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Original Article

Development of city-bus assessment in Thailand

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Abstract

Collisions between pedestrians and city buses are one of the severe casualties in Thailand. This research aims to develop an assessment program and to evaluate the front end of public city buses based on pedestrian injuries and mechanisms in Thailand. Therefore, vehicle preparation and marking, testing conditions, and HIC requirements, assessment criteria, and road map suggestions are studied for the development of the bus assessment. A grid will be marked on the outer surface of front-end of the city buses in terms of vehicle preparation and marking. The determination of grid size and grid location should refer to real-world accidents. Grid locations are defined based on anthropometric data. Testing conditions were identified by the real-world accidents in a preliminary study and also the Head Injury Criterion was adapted in the assessment. Moreover, chest and leg zone test information should be combined to improve the rating scores in future work.

Keywords: bus, city-bus, assessment, city-bus assessment

1. Introduction

Since the first Euro NCAP (European New Car Assessment Programme, https://www.euroncap.com/en) published the pedestrian rating in 1997, the following protocol deals with the assessments made in the area of pedestrian protection in case of accident between pedestrians and passenger cars. However, it does not cover the bus assessment based on pedestrian injury criterion.

In Thailand, the number of road accidents has steadily increased over the last decade. Based on the statistical records of road accidents from National Information Center of Thailand between 2003 and 2007, there were over 100,000 accident cases, 70,000 injury persons, and average of 12,000 fatalities annually (National Information Center of Thailand, 2013). Despite the public's growth of awareness of road accident prevention due to the media, the number of fatalities increased after 2010. Pedestrians are a high-risk group for road accidents especially in urban areas. Pedestrian road accidents occur not only with the passenger cars, but also with public transportation vehicles. In a preliminary study from a Thai insurance company, it was revealed that 65% of road accidents in urban areas between 2010 and 2013 were found in public transportation, namely the "Bangkok Mass Transit Authority" (Dhipaya Insurance Public Company Limited, 2013). The causes of injuries and fatalities among pedestrians were recorded. In addition, there is a rising trend of the accidents between city buses and pedestrians in Thailand. An investigation of accident scenarios between pedestrians and city buses in Thailand found that the location of the bus windshield is one of an important parameter (Lakkam & Koetniyom, 2015). Collision cases were categorized by differences between low- and high-located windshield types with regards to the behavior and body region of pedestrian injuries. Moreover, it was discovered that pedestrian injuries were more severe at impact speeds of approximately at 20 to 50 km/h. However, the 90th percentile impact speed was not over 30 km/h.

For the city bus assessment, it is different from the assessment of passenger cars according to injured body region

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of human. In this research, the scope was set covering only the test of headform impact area. Therefore, the pilot city bus assessment should be identified in the headform impact area.

2. Background and Literature Survey

2.1 Injury restraint innovations for pedestrians

In Japan, 101 cases of pedestrians who were struck by the front of a vehicle were investigated (Kozo *et al.*, 2000). The results show that the frequency of chest injuries in flat-front vehicle collisions (30.3%) was significantly higher than in bonnet-front vehicle collisions (11.8%). Lower leg fractures were more common in the bonnet-front vehicle collisions than in flat-front vehicle collisions. Pedestrians who were struck by flat-front vehicles tended to sustain more severe injuries, particularly in the chest under the lower impact speeds.

In the United States of America, the influence of different vehicle front profiles on the injuries with different regions of the human body was investigated (Ballesteros, Dis chinger, & Langenberg, 2004). Based on statistical records, there is a correlation of injury patterns from accidents between vulnerable road users (VRU) and light truck vehicles (LTV), as well as between VRU and heavy goods vehicles (HGV). From the Maryland Trauma Registry information, it was revealed that cars, sport utility vehicles (SUVs) and pickups caused a higher risk of serious injuries to the thorax and abdomen. However, there was a lower risk of injury at the region below the knee. Furthermore, 59% of the fatalities had an abbreviation injury score (AIS) of 4+ at torso based on statistical records of pedestrian injuries (Fildes, Gabler, & Otte, 2004).

Furthermore, the pedestrian crash data study (PCDS) was used as database to study injury patterns of pedestrians struck by different vehicle types (Longhitano *et al.*, 2005). The injury patterns of VRU hit by either a passenger car or LTV revealed that extremely thoracic injuries frequently occurred during LTV and VRU collisions. Besides, the impact area for the passenger car was frequently found at the windshield and bumper, whilst for the LTV it was at the hood and leading edge.

