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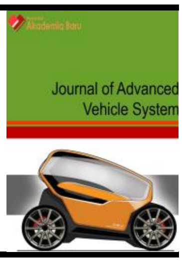

Prediction on N1 Injury Severity Correlating Operational Speed

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ABSTRACT

Growth of e-retailing business has brought to the growth of Light Commercial Vehicles (LCV) on the roads. It is estimated that LCV accounted for about 40% shares of total vehicle production in ASEAN market. Unfortunately, since there is no vehicle safety regulation imposed, almost 80 percent of small lorry and light panel van which falls under Light Commercial Vehicle (LCV) segment was not designed to meet minimum vehicle safety standards. Even though, only 6% of the total fatalities involving goods vehicles were reported in Malaysia, the fatality index per 10,000 respective vehicles was 2.6 which is almost as high as the fatality index for motorcycles (3.0) in 2018. By allowing this vehicle to operate on public roadways, we are introducing into the traffic mix a vehicle with questionable stability and crash protection. As consequences, this will increase the risk of accident severity among this vehicle category. Acknowledging the fact that speed is one of the contributory factors to traffic crashes, this study was carried out to correlate the operational speed of N1 vehicles with the ASEAN NCAP crash test results. The results of the 5 models of N1 vehicles tested by ASEAN NCAP were used as a surrogate data for small lorry and panel van observed on the roads. Based on the speed data, it was found that about 65% of the small lorry drivers were at risk of sustaining severe injury level of AIS3+ while for panel van driver, 57% of them would experience HIC15 of MAIS 3+ injury.

Keywords:
N1 Vehicle, LCV, Small Lorry, Panel Van, Injury Severity

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1. Introduction

Growth in global trade has shown an upward trend towards the logistics industry in Malaysia. According to the World Bank Logistics Performance Index (LPI) (2016), Malaysia had the highest LPI score after Singapore in the Southeast Asian region. As the growth of the logistics sector is expected to be positive in the future, there is much scope for improvement.

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Mentioning about freight industry, it plays a vital role for the inbound and outbound sides of the businesses to deliver products in a timely manner. Light Commercial Vehicles (LCV) or also known as 'People Mover' is usually used for this purpose. Mordor Intelligence (2019) reported that LCV covered almost 40% of vehicle production in ASEAN market. Following the increase in demand, it is expected that this type of vehicle will dramatically increase the traffic volumes on the street.

However, by allowing this type of vehicle to operate on public roadways, we are introducing a mix of vehicle with questionable stability and crash protection into the traffic mix. Hisleius. L (2004) explained that the heterogeneous traffic stream (a combination of heavy and light vehicles) has a major effect on accident trends.

Furthermore, since there is no vehicle safety regulation imposed in the market, about 80% of small lorry and light panel van which falls under LCV segment was not designed to meet minimum vehicle safety standards. In Malaysia, light N1 vehicles were manufactured to the level that differ significantly from global vehicle safety standards. As a result, there is no assurance to what extend the level of occupant protection this type of vehicle have.

The details for N1 vehicle class are further discussed in the following. N1 vehicle was divided into three major types which are Pick-up Truck, Panel Van and Light Truck or Small lorry. They also familiar as light-commercial vehicle or light-duty vehicle. As showed in Figure 1, panel van or small lorry mostly designed to ensure large cargo space. Though for pick-up truck, it is typically designed to carrying goods and also passengers. The basic design of these vehicle mostly depends on the key purpose which finally justified the idea of 'flat head type' or 'front engine type'. As a result, the vehicle safety standards for most of pick-up truck apparently much better if compare to the other two sub-categories.

