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Evaluation of ASEAN NCAP's Adult Occupant Protection on Body Region using Analytical Hierarchy Process

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Abstract – *Global efforts in reducing road accidents were lead to the existence of a new car assessment program to ensure that the produced car may give life protection from traumatic death or injuries. Adult Occupant Protection (AOP), Child Occupant Protection (COP) and Safety Assist Technology (SAT) are domains used for the New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP). Focusing on AOP domain, it is contributing for 50% of the overall rating system of ASEAN NCAP with a maximum 36 points from three main assessments: (1) offset frontal test (OFT), (2) side impact test (SIT) and (3) head protection technology (HPT). However, for this study, only OFT and SIT assessments are focused. Knowing that ASEAN NCAP is struggling to provide an accurate assessment of every new car evaluation. However, it is also important to ensure that the accurate assessment stays relevant. So, to what extend OFT and SIT may be giving protection to the car driver and passenger if there is any collision, need to be explored. Therefore, experts from various related industries were gathered in one expert panel meeting to brainstorm and discuss how OFT and SIT work and how robust they can be giving protection when an accident happens. Analytical Hierarchy Process (AHP) is used to analyse the experts' input. Based on the finding, it is proved that the ASEAN NCAP assessment for AOP with considering OFT and SIT assessments were well developed and suitable to the current needs. In the future, cars on the road will become safer due to every party response to the ASEAN NCAP initiative positively.*

Keywords: ASEAN NCAP, Adult Occupant Protection (AOP), Analytical Hierarchy Process (AHP)

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1.0 INTRODUCTION

New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP) was established in 2011 to increase road safety standards by gaining global commitment to reducing losses due to a road accident. To date, ASEAN NCAP has been seen as one of the successful initiatives that managed to set safety in the automobile industry at its high level. Along the journey of ASEAN NCAP, it also can be seen how consumer demands about safety features that they should have in their car had raised and at the same time market for safer vehicles in Southeast Asia Region (ASEAN community) had increased significantly (Jawi et al., 2013; Abu Kassim et al., 2017).

Adult Occupant Protection (AOP), Child Occupant Protection (COP) and Safety Assist Technology (SAT) are domains used for ASEAN NCAP. Focusing on AOP domain, it is contributing for 50 % of the overall rating system of ASEAN NCAP with a maximum 36 points from three main assessments: (1) offset frontal test (OFT), (2) side impact test (SIT) and (3) head protection technology (HPT). However, for this study, only OFT and SIT assessments are focused.

For the ASEAN NCAP AOP OFT, the 50th percentile male anthropometry body dimension was used as dummies for driver and front passenger (ASEAN NCAP, 2017; Isa et al., 2016). After crushing at the speed of 64 km/h the installed sensors in dummies will provide readings according to the body region which the results are showing the worst effects after the crash from each body region (for OFT: head, neck, chest, femur, knee, upper and lower legs; for SIT: head and neck, chest, abdomen, and pelvis).

A post-test assessment also needs to be accounted after the crash test which is known as “modifier” (Solah et al., 2014), before the final result of AOP can be finalized and star rating can be awarded as per in Table 1. However, the AOP score for a five-star rating is also predetermined by the fitment of the SAT including Seatbelt Reminder (SBR) and Electronic Stability Control (ESC) (or equivalent). Meanwhile, for the three-star rating (and above) there is a requirement that needs to be fulfilled which lateral impact (side impact test) following UN Regulation No. 95. (Abu Kassim et al., 2017). From year to year, the trend of assessment becoming more stringent. This indirectly giving a lot of pressure for a manufacturer to design futuristic accident protection technology that may help them to score five-star of NCAP rating, thus making their car marketable. This situation also benefits the consumer in terms of having a safer car with affordable prices and will make the road safety ecosystem safer.

Table 1: Scoring scheme for AOP assessment

Adult Occupant Protection	
Final Score	**Star Rating**
14.00 – 16.00	Five-Star
11.00 – 13.99	Four-Star
8.00 – 10.99	Three-Star
5.00 – 7.99	Two-Star
2.00 – 4.99	One-Star
0.00 – 1.99	Zero-Star

2.0 METHODOLOGY

Five experts from various related industries were gathered in one expert panel meeting to brainstorm and discuss how OFT and SIT work and how robust they can be giving protection when accidents happen. At the beginning of the meeting, researchers explained the project's objective, to have a consensus from all experts about which body area that most affected (severe) if the drove car involves with an accident. There are also a few considerations that the experts need to have in their mind; i.e. (1) the car driver and the front passenger are using seat beat; and (2) the car driver and the front passenger are healthy and free from any medication. Experts' knowledge, experience, and judgment are important to determine the subjective scale of body region's severity.