To investigate the pedestrian injuries under vehicle collisions between 20 and 30 km/h of impact speed, the MAthematical DYnamic MOdels (MADYMO) and Martin's transformation matrix based on database of the APOLLO WPII project were used (Feist *et al.*, 2009). This project illustrated that 69% of the sustained head injuries were subjected to a rotational load. The other head injuries were 21% and 10% for translational and complex loads, respectively.

Similarly, MADYMO was used to identify critical parameters of HGV (Chawla, Sharma, Mohan, & Kajzer, 1998). Critical variant parameters of impact velocities from 15 to 45 km/h between pedestrian and front structures were used in pedestrian simulations. Results indicated that changes of the front vehicle geometry had higher influences on the torso and head injury risks.

In addition, the reconstruct material model under pedestrian collision was studied (Xu *et al.*, 2009). The dynamic process of pedestrian head impact on the glaze windshield was modeled by numerical methods. Relations between pedestrian impact speed and *et al.*, deflection of glaze windshield were based on the impact dynamics and thin plate material model.

Likewise, the possibilities of designing safer vehicles with flat fronts by numerical simulation techniques was investigated (Kajzer, Yang & Mohan, 1992). A padding 160 mm of bumper thickness was used at the front bumper of bus. Numerical results showed clearly that at 35km/h vehicle impact speed the head acceleration was reduced by 33% and the impact forces at the upper torso, thigh, and leg were reduced by up to 75%.

2.2 Consumer tests

In the 1980's pedestrian specific test devices were developed as a rotationally symmetrical pedestrian dummy. In the early 2000's Autoliv and Chalmers University developed pedestrian dummies in adult and child sizes. Generally, pedestrian dummies are appropriate tools for research purposes, but are not optimal for legislative purposes. To use pedestrian dummies for legislative testing, a large range of sizes with small size increments would be necessary to assess all impact locations of a vehicle front, since the injury response is sensitive to impact location in pedestrian impact. They proposed a lower legform to represent lower extremity-to-bumper impact, an upper legform for the thigh and pelvis-impact to the hood leading edge, and a child 2.5 kg and an adult 4.8 kg headform for the head-to-hood impact. A new legform, Flex PLI (Flexible Pedestrian Legform Impactor), has been developed in Japan (Konosu & Tanahashi, 2003). In contrast to the WG17 legform it has a flexible tibia and femur measuring ligament elongation and tibia-bending moment, and has a knee design which allows new tests without part replacement as shown in Figure 1.

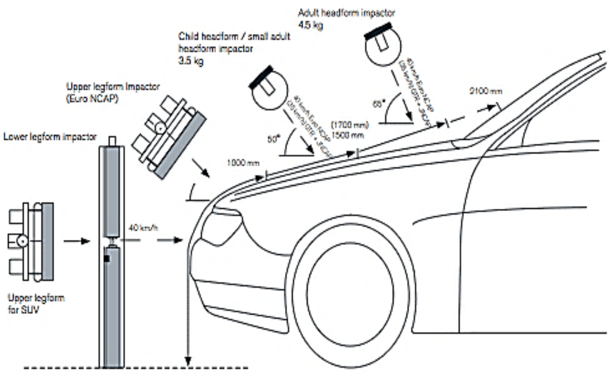

Figure 1. Component test methods.

3. Development of Bus Assessment in Thailand

The city bus assessment is different from the assessment of passenger cars according to injured body region of humans. In this research, the scope was set covering only the test of headform impact area. Therefore, the pilot city bus assessment should be identified in the headform impact area because the first cause of death is the head injury (Lakkam & Koetniyom, 2015).

3.1 Vehicle preparation and marking

Regarding the headform impact area, a grid will be marked on the outer surface of front-end of the city buses. Starting at the vehicle centerline, the grids should be marked. The determination of grid size and grid location should refer to a real-world accident.

For the grid size, it is supported by the cracking process of glass which is divided into three phases: radial crack phase, circular crack phase, and plastic deformation phase (Peng *et al.*, 2015). The radial crack phase precedes the circular crack phase. The appearance of circular cracks during the plastic deformation phase stays nearly constant. Windshield FE models were set up using different combinations. The modeling of glass and PVB were combined with various connection types and two mesh sizes (5 mm and 10 mm) at 9.16 mm of the total thickness. Each windshield model was impacted with a standard adult headform in an LS-DYNA simulation environment, and the results were compared with the experimental data. The results indicated that the influence of glass fracture stress on the same windshield model, the cracked area, and the peak value of the headform's linear acceleration were determined by the critical fracture stress. The diameter of crack area agreed well with the experimental impact test results for general windshield fracture at 115 mm. Therefore, the grid size should be mark every 115 mm in both vertical and horizontal lines.