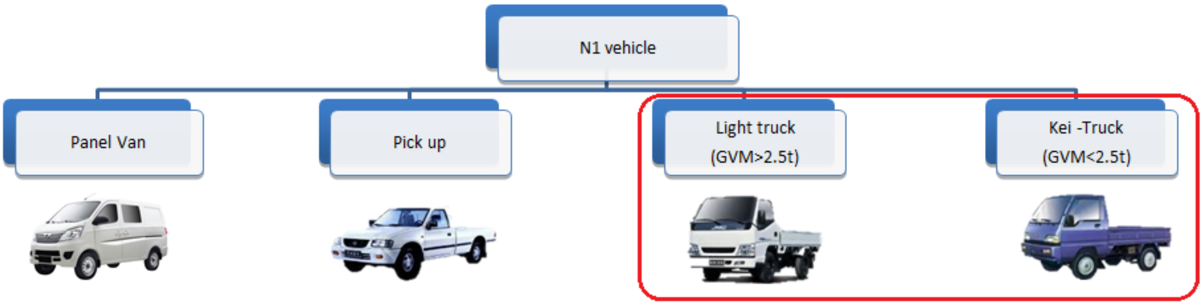


Figure 1: N1 Category vehicle divided into three major types

With the rapid growth of N1 vehicles, the number of road death and casualties is likely to rise. In Malaysia, goods vehicle (logistic, courier company etc.) recorded the 3rd highest accident rates after Motorcycle and Passenger Car in year 2018 (PDRM 2019). In terms of fatality per 10,000 respective registered vehicles, the fatality index was 2.6 which is very close to the motorcycle fatality index of 3.0 (Table 1).

Table 1: Malaysia index fatality per 10,000 registered vehicles in 2018

Type vehicle	Registered Vehicle	Total Fatality	Index Fatality per 10,000 registered
Motorcycle	13,725,918	4128	3.0
Passenger Car	14,189,693	1167	0.8
Goods Vehicle	1,262,064	327	2.6
Bus	62,022	39	6.3
Other	592,229	94	1.6

Road safety is one of the major apprehensions to fight against the ever-growing road traffic related problems. Moravčík & Jaśkiewicz (2018) stated that vehicle infrastructure, active and passive safety features are some of the key factors in improving the road safety.

Therefore, in view of N1 vehicle, an approach of the minimum safety regulation has to be implemented to counter this matter. The minimum safety regulations and standards in the automotive sector have evolved in Europe, US, Japan and the other regions over the last 50 years. Even though there are differences in certain part among these countries, the objective is same which is to provide the highest level of cost-effective safety performance. Table 2 presents the available regulation on N1 vehicles in several countries.

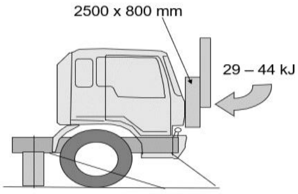
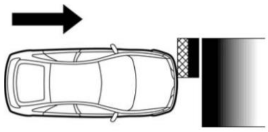
Table 2: N1 vehicle regulations around the world

Country	Regulation	Year of Adoption
Japan	Article 18	1998
US/Canada	FMVSS 208	2012
Europe	R29	2011
Malaysia	R29	2020
India	R29	2008

In Malaysia, ECE-R29 was enforced since year 2020 as a specific test conducted on N1, N2 and N3 commercial vehicle (VTA by JPJ 2017). However, as N1 category vehicles have approximately similar structure with M1 category (mass, design etc.), it seems that R29 is insufficient for the designated test in term of passive safety assessment. An analysis of the accident data by Gwehenberger et al. (2002) reveals that cab design based on the optional regulation ECE-R 29 is totally inadequate to provide affordable protection afforded to occupants in the case of head-on collisions.

The tests for Regulations No 29 are slightly different with Regulations No 94. Basically, ECE-R29 test requires the test vehicle to be impacted by hanging pendulum and crushing into the upper cabin structure. The cab must be designed in such a way that in event of crash, there is sufficient survival space for the occupants. ECE-R29 uses pre-set limits of cabin crush to ensure occupant protection rather than measuring the occupant injury based on Anthropomorphic Test Devices (ATDs), or dummies. While, regulation test No 94 which more familiar to passenger car basically is a dynamic crash test. Table 3 summarises the comparison between ECE R29 and ECE R94 tests.

