, AHP, expert assessment

1.0 INTRODUCTION

Road accidents have been recognized as the dominant cause of injuries and deaths worldwide, and Malaysia is no exception to such a scenario. Investigation and statistical analyses in Malaysia from 2007 to 2016 indicate more than 5.3 million police reports on motor vehicle crashes, involving 67,721 fatalities and over 180,000 injuries (Ministry of Transport Malaysia, 2017). Yearly comparison shows that car crashes have been the most frequent type of accidents on Malaysian roads (Figure 1). Although most drivers are convinced they can avoid such a tragedy, statistics have proved otherwise with an escalating number of road deaths every year. Therefore, there is an urgent need to reduce the occurrence of motor vehicle accidents.

TAHUN Year	MOTOSIKAL Motorcycle	MOTOKAR Motocar	VAN Van	BAS Bus	LORI Lorry	PEMACU 4 RODA Four Wheel Drive	TEKSI Taxi	BASIKAL Bicycle	LAIN-LAIN Others	JUMLAH Total
2007	111,765	426,941	21,109	10,285	47,696	21,823	8,809	2,690	14,909	**666,027**
2008	111,819	435,665	20,392	9,356	48,250	22,793	8,769	2,463	11,571	**671,078**
2009	113,962	472,307	19,220	9,380	46,724	23,581	8,669	2,486	9,294	**705,623**
2010	120,156	511,861	18,788	9,580	50,438	25,777	9,899	2,178	11,756	**760,433**
2011	129,017	546,702	17,916	9,986	53,078	30,828	11,197	2,033	16,394	**817,151**
2012	130,080	655,813	15,143	10,617	42,158	32,891	11,680	1,310	21,540	**921,232**
2013	121,700	632,602	17,148	10,123	39,276	52,512	11,651	1,370	15,441	**901,823**
2014	125,712	617,578	15,041	9,193	37,481	41,464	10,856	1,275	27,743	**886,343**
2015	123,408	625,758	14,565	8,804	34,942	46,163	9,591	1,119	29,924	**894,274**
2016	135,181	670,935	14,470	9,462	35,064	48,907	8,399	1,318	36,833	**960,569**

Source: Royal Malaysia Police Traffic Branch, Bukit Aman

Figure 1: Total number of motor vehicles involved in road accidents by type of vehicle in Malaysia, 2007-2016 (Ministry of Transport Malaysia, 2017)

Global road accident studies indicate that the severity of injuries due to frontal impact is the most relevant factor pertaining to car occupants' deaths (Johannsen et al., 2013). A front-impact car accident (or normally referred to as a head-on collision) occurs when the front-end of two vehicles collide with each other. Although head-on collisions are not as frequent as the rear-impact or side impact collision, they often lead to occupant fatalities. According to World Health Organisation, traumatic brain injuries (TBIs) accounts for almost half of the 1.3 million annual traffic-related deaths as well as 50 million traffic-related injuries worldwide (WHO, 2013).

Due to the potentially fatal injuries in a front impact collision, MIROS had spearheaded the campaign to establish a new car assessment program (NCAP), which was based on its Malaysian Vehicle Assessment Program (MyVAP). Thus, the New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP) was launched in 2011. The objective of such a program is to reduce road accidents by focusing on the vehicle pre-crash safety features. In addition, ASEAN NCAP was founded to produce a fair, meaningful and objective assessment of the car's impact performance, aside from providing a mechanism to inform consumers (Mohd Jawi et al., 2013).

