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Investigation of Unexpected Crossing-Lane Activity on Curving Road Using Digital Human Modelling Analysis

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Abstract

Accidents on the curving road in Indonesia contributed to 5% of the total accident (104.327) based on road geometric; however, almost an accident involving a truck placed on 4th rank. Since around PUSPIPTEK has several curving roads with crossing lane geometry on National Road, the unexpected crossers cannot be avoided, leading to an accident. Recently, one such technique that can reconstruct a site and predict the unexpected crossers on curving road situation is Digital Human Modeling Analysis (DHM) combined with Geographic Information System (GIS) that capture road environment through drivers and on real road geometric. The study aimed to investigate an unexpected crossing line on a curving road site by DHM truck driver vision and suggested driver perception time. The result shows that the DHM vision was blocked by pillar A, and the motorcycle did not appear on the DHM vision. The driver perception time found that truck at a speed of 70 km/h at a distance of 8 and 5 meters before the curving road generated hard deceleration and took time for the truck driver to react. Decreasing velocity is vital on the curving road with unexpected crossers lane since the driver's vision failed to identify a motorcycle object behind another.

Keywords: *curving road accident, truck driving posture, truck driver visual impairment*

INTRODUCTION

Several accidents and fatalities in road safety are the main issues to be solved in most countries. Eun-Ha Choi (2010) in the USA revealed that the crash factor on scene perspective occurred at about 36% at intersections, with around 11% of vehicles across the lane line, while Overspeed and loss control shows 5%. A critical reason the accident happened was recognition error and decision errors 55.7% and 29.3%, respectively. Indonesian national Police: Law Enforcement Directorate (2017) shows that in 2017 about 5.82% of 103.645 accidents occurred by geometric type in Indonesia. Several studies have been performed on curving geometric roads that cause an accident. (Widianty et al., 2017, 2019) summarized based on side slop and curve radius found that narrow curving road with smaller radius has a serious chance of an accident occurring. Some curving is not well designed based on the velocity design guide, and the driver takes the risk of Overspeed on the curving road. Adding a convex mirror, a guardrail, and a larger curve radius can minimize the risk of accident probability. However, Amerson and Little (1983) revealed that drivers found the convex mirror generally ineffective: image projections were too small to be easily seen and deceptive by motion. Other research by Olson (1989) revealed that a roadway system needs to understand how

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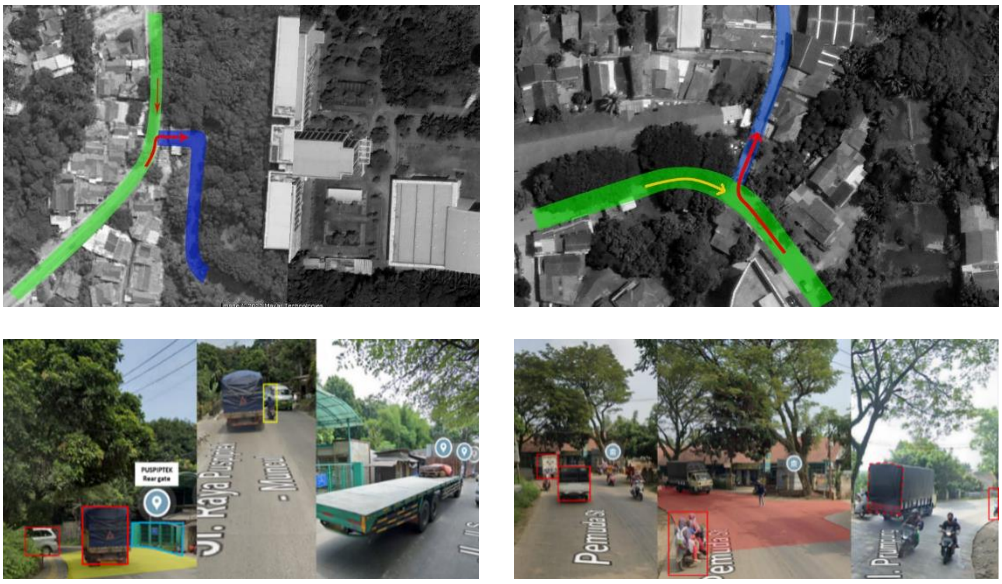
a driver time responds facing an unexpected situation. The information from the eye sensor through data processing in the brain resulting delayed response to perceiving.