Table 3: Test characteristic comparison for ECE R29 and ECE R94

Regulations	**R29**	**R94**
Test Area	 Pendulum: 1500kg Energy impact: 29.4 kJ	 $Eabs_{barrier} \neq 0kJ$ Deformable Barrier Barrier width: 1000mm
Structure Damage	Chassis upper cabin.	Lower cabin. Offset frontal area.
Impact Energy	For N1 vehicle, using similar pendulum (≥1500kg) impact with 29.4 kJ.	Weight × Speed Example: 1.5 t × 64 km/h Ek = ½ mV2

In this direction, the improvement efforts should cover all aspects. Thus, this study aims to explore the safety performance of light N1 vehicle in Malaysia including the crashworthiness performance. Instrumented dummy injury data was analyzed from ASEAN NCAP official crash test results while speed profile data was extracted from observation project regarding commercial vehicle operational characteristic.

2. Methodology

This research aims to identify and evaluate the safety performance of N1 vehicle in Malaysia by correlating the observed speed with the ASEAN NCAP test results. This study can be divided into 2 parts, which are:

2.1 Vehicle Crash Test: Dummy Injury Data

A crash test is a type of destructive testing undertaken to ensure the safe design standards with regards to crash compatibility and crashworthiness. There are five (5) models of light N1 vehicles that have been tested by ASEAN NCAP. The 5 models of the N1 vehicles are listed in Table 4.

Table 4: Models of N1 Vehicles tested by ASEAN NCAP

Brand	Model	Made	Test year	Kerb Mass (Kg)	Star Rating
Chery	Transcab	China	2017	1041	Zero
Suzuki	Carry	Japan	2017	1107	Zero
TATA	SuperACE	India	2018	1260	Zero
Chana	Era Star II	China	2019	1115	Zero
DFSK	V25L	China	2019	1255	Zero

For each crash, there will be two test configurations applied (Figure 2 demonstrates the crash test configuration):

1. Frontal offset crash test - These consist of an impact into a honeycomb barrier (EEVC barrier) with a 40 percent overlap. The impact speed for the testing is at 64 km/h.

2. Side impact crash test – Moving deformable barrier install on the trolley with kerb mass 950Kg ± 20Kg impact into stationary test vehicle at the speed of 50 km/h.

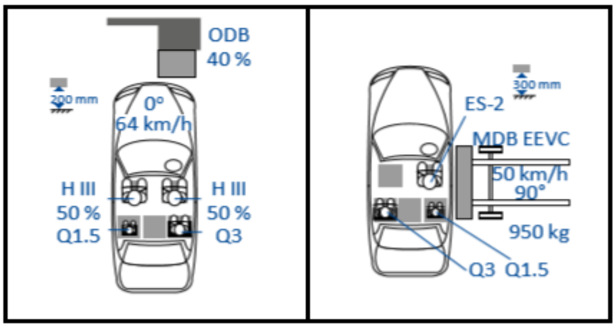


Figure 2: Frontal Offset Crash Test (Left) and Side Impact Crash Test (Right)

Anthropomorphic Test Device (ATD) or crash test dummy was the core instrument used to collect the data during the crash and the results will be used to gives an evaluation for the crashworthiness performance of the tested vehicle. The ATD is a frontal test Hybrid-III, 50th percentile male test dummy. The dummy has stature of an average U.S. male adult (height equals 175 cm, weight equals 78 kg) and characteristics resembling the human body.

Dummy injury in the event of frontal crashes will be a reference to understand the severity of injury. As explained by Paul et al. (2004), for compliance with regulation, dummies in the driver and front passenger must score injury assessment values below those established for human injury thresholds for the head, chest, and legs as mentioned in Table 5.

Table 5: Models of N1 Vehicles tested by ASEAN NCAP

Reccomended Criteria	**Mid – Size Male**
Head (HIC_{15})	700
Neck	
Tension and compression (N)	4500
Flexion (Nm)	310
Extension (Nm)	125
Chest	
Chest compression (mm) Viscous criterion (m/s)	42
Lower Extremity	
Lower leg Compression (kN)	8
Lower leg Tibia index	1.3

2.2 Vehicle Speed Profiling

Vehicle speed profiles is required to allow detail interpretation of operational driving behavior which could relate to injury risk analysis due to the act. Thus, primary road consist of Federal and Secondary road in Selangor were selected as the observation sites. The samples were targeted at small lorry and panel van. The data are collected at various sites between 10:00 AM and 2:00 PM.