Adult Occupant Protection (AOP) is one of the vital areas for automobile safety assessment in ASEAN NCAP. The AOP is based on the protocol used by the European NCAP. The overall rating system has allowed Euro NCAP to continue to push for better fitment and higher performance of passenger vehicles sold on the European market (van Ratingen et al., 2016). Starting from 2017, a single rating system has been introduced in ASEAN NCAP whereby the AOP shall contribute around 50% of the overall rating with a maximum of 36 points; split into three main domains including offset frontal test (OFT), side impact test (SIT) and head protection technology (HPT). In addition, OFT impact assessment involves the evaluation of injury to the head, neck, chest, knee, femur and pelvis, lower leg together with foot/ankle of the driver as well as the front-seat passenger's (ASEAN NCAP, 2017). However, the effectiveness of OFT in protecting car drivers and passengers during a collision in the local context still needs to be explored.

In this study, the Analytical Hierarchy Process (AHP) method shall be used to analyse the experts' input. AHP is a multi-criteria decision-making (MCDM) methodology based on a hierarchical structure. Its hierarchical and systematic features make it a popular technique to solve MCDM problems; with AHP successfully implemented in various fields ranging from education (Othman et al. 2012), chemical process assessment (Abdul Aziz et al. 2017) and even traffic accidents causation (Xi et al. 2016). The method provides a mathematical means to process the subjective and personal preferences of individuals or groups in making a decision. In addition, the decisions made are well suited in which the criteria are qualitative and possess a large subjective component, thus requiring judgments.

2.0 METHODOLOGY

2.1 Evaluation of AOP based on Body Region Injury from Frontal Crash using Analytical Hierarchy Process (AHP)

AHP involves three fundamental principles, namely decomposition of structure, comparison of judgments and hierarchical composition of priorities.

2.1.1 Problem Decomposition

Problem decomposition is imperative in decision making. The best and most organized way to decompose a problem is by structuring it into a hierarchical form which 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 which describe the system.

The analysis goal is to identify which body area that is most severely affected when frontal crash occurs. The existing OFT assessment consists of four groups of body region including the head and neck; chest; pelvis, knee and femur; with lower legs set as the alternatives to be evaluated. In this study, one of the body region group has been restructured whereby the pelvis has been assigned as a standalone instead of being combined with the knee and femur. Such a recommendation was made by one of the panel members with wide experience in handling severe crash accidents, whereby the panel member stated that whenever severe injury involves the pelvis, the accident victim will not survive due to loss of excessive blood. Thus, in this study, the body region groups consist of the (1) head and neck, (2) chest, (3) pelvis, (4) knee and femur and (5) lower leg.

2.1.2 Pairwise Comparison Matrix

In a pairwise comparison, two components are compared with respect to the upper level control criteria using a scale of relative importance. We first identified a value of A_{ij} which indicates the importance of i-th element (left), compared to the j-th element (top) as shown in Table 1. The scaling factor was based on the guideline by Saaty (1980) (refer Table 2). It is important to note that assigning a scale to the elements was subjective, thus, the assessor's knowledge, experience, and judgement were crucial. AHP summarizes these judgments by ensuring their consistency. Here, the *TimbangTara* software was used for weight calculation.

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

In this study, five experts from various related fields were gathered in one expert panel meeting to brainstorm and discuss how OFT works and how robust OFT can be in giving protection in the event of an accident. At the beginning of the meeting, the researchers explained about the project's objective in order to obtain consensus from all the experts about which body area that is most severely affected if the driven car gets involved in an accident based on current cases. Experts' knowledge, experience, and judgment were important in determining the subjective scale of body region's injury severity.

The next step is to construct a pairwise comparison. The comparison process can be aided using a series of questions on the relationship of the compared elements and the control criterion. So, the participated experts were led to answer a series of questions related to the driver and front passenger's body region during a car accident. In this case, the question was "How severe is head and neck injury compared to chest injury when frontal crash happens?". In-depth discussions were also carried out before each answer was finalized.