Issues in the Megacity sort of Jakarta found a potential problem related to lane crossing with unexpected activities. The problem occurred when along the curving road, visibility was deteriorating due to curve sight or a barrier. The driver needs a proper reaction time to avoid hard deceleration and crashes during travel at the corner. Figure 1 describes a satellite image of a crossing lane activity on a geometry-curving road. Two crossing lane sites are scattered at BRIN Serpong- South Tangerang area. It can be drawn from the figures that some motorcycle was doing their activity across the lane (i.e., overtaking and crossing to the opposite side) around the large truck and other vehicles. According to accident reports in 2017, motorcycles and large trucks were recorded as the top five types of vehicles involved in accidents.



(a) (b)

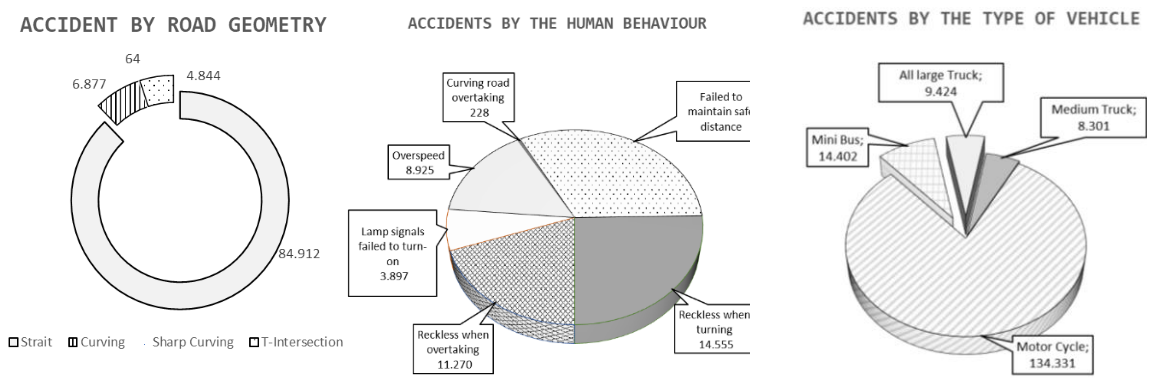
Figure 1. Two site location of crossing lane (a) PUSPIPTEK rear gate and (b) Gunung Sindur curving road

These results indicated that there was a serious potential risk of an accident. This is consistent with the finding of Manggala et al. (2015) conducted an assessment of sharp curving roads and found that some interruptions, such as reducing speed using rumble strips and putting signs on curving roads, can reduce an accident. However, the human factor and curving designed speed variable still had risks. Instead of conducting research by site observation costly and consuming time, a solution using geographic information system (GIS) combined with Digital Human Modeling are quicker and more reliable. Recent studies about Digital Human Modeling (DHM) use DHM to fit driving posture rigs on sedans and trucks (Mark & Gyi, 1998; Philippart et al., 2018). Besides, Summerskill et al. (2016) conducted a study on a truck driver vision projection on the mirror using DHM also. Therefore, the study of unexpected crossing-lane activity on the curving road will develop an understanding of how its unexpected crossing activity can be prevented by adding a new traffic aid for safety. Furthermore, delayed perception versus driver velocity and distance of the vehicle were also reviewed.

LITERATURE REVIEW

According to Indonesia Traffic Police, in 2017, accidents caused by road curving geometry contributed to around 6934 accidents in a year. Most involved vehicle types were dominated by motorcycles, minibus, and trucks, with number 134,334, 14,422, and 9424 accidents, respectively (see Figure.1). Majority of accidents on the curving road due to Overspeed, reckless when overtaking, and blind spot. Widianty et al. (2019), in an evaluation study, performed road analysis safety based on side slop and curve radius and found that narrow curving road with smaller radius has a serious chance of an accident occurring. Adding a convex mirror, a guardrail, and a larger curve radius can minimize the risk of accident probability. Widianty et al. (2017) also identified poorly designed curving based on the velocity design guide and the driver risks of Overspeed on the curving road. Manggala et al. (2015) assessed sharp curving roads and found that the radius curving design did not comply with design guidelines and speed variables. Ultimately, the human factor significantly contributes to the accident on the curving road, around 70%. Reducing speed using rumble strips before the curving and putting signs on the curving road played roles in reducing an accident.