Analytical Hierarchy Process (AHP) method was used to analyse the experts' input. In AHP, the pairwise comparison, need to be constructed. So, the participated experts were lead to answer series of questions that relate to the driver and front passenger's body region during a car accident. Thorough discussions were also conducted before the answer to each question can be finalized. The series of questions are as in Table 2. The answer was based on Saaty (1980) guideline as presented in Table 3.

Table 2: Series of questions

Number	Questions
1	How much severe are head and neck injury compared to the chest when frontal crash happened?
2	How much severe are head and neck injury compared to pelvis, knee, and femur when frontal crash happened?
3	How much severe are head and neck injury compared to lower leg when frontal crash happened?
4	How much severe is chest compared to pelvis, knee, and femur when frontal crash happened?
5	How much severe is chest compared to lower leg when frontal crash happened?
6	How much severe are pelvis, knee, and femur compared to lower leg when frontal crash happened?
7	How much severe are head and neck injury compared to the chest when side crash happened?
8	How much severe are head and neck injury compared to abdomen when side crash happened?
9	How much severe are head and neck injury compared to pelvis when side crash happened?
10	How much severe is chest injury compared to abdomen when side crash happened?
11	How much severe is chest injury compared to pelvis when side crash happened?
12	How much severe is abdomen injury compared to pelvis when side crash happened?

Table 3: The fundamental scale of the 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

AHP is a multi-criterion decision-making (MCDM) methodology based on a hierarchical structure. It's also a systematic method, thus makes it a popular technique to solve MCDM problems and has been successfully implemented in various fields of education (Othman et al., 2012). AHP method was used to summarize the obtained experts' judgments by ensuring their consistency. Then, the *TimbangTara* software was used to calculate the weight.

3.0 RESULTS AND DISCUSSION

This section shall discuss the results obtained from this study.

3.1 Group of Body Region for OFT and SIT Assessment

Each body regions' protection was discussed thoroughly in the expert panels' meeting session. The existing group of OFT's assessment for body regions was consisting of four groups (head and neck; chest; pelvis, knee, and femur; lower leg). However, at the early discussion, the body region's group was restructured into five groups which consist of: (1) head and neck; (2) chest; (3) pelvis; (4) knee and femur; and (5) lower leg. Pelvis, knee, and femur were split into two groups whereby the pelvis was assigned as standalone. The justification was given by one panel who has many experiences in handling severe crash accident which whenever severe injury involve with the pelvis, the person will not survive because of losing excessive blood. Meanwhile, for SIT, the group of body region remained as it is. Table 4 shows the difference between existing OFT's body region group of assessment and what had been used in this study for ASEAN NCAP future consideration. SIT's body region also included in Table 4.

Table 4: Assessment for body regions

Body Region Injury due to AOP Failure for OFT Assessment		Body Region Injury due to AOP Failure for SIT Assessment
Existing Assessment	**Future Consideration**	
Head & Neck	Head & Neck	Chest
Chest	Chest	Abdomen
Pelvis, Knee, Femur	Pelvis	Pelvis
Lower Leg	Knee, Femur	Head & Neck
	Lower Leg	

3.1.1 Head and Neck

Half of the 1.3 million annual traffic-related deaths and the 50 million traffic-related injuries are involved with traumatic brain injuries (WHO, 2013). It was estimated cost for traumatic brain injury after accidents such as medical cost, emergency services, lost work wages and loss of quality of life as the second-highest after spinal cord injuries (Zaloshnja et al., 2004). That is why head and neck injury prevention strategies must be set as the top priority. Without any doubt, many strategies had been employed to target the reduction of the risk of fatal due to traumatic brain injury, however, the risk reduction is still not achieved the target (Antona-Makoshi et al., 2018). One of the strategies is to enforce the use of seat belts and the obtainability of frontal airbags. Indeed, research showed that the effectiveness of seat belt use and frontal airbags may reduce the risk of head and neck injury (Antona-Makoshi et al., 2018). Seat belts may help to avoid driver and front passenger from being ejected from the vehicle while accident. However, from 383 cases of drivers killed in car crashes, 50 vehicle occupants that killed, who were stayed in the vehicle (seat belted), with head injuries being the certain source of fatality (Ndiaye et al., 2009). Due to that scenario, experts were also agreed that the head and neck are the most important body parts that need to be protected to stay alive. So, the consensus among experts was easier to obtain.