3. Results and Discussion

3.1 Crashworthiness Performance

Many evidences have shown that offset frontal test procedure could be able to simulate the life-threatening crash modes in the "real-world" environment yet not to cater all circumstances, at least significant to accommodate driver occupant's injury. The five models of N1 light vehicles (Chery Transcab, Suzuki Carry, Tata Super Ace; small lorry, Chana Era Star and DFSK V25L) were tested following the ASEAN NCAP frontal offset test protocols.

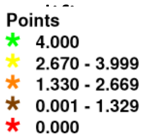
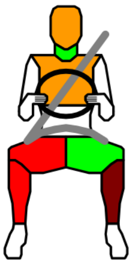
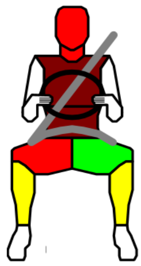
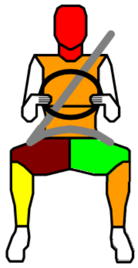
The results of the frontal offset test for the 5 models were presented in Table 6. TATA super Ace had the highest score of HIC_{15} for small lorry category while DFSK V25L panel van reported higher HIC_{15} score as compared to Chana Era Star II.

Table 6: Frontal ODB test on N1 category vehicles

Frontal ODB Test		Cherry Transcab 2017	Suzuki Carry 2017	TATA Super Ace 2018	Chana Era Star II 2019	DFSK V25L 2019
Driver Injury		Value	Value	Value	Value	Value
Head	HIC15	595.61	395.37	839.78	560.10	1358.00
	Resultant Acc. 3 m/sec exceedance - g	80.53	72.18	85.40	98.37	141.51
Chest	Compression - mm	33.44	35.65	33.48	43.72	33.99
	Viscous criterion - m/s	0.17	0.14	0.48	0.38	0.20
Lower leg	Left Upper Compression - kN	3.10	0.88	1.50	1.77	1.77
	Left Lower Compression - kN	3.80	1.08	1.47	2.06	2.06
	Right Upper Compression - kN	1.49	1.4	1.50	1.49	1.69
	Right Lower Compression - kN	1.10	1.86	1.47	1.10	1.73
	Left Upper Tibia Index	0.96	0.21	2.62	1.69	0.34
	Left Lower Tibia Index	1.06	0.12	0.93	1.73	0.31
	Right Upper Tibia Index	1.36	0.33	1.65	0.57	0.57
	Right Lower Tibia Index	0.96	0.16	2.13	0.30	0.30

The overall test performance results for each model were converted into star rating (from 0 to 5 stars), as presented in Table 7. The result was based on the injury scale score. The final rating combines the passive and active safety assessment. It should be noted that NCAP assessment program does not cover the adjustment for differences driver characteristics and crash condition.

Table 7: ***Summarize of N1 vehicle driver injury rating without modifier***

	CHERY Transcab	SUZUKI Carry	TATA Super Ace	CHANA Era Star II	DFSK V25L
Rating without 					

Nevertheless, the most critical body region impacted during the crash was the lower extremity with risk injury (ASEAN's driver) discovered to reach almost 96% higher compare to passenger's side. As expected for flat head type that driver injury to the leg body region was highest after frontal offset collisions with MAIS 3+, followed by injury to the head and chest as well. The injury pattern was observed for each of tested vehicles with conclusion that all of 5 (five) model of light N1 vehicles driver sustained the highest MAIS 3+ for lower extremity and head body region.

The summary of all tested light N1 vehicle with vehicle characteristic and injury performance were presented in Table 8. The results show that all the 5 models would cause very serious injury in all the crashes.

Table 8: ***Summary of light N1 vehicle characteristic and performance***

	Chassis type	**D-value**	**Structure Compatibility**	**SRS Airbag**	**Injury Level**
Chery Transcab	Semi forward	<800	Weak	No	Poor
Suzuki Carry	Semi forward	>800	Marginal	No	Bad
TATA Super ACE	Full forward	<400	Poor	No	Poor
Chana Era Star II	Semi forward	<600	Bad	No	Poor
DFSK V25L	Semi forward	<600	Bad	No	Poor

3.2 Speed Profiling

Table 9 presents the distribution speed data of N1 vehicle which collected by observation survey along 3 main federal roads in Selangor (Meru Klang, UKM Bangi-Kajang and Taman Rimba Templer Rawang). The average speeds ranged between 63.05 km/h to 69.15 km/h for all types of N1 vehicles. Based on the observation that has been done on the chosen site, there are 60 pick-up truck, 61 light N1 panel van, 34 heavy N1 panel van, 118 light N1 lorries and 206 heavy N1 lorries.