In terms of the grid location, the heights of the boundaries are defined based on anthropometric data. The marking out of the front of the vehicle should be specified into two zones, a man zone, and a woman zone using anthropometric parameters. The area where the head of a man and a woman are likely to hit should be referred to their average height. From preliminary studies, most pedestrians who were hit by bus were 35 years old, approximately (Lakkam & Koetniyom, 2015). Thus, the middle boundary of each test zone is defined at 170 and 158 mm which are men and women average heights, respectively, in case of a 35 years old person, 170 and 158 mm of height should be defined as the middle line of grids. For this reason, the grid location for the city bus assessment with 22 columns and two rows should be set up as shown in Figure 2.

In Figure 2, the grids should be separated into two zones; the compulsory and the random zone. Regarding the compulsory zone, it is an area where a head of a pedestrian is likely to hit and where most of the severe head injuries occurred. According to Kozo's study (Tanno *et al.*, 2000) severe head injuries of pedestrians were commonly caused by the windshield frame, the A-pillar in cases of pedestrian crossing the road directly in front of vehicle. Besides, the glass area near the windshield frame and/or the A-pillar occasionally was designed as a curve shape. It is due to the fact that laminated glass which is generally used as the bus windshield material is anisotropic material which is the property of being directionally dependent, and implies different properties in different directions (Figure 3). The strength and Young's modulus of anisotropic glass approximately increased 160% and 140% respectively, compared with the values for the isotropic glass (Jun, Seiji, & Setsuro, 2015). Thus, the location where the laminated glass was installed as the bus windshield must be affected the impacted results from human body. Therefore, the 11th and -11th columns should be defined as the compulsory zone. In cases of a structure in the middle, the 1st and -1st columns should be included in the compulsory zone because these areas have the higher risk of severe injury. However, vehicle manufactures can design the front end of buses to alleviate vulnerable road user by means of the selected materials.

For the random zone, it is an area where the head of a pedestrian is likely to hit, which results in similar head injuries by means of the same condition and material properties. It considers that any area where is not the compulsory zone is classified as random zone. If non-uniform areas are found in the random zone (mixing between glass windshield, wiper blades, and hardness structures) a stiffer area must be selected ahead as the first random zone by means of more severe injury. This criterion should be considered and selected by engineering from the testing organization. This approach has been developed based on flat-fronted vehicles, which are the most common designs for buses in Thailand. Therefore, marking vehicles that are not flat fronted, which allows the wrap-around kinematics should be considered as an alternative approach.

In practical way, the pre-assessments are provided by the manufacturer. Results should be proofed by an external assessment. According to NCAP, generally 20% of grids were selected as the tested grids to recheck by means of the experimental works. By this hypothesis, a maximum of nine tested grids (9 out of 44) should be available for the headform test area. A minimum of compulsory zone consists of two, and seven tested grids in random zone are available. In case of a structure in the middle or non-uniform, a minimum of each zone should be available as shown in Table 1.

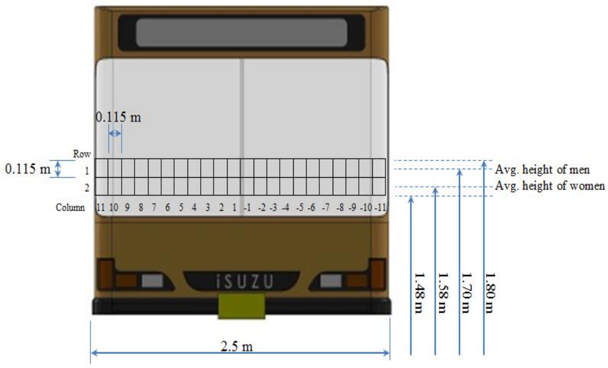

Figure 2. Grids on the outer surface of city bus front end.

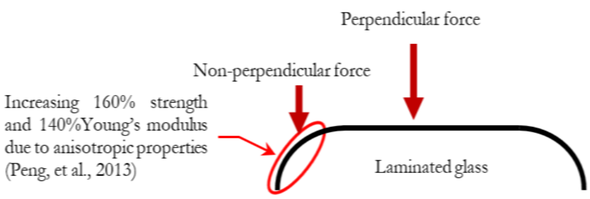

Figure 3. Different directions of impact in cross section view of laminated glass.

Table 1. Number of tested grids.

Cases	Number of tested grids			Total tested grids
	Compulsory zone	Random zone		
Uniform areas	2	7		9
	Compulsory zone	First random zone	Second random zone	
Non-uniform areas	2	2	5	9

3.2 Testing conditions and HIC requirement

Regarding testing conditions, real-word accidents in a preliminary study were conducted as a data base to identify testing conditions and also head injury criterions, which was adapted in the assessment.