A convex mirror's function is basically a traffic aid that helps road users to recognized other road users on the opposite side or in a blind spot position. Hassan et al. (2020) experimented with validating the convex mirror's Field of View (FoV). It found that using a convex mirror could increase the driver's field of view by up to 211%. The position of the convex mirror played a significant role in obtaining the optimal FoV. Moukhwas (1987) revealed that the mirror/convex mirror appeared as a device that can enhance safety behavior and could acclaim as a traffic aid. Contrary, Amerson and Little (1983) revealed that drivers found the mirror to be generally ineffective: image projections were too small to be easily seen and hard to see at a far distance. At some speeds, it was difficult to see clearly, and the actual condition was deceptive. Finally, climate exposure degraded the reflection of a convex mirror. Human Vision, ISO 24509 revealed that human vision is affected by several variables: distance, age, and lighting (International Standard Organization 2019).



(a) (b) (c)

Figure 2. Two pie charts of Indonesian traffic accident by type of vehicle (a) and by human behaviors (b)

Conducting an experiment involving a large object and a human has consumed time and cost. A breakthrough by simulating a human model inside a large vehicle using a computer machine saved anything. Several studies were conducted about Digital Human Modelling (DHM) in vehicles or other transportation. Choi et al. (2009) compare a visibility technique using DHM as a design factor when the driver does maneuver on the forklift. Driving Posture, Mark and Gyi (1998) found ergonomic driving posture packages for ranges of percentile and genders on sedan driving rigs. The results were determined on several criteria, for example, seating position, control position, and pedals. Similar to the study done by Philippart et al. (2018), it discussed truck driving posture guidelines by experiment. Marshall et al. (2020) started their study regarding a large truck. This case revealed that using DHM, the significant truck driver has a direct visual impairment (blind spot) to cyclists due to the truck's geometric design.

RESEARCH METHOD

1. Crossing Lane Hotspot and Road Surface Contour Extraction

Figure 3 illustrates potential conflicts scenario on a curving road. There were six hotspots of the curving road with potential risk on the national road and one on the city road. Before extracting the road contour, the targeted area was scattered at BRIN Serpong Technopark. There were two sites to be projected as contour: (a) Rear gate Puspiptek and (b) Gunung Sindur. The corridor road length was determined to be about 300 meters due to memory saving of a larger scale road model, and the unit meter was chosen. Throughout the study, the target area's offline map and digital elevation model data (DEM) were downloaded using the mapping software Q-Base 3D 2.30.48 (Quantum-Systems, 2022).