The results indicate that in general most of the N1 vehicles (7.63% to 72.13%) travelled fast and did not comply the minimum speed limit that has been displayed on the road. The lower the displayed speed limit, the higher the percentage of non-compliance rate. Thus, as the speed limit increased, the compliance increased.

Table 9: Distribution of speeds by vehicle types

Vehicle	N	Mean speed	85th%tile speed	Speed limit	Above speed limit (%)
Pick up	60	68.16	90.55	60	55.93
				70	44.07
				80	27.12
Light Panel van	61	69.15	84.70	60	72.13
				70	50.82
				80	19.67
Heavy Panel van	34	69.16	93.45	60	64.71
				70	44.12
				80	26.47
Light Small lorry (GVM<2.5t)	118	63.05	77.15	60	55.93
				70	32.20
				80	7.63
Heavy Small lorry (GVM>2.5t)	206	63.09	76.25	60	63.02
				70	33.85
				80	8.85

3.3 Injury Risk Prediction

Nilsson used his data to show the effect of change in speed towards the number of crashes that could be expressed by the formula:

$$A_2 = A_1 \left(\frac{v^2}{v^1}\right)^2$$

This formula basically said that the number of crashes after the change in speed (A2) equals the initial number of crashes (A1) multiplied by the quotient of the average speed after (v2) and the average speed before the change (v1) to the second power.

Nilsson reasoned that the number of serious crashes would be affected more by an increase in speed based on the principles of kinetic energy. He reported that the exponent of the function could be increased to 3 to describe the change in serious injury crashes (*I*) and to 4 to describe the change in fatal crashes (*F*):

$$I_2 = I_1 \left(\frac{v^2}{v^1}\right)^3$$

$$F_2 = F_1 \left(\frac{v^2}{v^1}\right)^4$$

Therefore, this concluded that a 10% increase in mean speed will lead to a 20% increase in all injury crashes, a 30% increase in fatal and serious crashes and a 40% increase in fatal crashes on average and approximately based on the power model, the rule of thumb (Nilsson, 2004).

Based on Nilson (2004) on speed theory and the dummy injury results from the NCAP crash tests for the 5 models N1 vehicles, the speed – injury severity prediction graphs for head, chest and lower leg were plotted as in Figure 3 (10% increase in mean speed will lead to a 20% increase in all

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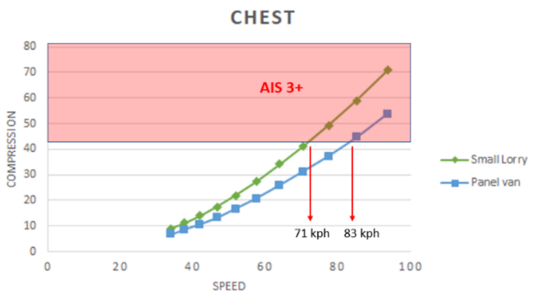
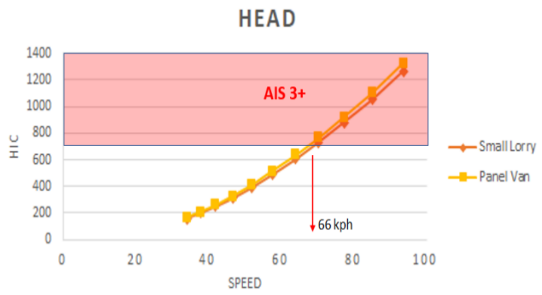
injury crashes). These graphs assume that the drivers were wearing seatbelt and no rollover or secondary impacts occur. It is also to note that the graphs were constructed based on limited available injury data (5 vehicle models), so the confidence intervals on these curves are relatively wide and should be considered as a best estimated only.