3.1.2 Chest

If the crash involves chest protection failure, most of the time mortality is high. One of the reasons is such injury in the chest area will associate with multi-system injuries. Although the human chest is protected by layers of skin, bone, muscle, and fat, too much force may break human's internal padding, resulting in injuries to any important organs. Chest fracture, for example, is related to lung injury such as punctured lung, collapsed lung and inhalation damage. Rib fracture, flail chest and sternal fractures are also common injuries caused by high-speed road traffic accidents which result in deceleration injury and compression forces (Evans & Hornick, 2005). Depends on the severity of the injury, based on the experts' discussion, the injured lung still has a chance to heal with proper medication and rehabilitation. The same goes for the liver which liver may regrow over time. However, regardless of what type of chest injury that happens, experts agreed that immediate medical treatment is required to avoid

potentially life-threatening complication. The previous study also highlighted that thorax (chest) and head are the vital areas for protection in the case of car drivers (Ndiaye et al., 2009).

3.1.3 Pelvis

One of the panels in the meeting was highlighted about pelvis injury that needs to split from knee and femur assessment. The reason was because of the pelvis has different risk factors compared to the knee and femur when the accident happens. One of the discussed issues was *'pelvis is in proximity to major blood vessels and nerves and digestive and reproductive organs'* (Mahadevan, 2018). If there is an injury such as pelvic fractures, it may cause extensive bleeding and at the same time, other near part of the body system may also affect and require urgent treatment. Immediate or delay death is expected if the injury is failed to be managed properly.

3.1.4 Knee and Femur

To guarantee the knees are protected, car manufacturers have to ensure that the knee area is free from hazards. Based on the crash test for frontal impact using adult dummies, the knees always hit the same small areas of the facia (the region of the steering column) (van Ratingen, 2016). The space allowance is important to be highlighted for the driver or front passenger compartment to reduce the risk of knee and femur injury. Many studies combined knee and femur with lower leg assessment. The limited study that only focus on knee and femur without lower leg, making the review of this body area is difficult. Due to that also, during the expert panel meeting, the answer for *"How much severe are pelvis, knee, and femur compared to lower leg when frontal crash happened?"*, was also tough to get. A simple explanation is just like to answer this question. How severe lower leg injury compared to the knee if the car engine goes out and press the lower extremity? It ends up with no solid answer that can be recorded.

3.1.5 Lower Leg

Many cases showed that car drivers or front passenger or both killed due to the hard impact of the interior of the car or the intrusion of part of the car into the driver or front passenger compartment (Hitosugi & Takatsu, 2000). Martin et al. (2000) had published one work that revealed the threat-to-life hierarchy and the body region, which shows the lower leg injury (including injuries to femur and pelvis) was at the number three after spinal cord injury and brain injury. This also supported by the expert's agreement which they did mention if femur fractured, or lower limb had a severe injury, it may affect of losing large amounts of blood quickly can lead to serious complications or death. Airbags, however, are not as effective in preventing upper and lower extremity injuries, and thus arm and leg injuries will become more prevalent in years to come (Martin et al., 2000). The same goes for seat belts which designed to protect the driver's upper body for being in contact with a hard object. Although seatbelt is proved to decrease the incidence of injuries and can save lives even in severe crashes, however for lower extremity protection (lower leg, knee, and femur) when there is a crash whether from front or side or vehicle, nothing can be done to avoid lower extremity to absorb force which most of the time, will make them injured badly. Due to that, this issue is expected to become an attention in many potential research in the future.

3.1.6 Abdomen

In one study conducted in Spain by Santamariña-Rubio et al., (2007), the abdomen and chest (torso) are grouped to form a single body region in their assessment. In their study, the result showed that the torso region sustains more injuries compared to other body regions including the head in fatal cases or high possibly responsible for death). The explanation that can be made is because of the injuries to the internal organ for example liver, kidney, spleen, and urinary bladder (Ndiaye et al., 2009).

3.2 Source of Injury During a Crash

In the expert panel meeting, the sources of injury for body regions were into experts' panel attention. Everyone in the meeting agreed most of the injuries in car accidents are due to the impact of the driver or front passenger against some part of the interior of the car or the intrusion of part of the car into the driver or front passenger compartment (also mentioned in Hitosugi & Takatsu, 2000). The obtained findings were in line with the published work by Acierno et al. (2004), as presented in Table 5.