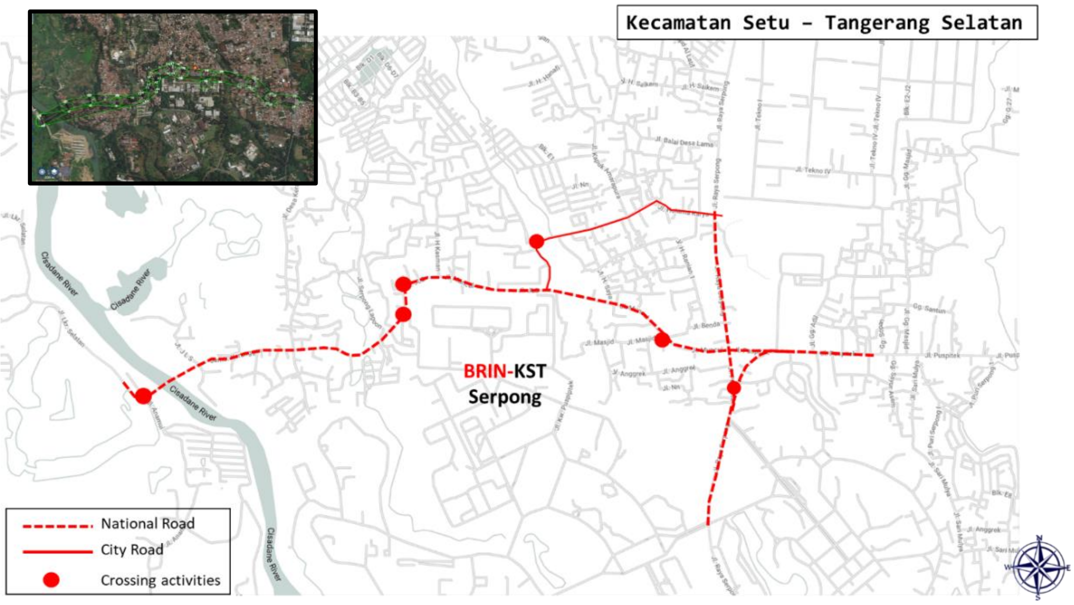
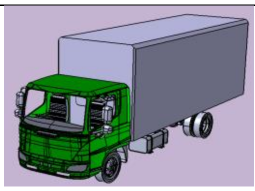
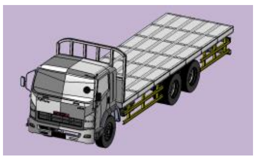


Figure 3. Crossing lane scenario conflict on two curving road sites

2. Vehicle geometry

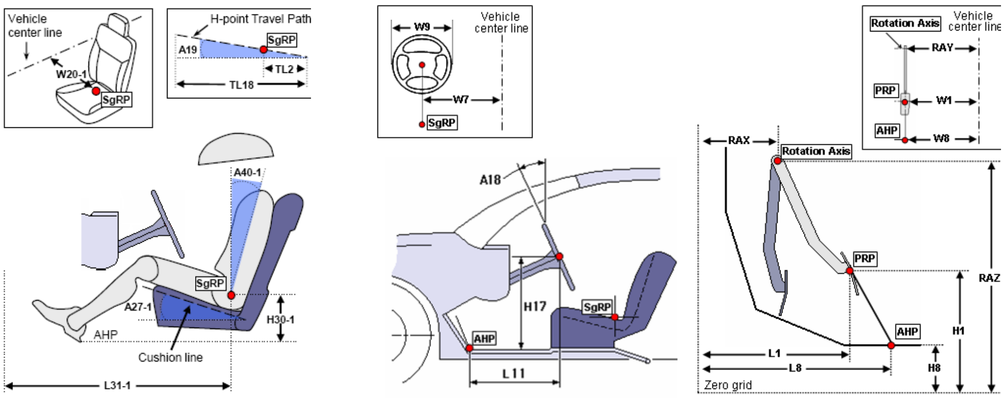
The scenario was challenged; the vehicle was downloaded from the GrabCAD community library (GrabCAD, 2022). The truck was selected due to causing the most fatality in the accident (Indonesian National Police: Law Enforcement Directorate 2017). While the blocker truck was randomly selected. The SUV was selected because it is boxy and represents the favorable Indonesian car type and its geometry roles as a blocker. Then, a naked motorcycle was selected over a scooter since the scooter model equally represents the geometric length and width. The following table summarizes the vehicle geometry data as a part of the crossing lane scenario (Table 1).

Table 1. Summary of Vehicle 3D modelling to support Simulation Scenario

Role of Plays	Ilustration	Dimension (mm)	
Main Lorry		Out. Length	7520
		Out Width	2450
		Driver Height Positon	2400
Crosser		Out. Length	2031
		Out Width	796
		Driver Height Positon	-
Blocker		Out. Length	4435
		Out Width	1695
		Driver Height Positon	1100
Blocker		Out. Length	8945
		Out Width	2485
		Driver Height Positon	2400

3. Digital Human Modeling and Truck Driving Platform

Digital human modeling was built on Computer Aided Software (CAD). The gender of manikin was defined as man, and the population set was Japanese. Using the posture editor, the detail sets were adjusted following Indonesian anthropometry provided by the Indonesian Anthropometry website (Antropometri Indonesia, 2013). Overall, the whole method was derived and adopted for truck posture based on Mark and Gyi, and SAE Class B regulation of seat position and the truck's cabin geometry. Figure 4 describes the package criteria to construct truck driving posture regulated by SAE J1517-201110 (Truck and Committee, 2011; Philippart et al., 2018).