2.1.3 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 as:

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

where A is a pairwise comparison matrix while n is the order of the matrix i.e., the number of factors compared. On the other hand, the normalized relative weights are calculated using Eq. (2) by dividing each element in a column by the sum of its respective column given by

$$A'w' = \lambda_{max}'w' \quad (2)$$

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

Also, the priorities are calculated using Eq. (3) and (4) given by

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

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 with respect to its upper level criteria (eigenvector). Next, we check the consistency of judgment by using the Principle Eigen Value, λ. This Eigen value is obtained from the summation of products between each element of eigenvector and the sum of reciprocal matrix column. Here, the Consistency Index (CI) is defined as

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (4)$$

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 (Aguaron and Moreno-Jimenez, 2003). This term is defined as the expected value of the CI corresponding to the order of matrices. Then, Consistency Ratio (CR) is proposed to be compared between the CI and the RI using the following formula given by

$$CR = \frac{CI}{RI} \quad (5)$$

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

Table 3: Random consistency index, RI (Aguaron & Moreno-Jimenez, 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

3.1 Evaluation of AOP based on Body Region Injury from Frontal Crash

In this study, the body region groups comprise the (1) head and neck, (2) chest, (3) pelvis, (4) knee and femur, and (5) lower leg. Figure 2 illustrates the hierarchical problem decomposition of AOP evaluation for OFT. The analysis goal is to identify which body area is most severely affected when a frontal crash occurs. The expert discussion considered conditions as follows; (1) the car driver and the front passenger were using seat belt, (2) the car driver and the front passenger were healthy and free of any medication.

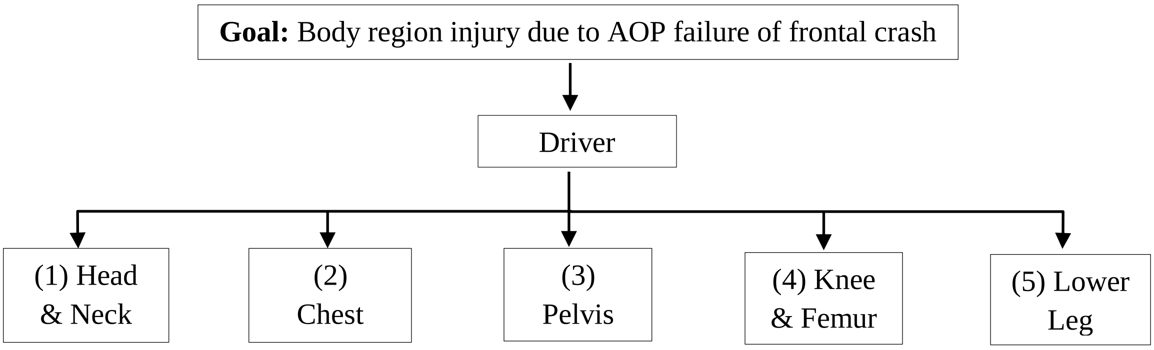

Figure 2: Problem decomposition hierarchy

The pairwise comparison and the judgment matrix from the expert input are tabulated in Figure 3 and Table 4, respectively. Through the Judgement Matrix, we can estimate the weight of the level index. As shown in Table 5, the weight of the level index indicates that head and neck possess similar risk level with the chest, if a frontal crash occurs with a relative weight of 0.3704. This is followed by knee and femur, pelvis and lower leg which have relative weight of 0.1596, 0.0604 and 0.0392, respectively. The consistency ratio of the analysis is 0.06 which is below 10%, thus implying that the pairwise judgments may be trusted. The panel of experts highlighted that the most common type of injuries in a head-on collision included broken bones and joint as well as muscle injuries. Furthermore, due to the mechanics of the body moving rapidly upon impact, the lower extremities including the pelvis, knees, leg, ankles and feet are subject to injury as they absorb the full force of the crash. Therefore, failure to protect all the mentioned body regions could lead to serious injuries and even fatalities to both the driver and front passenger in the event of a front collision.