Table 5: Type of injuries in car accidents – frontal and side impact

Frontal Impact Injury Data	
Type of Injury	**Source**
• Zygomatic arch fracture	External hood intrusion
• Femur, pelvis, radius/ulna fracture • Pelvic fracture, hip dislocation, sciatic nerve injury	Instrument panel
• Femoral shaft fracture	Knee bolster
• Ankle fracture	Toe pan
• Spleen contusion	Steering wheel
• Abdominal contusion	Belt
• Pneumothorax (collapsed lung) • Caused by a fractured rib penetrating the lung parenchyma (Evans & Hornick, 2005)	Seatbelt
Side Impact Injury Data	
Type of Injury	**Source**
• Pneumothorax • Perinephric hematoma • Multiple pelvic/sacral fractures • Subarachnoid • Flail chest, heart laceration, diaphragm injury	Door

3.2 Prioritization of Body Regions

Based on the *TimbangTara* analysis (Table 6), the index level of OFT shows the head and neck have a similar risk level with chest if a frontal crash happened with the value of relative weight is 0.3704. This is followed by knee and femur, pelvis and lower leg which have the value of relative weight 0.1596, 0.0604 and 0.0392 respectively. The consistency ratio of the analysis is 0.06 which below 10 %, thus the pairwise judgements among the expert panel that have been made can be trusted. Experts also highlighted that failure to protect any of the above body regions could bring to serious injuries and fatalities to the driver and front passenger but it depends on the level of severity plus the how effective treatment can be performed. The previous study showed that in 287 killed drivers, the three most frequent locations for injuries were at thorax (30 %), head (23 %) and the combination of both (18 %) (Ndiaye et al., 2009). Besides, Santamariña-Rubio et al., (2007) also found almost the same whereby, the most frequently affected body regions were head (traumatic brain injury) (78 %), thorax (58 %) and face and neck region (45 %). So, the finding of this paper for the offset frontal test is in agreement with the practice of ASEAN NCAP and with what has been proven by other researchers.

Meanwhile, for SIT, the index level shows the most severe bodily injury is chest if side crash happened with the value of relative weight is 0.5068. Followed by abdomen, pelvis, head, and neck which the value of relative weight 0.2641, 0.1428 and 0.0863 respectively. The consistency ratio of the analysis is 0.0079 which below than 10 %, thus the pairwise judgements that have been made can be trusted. The previous study also found the abdominal injuries are less frequent than thoracic (chests) injuries for fatality cases due to car accidents (Ndiaye et al., 2009).

Table 6: Prioritization of body regions – OFT & SIT

Offset Frontal Test (OFT)	Body Region	Prioritize of OFT	Side Impact Test (SIT)	Body Region	Prioritize of OFT
	Head & Neck	0.3704		Chest	0.5068
	Chest	0.3704		Abdomen	0.2641
	Knee & Femur	0.1596		Pelvis	0.1428
	Pelvis	0.0604		Head & Neck	0.0863
	Lower Leg	0.0392			

4.0 CONCLUSION

In this study, evaluation of AOP on body region injury focusing on OFT and SIT domain had been conducted. Experts from various related fields were gathered in one meeting to explore their agreement on which body region is at most danger if any collision form front and/or side. Based on the current situation, the head, neck, and chest remain the most affected (severe) body region's if the front crash happened. Meanwhile, for side impact crash, chest injury is leading. However, failure to protect any body regions from the severe crash could bring to serious injuries and fatalities to the driver and front passenger. During the fruitful discussion, a recommendation also given by panels to assign pelvis as standalone in a future assessment. Based on the finding, it is proved that ASEAN NCAP assessment for AOP with considering

OFT and SIT is well developed and suited to the current needs, but there is still have room for improvement.

ASEAN NCAP initiatives were by far successfully encouraged current best practice for the automobile industry to produce a marketable vehicle. At the same time, from the initiative too, the vehicle safety info that available is disseminated to the potential vehicle buyer. With the direct and indirect pressure from the potential buyer to have such protection of accident avoidance technologies in their car and they also can simply compare one car to another based on the ASEAN NCAP rating system, manufacturers will have no choice but to design a safe car as per demand. It can be predicted cars on the road in our future will be the safest machine on the planet. However, to what extent the technologies are used and can help in the total reduction of road crash is still questionable. This is because road accidents are multifactorial, thus systemic approach is required to explore the means to have high-level road safety standards.

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