(a) (b) (c)

Figure 4. Package definition of driving posture platform for truck driving posture set

4. Perception Driver time

Stopping sight distance was calculated to regulate the minimum distance required when a driver spotted the stationary object (e.g., a navigation sign) at the designed velocity (Olson 1989). To prescribe the calculation, the first part of the general equation is governing the reaction time:

$$d = d_{pr} + d_{brake} \tag{1}$$

where, d is a “distance for vehicle stopping”, then d_{pr} is a “distance when the driver perceive and react to an object” ,and d_{break} is the distance to brake. However, one component can be assumed according to the design or reaction scenario to get the reaction time or distance. Subsequently, the equation.1 result will answer the stop sight distance as shown in the Equation 2:

$$\mathrm{SSD} = V_0 . T_{\mathrm{pr}} + \frac{V_0^2 - V_f^2}{2g\left(\frac{a}{g} + G\right)} \tag{2}$$

Where, stop sight distance set as “*SSD*”, the initial velocity is set as “V_o” while the acceleration or deceleration set as “a”, “T_{pr}” sets as reaction time and gravity set as “g” then, the level roadway (e.g., Inclination level) set as “G” refers to Australia Road Design Guide: Geometric (Hubner et al., 2010) The velocity, and distance will be assumed regarding average speed on allowable city speed by regulation.

5. Data Analysis

The 3D road situation and driving truck posture result were analyzed using DHM vision. The vision will be examined what the DHM seen inside focus area, and was the motorcycle clearly seen? After that using an Australian road guide whether the driver sight was obeyed to standard. Then, using deceleration coefficient determined how much distance and time a driver required to stop when facing an unexpected activity on curving road.

FINDINGS AND DISCUSSION

1. Road Contour and Scenario Assembly

In order to identify accidents of interest to critical reasons for curvature crossing lane accidents, some relevant variables such as road contour level and distance are explored, as explained in Figure 5. The software Q-Base estimated the 2D side contour of the elevation model for the distance and elevation PUSPIPTEK rear entry gate (a) and Gunung Sindur corner (b). The following figures show two comparisons of the PUSPIPTEK rear gate site curving road versus the 3D scenario model. The green lorry (green color) identifies the motorcycle on the opposite lane. In contrast, the motorcycle must cross the lane on a curving road as they need to do so. Another vehicle and side perimeter object rolling as vision blocker, e.g., a white lorry, SUV, and business loft building. None of the convex mirrors was created.

a.

b.