HIC15 at different speed for head injury



Compression of chest at different speed for chest injury

Index of lower leg at different speed for lower leg injury

Figure 3: Speed - injury risk for head, chest and lower leg

Based on the graphs, the injury severity on head, chest and lower leg faced by the driver can be predicted related towards the observation made on small lorry and light panel van. For small lorry, there are about 55.93% driver possibility of sustaining of 500 HIC15 value for head injury, 28 mm chest compression for chest injury and 0.9 for lower leg injury when they drive above 60 km/h. There is also 32.2% of driver that drove above 70 km/h. Thus, they are having chances to face 700 HIC15 value for head injury, 35 mm chest compression for chest injury and average of 1.2 for lower leg injury. In addition, 7.63% driver drive at above 80km/h possibility of facing 900 HIC15 value for head injury, 50 mm chest compression for chest injury and average of 1.6 for lower leg injury which equivalent to AIS >= 3 indicate increasing probability of over 10% risk of fatality.

Meanwhile, for panel van, there are about 72.13% driver possible to injured at 500 HIC15 value for head injury, 28 mm chest compression for chest injury and average of 0.9 for lower leg injury when they drive above 60 km/h. There is also 50.82% of driver that drove above 70 km/h. They are possible of sustain 700 HIC15 for head injury, 41 mm chest compression for chest injury and average of 1.2 for lower leg injury. In addition, 19.67% driver drive at above 80km/h facing 900 HIC15 value for head injury, 52 mm chest compression for chest injury and average of 1.6 for lower leg injury which equivalent to AIS >= 3 indicate increasing probability of over 10% risk of fatality.

4. Conclusion

The study shows that that on average, more than 55% of light N1 category vehicle's driver will sustain very severe injury if the frontal crash happens. As shown in Figures 4, for panel van driver, head and legs injuries have an almost similar higher percentage risk of AIS 3+ injury in the offset frontal impacts than chest body regions. In fact, HIC and legs percentage was almost 35% higher than injury recorded on the chest. While, 65.25% of small lorry driver were at risk of sustaining severe injury level AIS 3+ on leg body region if frontal offset crash happens. Based on the graphs, it was revealed that driving characteristic of small lorry and panel van driver will result of a higher injury risk either to head or lower extremity body region. Thus, reducing leg and head injuries should be a prime objective in addressing offset crashes among light N1 vehicle in ASEAN or even Malaysia.

Panel Van | Small Lorry

Figure 4: Prediction of observation speed vs injury risk to panel van and small lorry drivers

Based on the crash tests conducted on 5 models of N1 vehicles by ASEAN NCAP, it was found that all the 5 models had poor frontal structures which resulted in excessive intrusion into occupant compartment and exposed to contact injuries. The good structure compatibility can sustain the impact force thereby minimising the deformation while reducing the crash pulse in favour of restraint loadings on the occupants. The cross reference of the operational speeds for small lorry and panel van on selected roads in Malaysia provide evidence that in case of collision (at travel speed of 60 km/h), there are more than 50% of the drivers would sustain very serious injury on head, chest and lower legs. In view of this results, it is an urge to the government to implement more stringent policy on the new car safety sold in Malaysia in ushering the UN Sustainable Development Goals. In conclusion, this study helps in acknowledge driver about the risk of injury that they will be facing off with the amount of speed they were driving at as it was observed that more than half of the commercial vehicles travelling above the speed limit (60 km/h) state roads.

5. Limitation of the study

There a few limitations associated with this study. Several assumptions are made:

- Assumed that the safety level of tested small lorries and panel vans were equivalent to the minimum safety standard for most of the models offered in market.
- The assumption being made on the structure among panel van and small lorry is quite parallel in term of the arrangement of frontal structure that result the passive safety performance between both is fairly similar.

- The analysis on the crash test results were based on assumptions due to limitation of recorded data which only three small lorries and two model of panel van have been tested in ASEAN NCAP, resulted as injury assumptions is slightly overestimated.
- The analysis also involved assumption on impact speed, angle of crashes and conditions of drivers (belted) due to limitation of data during observation.

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