3.2.1 Impacted angle and speed

In this part, the preprocessing was done using Hypermesh (meshing geometry), and XMADgic for setting up Multibody Dynamics analysis. MADYMO solver ver7.5 was used for computing analysis results. MADpost was used for post-processing. The front end of bus was set as the rigid shell property and the dummy was set as multibody property criterion. Generally, although the posture of the pedestrian has an influence on the kinematics, the sequence of impact is not different. First, legs and chest were impacted by the bumper and the front body of the bus. Next, the neck will be bended, and the head will be impacted by the windshield or the windshield frame. To simulate this scene, the propelled headform should be conducted in this assessment. Normally, 30 degree angles from horizontal were investigated and recorded according to the results of the preliminary study in this research as shown in Figure 4. Therefore, this value should be set up in the assessment. Likewise, the average impact speed in the real-world cases according to the preliminary study based on analysis of accident data that recovered approximately 90% of city accident occurs at impacted speed up to 30 km/hr should be conducted in the assessment (Lakkam & Koetniyom, 2015).

3.2.2 Head injury criterion

According to the Insurance Institute for Highway Safety, head injury risk is evaluated mainly on the basis of head injury criterion (HIC). The interval during HIC attains a maximum value. The maximum time duration of HIC, t2–t1, is limited to a specific value between 3 and 36 ms, usually 15 ms (Charles *et al.*, 2001). As the previous study, the AAMA and NHTSA suggested limiting the HIC evaluation interval to maximum of 15 milliseconds. Therefore, the 15 ms Head Injury Criteria (HIC15) should be used for the public-city bus assessment. For example, acceleration data to calculate for HIC 36 is shown in Figure 5 that is an identical criterion with HIC 15. These data shall be expressed as a color according to the corresponding color boundaries based on the HIC15 performance as shown in Table 2.

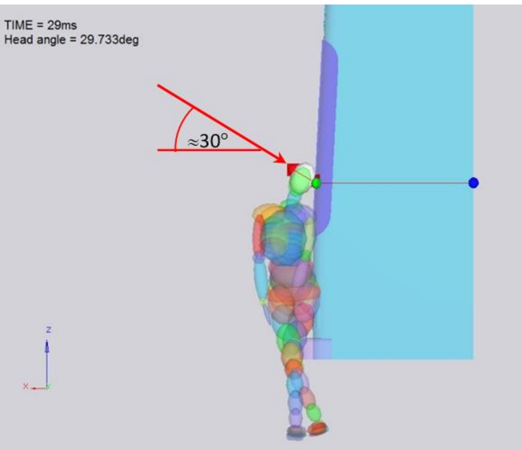

Figure 4. Head of impact angle.

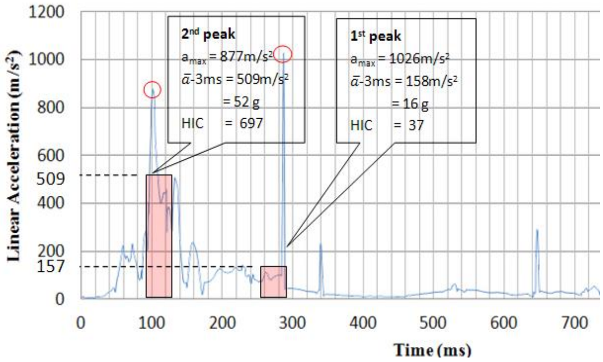

Figure 5. Example of acceleration data to calculate for HIC 36 ms (Henn, 1998).

Table 2. Performance criteria.

HIC	Points	Color rating
HIC15 < 650	1.00	Green
650 ≤ HIC15 < 1,000	0.75	Yellow
1,000 ≤ HIC15 < 1,350	0.50	Orange
1,350 ≤ HIC15 < 1,700	0.25	Brown
1,700 ≤ HIC15	0.00	Red

3.3 Assessment criteria

Figure 6 shows an example of the selected test locations in case of a structure in the middle. The test zones consisting of four tested grids in the compulsory zone and five tested grids in the random zone were selected. A maximum of nine points is available for the headform test zone. The total points are converted to an overall score by calculation as a percentage of the maximum achievable score, which is then multiplied by 10 scores. The bonnet leading edge and bumper test zone (future work) will be awarded a maximum of 10 points each. A total of 30 scores are available in the pedestrian protection assessment for city buses. The overall score for the headform test zone in this vehicle is calculated as shown in Table 3.

Table 3. Calculation of the overall score.