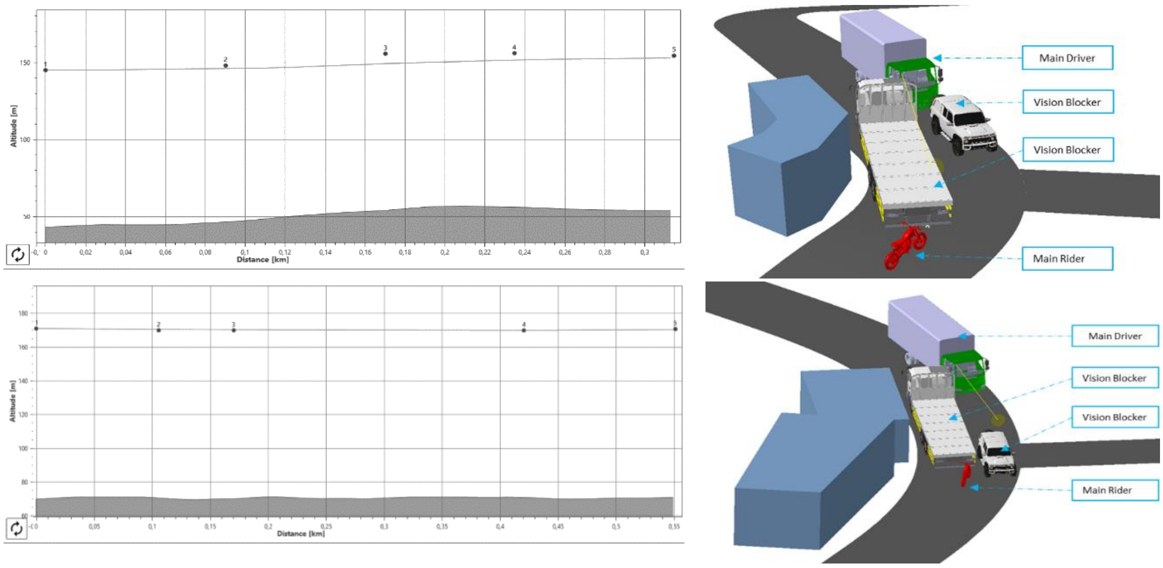


Figure 5. PUSPIPTEK and Gunung Sindur road elevation contour in two-dimensional (2D), scenarios of curving road represent the locations

2. Digital Human Modelling and Posture

From the Indonesia Anthropometry data that has been arranged, it revealed using DHM that Figure 6 (a) shows the percentile of stature comparison in series, the statures are 5%ile = 1170 mm; 50%ile= 1688 and 95%ile= 1870 mm. Regarding DHM's standing posture result, the 50%ile selected to represent the mean population. While the following picture illustrates the driving truck posture constructed from Philipart et al. and SAE driving posture setting to truck cabin position. The posture represents the steering wheel section dimension, the full-back spine derived from the seat section, and the lower limb consequential from the pedal and seat section, as shown in Figure 6 (b).

(a) (b) (c)

Figure 6. (a) Driver stature percentile in 5,50 and 90%ile; (b) Driving posture, and (c) assembly to truck set cabin

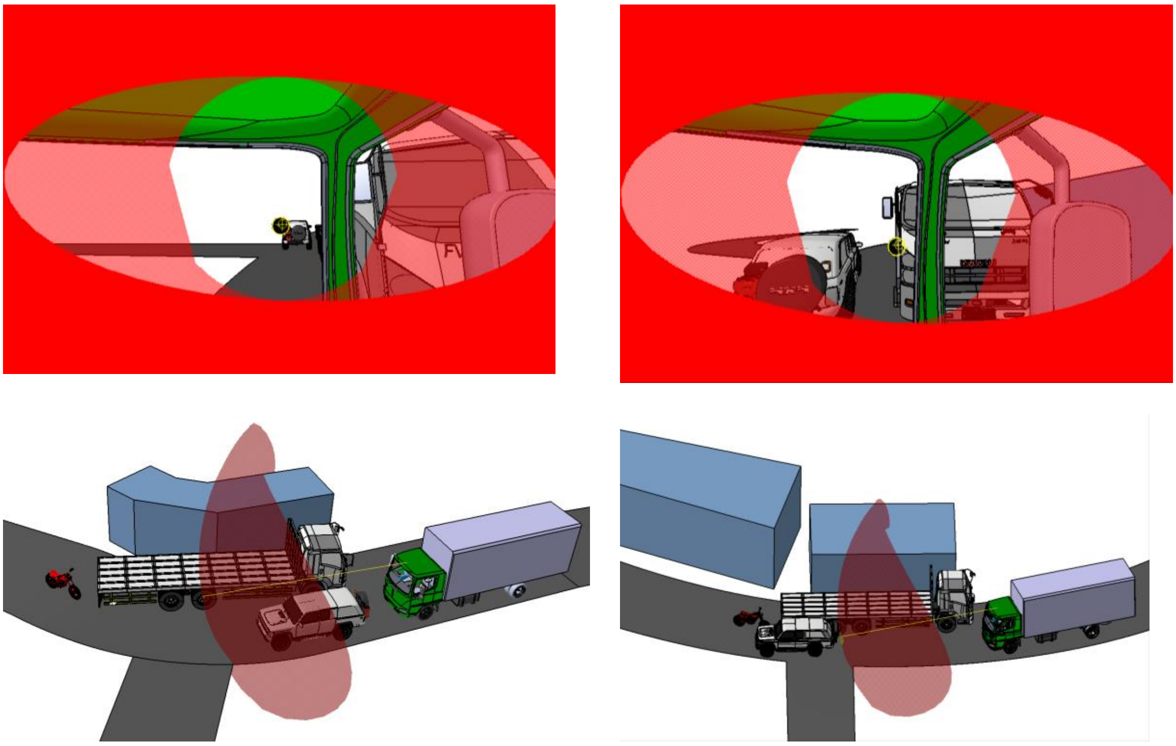
To better understand the objective parameter of truck posture, Table 2 explains the output parameter value for truck driving posture generated from DHM 50%ile. The value L31-1=1060 describes how a neutral point (SgRP) correlates stature through pedal position and seat angle to the X direction. At the same time, H30-1= 332 mm represents the neutral point in the Y direction. Other results show in the steering dimension section, whereas the L11 determined around 320 mm, from the pedals to the steering wheel or hand reaching. The H17=607 mm defined height distance from the pedal to the center of the steering wheel. A-18 adjusted to 70° as a consequence of the truck design cabin.