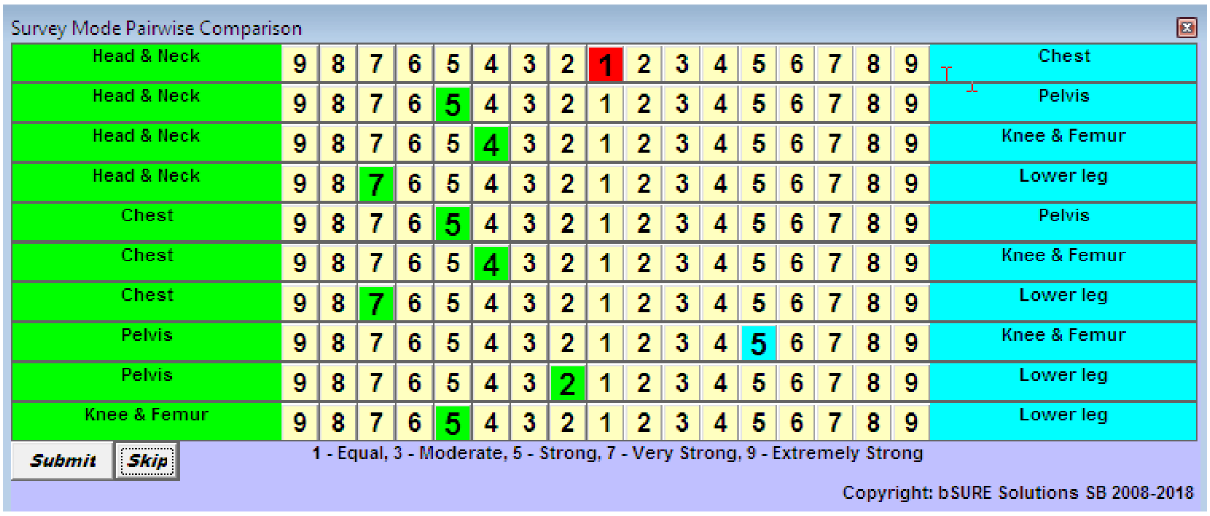

Figure 3: Survey mode pairwise comparison

Table 4: Judgment matrix

Driver	Head & neck	Chest	Pelvis	Knee & femur	Lower leg
Head & neck	1	1	5	4	7
Chest	1	1	5	4	7
Pelvis	1/5	1/5	1	1/5	2
Knee & femur	1/4	1/4	5	1	5
Lower leg	1/7	1/7	1/2	1/5	1

Table 5: Priorities of OFT domain based on body region injury

Body Region	**Prioritize**
Head & neck	0.3704
Chest	0.3704
Knee & femur	0.1596
Pelvis	0.0604
Lower leg	0.0392

These results show that the head, neck and chest are at the top of our finding. This is in line with the focus of ASEAN NCAP's AOP protocol whereby these three body regions are deemed as the critical parts and require sufficient protection. A recent study by Antona-Makoshi et al. also highlighted that the head and neck injury prevention strategies must be set as the top priority in order to reduce fatal or serious head injury (Antona-Makoshi et al., 2018). Besides focusing on the critical body region, OFT basic assessment criteria also covers all the other regions and comes with the upper and lower performance limits for each parameter. In the cases where multiple criteria exist for an individual body region, the lowest scoring parameter is used to determine the performance of that region. The lowest scoring body region of the driver or passenger is used to determine the score (ASEAN NCAP, 2017). This proves that rigorous crash tests have been performed in this rating program. Thus, it is believed that ASEAN NCAP has brought about tremendous driver safety improvements to new cars.

4.0 CONCLUSION

In this study, an evaluation of AOP on body region injury focusing on OFT domain has been conducted involving input from various related field experts. Based on the current situation, the head, neck and chest still remain as the most severely affected body regions in the event of a front crash. However, failure to protect other body regions may also bring serious injuries and fatalities to both the driver and front passenger. Other than that, the panel of experts recommends assigning the pelvis as a standalone in future assessments. Based on the findings of this study, it is proven that ASEAN NCAP assessment for AOP with consideration of OFT has been well developed and therefore, is suitable with the current needs.

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