Test No.	Test zones	Grid points	Test results (HIC15)	Test results (pts)
1	Compulsory	R2,C11	2,000	0
2	Compulsory	R1,C1	500	1
3	Compulsory	R2,C-1	2,000	0
4	Compulsory	R1,C-11	850	0.75
5	Random	R1,C9	1,115	0.50
6	Random	R2,C6	300	1
7	Random	R1,C4	1,250	0.50
8	Random	R1,C-7	1,400	0.25
9	Random	R2,C-8	500	1
			Total points	5
			Overall score	5.6

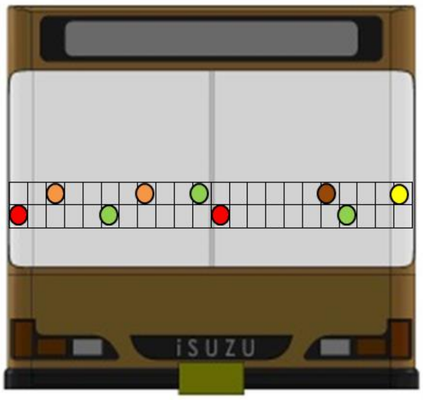

Figure 6. Example of test locations of city-bus front end.

The score in terms of percentage of the maximum achievable score is 5/9 = 56%. Finally, the headform score is 56% × 10 = 5.6 score.

3.4 Road map suggestion

The public city bus assessment aims to reduce the number or severity of pedestrian casualties from accidents involving buses by providing guidance to manufacturers/ designers of such vehicles. The test zone can be classified into three zones as head, chest, and leg zone by means of the body region of pedestrian during the impact. Each individual test zone should be assessed on scale from 0 to 10 depending on the encouragement strategy as shown in Table 4. In this research, it only contributes one third of the overall rating focusing on the headform test zone. This differs significantly from previous requirements in which only the head assessment system is considered as prerequisite for satisfied pedestrian protection (PP) rating.

Furthermore, the score calculation for all three elements is based on the statistical records in the local area. The road map suggestion of the city bus assessment decided by the frequency of severe injury is shown in Table 5. From the statistical record, the cause of death of the pedestrian casualties was severe injury on top body regions as head, chest zone. There is a lower possibility for pedestrian casualties from severe leg injuries. It conforms to a former study (Ballesteros, Dischinger, & Langenberg, 2004) in the fact that the general cases in Maryland the vehicle collisions with pedestrians a greater risk for serious injury to the thorax, and

Table 4. Example of weighting strategy and encouragements.

Assessment zone	Weighting level		
	0	5	10
Head zone			▲
Chest zone			▲
Leg zone		▲	

Table 5. Road map suggestion of city-bus assessment by means of statistic.

Season	Development of test zone			Overall rating
	Head	Chest	Leg	
1	10 score	10 score	5 score	1/3
2	20 score			2/3
3		25score		3/3

Remark: Score is based on the frequency of severe injury.

abdomen, whereas a lower risk of injury to the region below the knee. There is a slightly difference with accidents in Japan, as the study by Kozo *et al.* (2000) found that in cases of a flat-front vehicle collisions with pedestrian the frequency of injuries in head, chest, and leg zone was 36, 40, and 22 percentages, respectively. However, the chest and leg test zone should be included in the pedestrian protection (PP) rating in the future. This suggestion will enhance bus front end designs. Therefore, the safety assessment of city buses should conduct additional chest and leg test zones to encourage manufacturers.

4. Conclusions

This study related to develop of an assessment program and to evaluate the front end of public city bus was supported by information based on pedestrian injuries and mechanisms in Thailand. The headform impact area is determined by injured body region of human. A grid will be marked on the outer surface of front-end of the city buses referred to their average height. The determination of grid size and grid location should refer to a real-world accident. Moreover, the grids should be separated into two zones; the compulsory and random zone to calculate in terms of overall score. The impacted angle and speed were referred from the real-world cases that recovered approximately 90% of city accident. Furthermore, real-word accidents were conducted as data bases to identify the testing conditions and also Head Injury Criterion was adapted in the assessment. However, this research provides the head zone test information. The combined score from the experimental tests into an overall crashworthiness rating easier is summarized to establish the rating information for road users. Therefore, this program will provide the incentive for manufacturers to further improve safety, and consumers can understand non-significant differences among new buses. In addition, the chest and leg zone test information should be combined to improve the rating score in the future work. An important key of assessment program is to promote the rating results and encourage the manufacturers for safer cars across the global automotive market. Moreover, an independent organization that carries out research innovations in vehicle safety technologies, their global market applications, and the policy development globally could accelerate the city bus assessment for pedestrian injury criteria.

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