Table 2. Truck driving posture output value parameter

Driver Cabin	Item	Code	mm	deg
Seat Section	(SgRP)	L31-1	1060	
		W20-1	-295	
		H30-1	332	
	Travel path	A-19	0	
		TL2	50	
		TL-18	265	
	Cushion	A271		20
		A40-1		-10
Steering Wheel	Frame SW	L11	320	
		W7	-380	
		H17	607	
		W9	400	
		A18		70
	Grip	Diameter	30	
Pedal Section	Rotation Axis and Position	L8	380	
		W8	-235	
		H8	180	

3. Vision Analysis

Regarding vision using the binocular setting display in both scenarios, the vision performance of Truck DHM shows a focus point and blockage pillar on the binocular area. In contrast, the surrounding truck object identified with blurry vision e.g.mirror glass (RH), opposite truck (RH), and SUV car. Figure 7 indicates that none of the motorcycle's silhouettes are seen in the scenario. Curving road, opposite truck, and pillar are blocking the line sight of the driver. Another figure illustrates the cone bounding focus distance of driver sight through windshield glass (e.g., 8000 mm) in the scenario. At this level, the driver focuses on the peak curving section area. The figures also explain the coverage of the cone bounding vision linearly to focus distance.



(a) (b)

Figure 7. Binocular vision analysis comparison between PUSPIPTEK rear gate and Gn.Sindur curving road

4. Perception Time

According to driver response perception, the parameter inputs were distributed to the formula described (see Equations 1 and 2). Table 3 shows the result of how velocity and time response generate a consequence of deceleration. The setting was grouped into two sections: distance to the final velocity, the initial velocity around 70 km (19.6 m/s), and about 8 to 5 m before entering the peak of the curving road when the motorcycle crosses the lane. The final velocity of the truck when it arrived on the peak curving road was around 30 Km/h (8.4 m/s). The result shows that at about 6,9 seconds, the driver's minimum reaction time should decelerate at 8 meters to avoid the crash. In comparison, using the distance scenario about 5 meters with a similar setting, the reaction time obtained about 3.93 seconds to the truck driver reduces the velocity when seeing the motorcycle prepare to cross the lane.

From the Australian standard road design, the allowable reaction time for the driver crossing in typical road conditions starts from 1.5 through 2.5 seconds (Hubner et al., 2010), while the truck simulation shows the minimum result of 6.93 and 3.93 seconds.

Table 3. Truck driver perception time on the curving road on several velocity scenarios.

Velocity		Distance-1 (m)	Distance-2 (m)	Rt-1 (sec)	Rt-2 (sec)	SSD-1 (m)	SSD-2 (m)
Km/h	m/s						
70	19,6	8	5	6,93	3,93	165,17	114,77
60	16,8	8	5	8,00	5,00	183,21	132,81
50	14	8	5	8,91	5,91	198,48	148,08
40	11,2	8	5	9,65	6,65	210,96	160,56
30	8.4	8	5	10,23	7,23	220,68	170,28

*$RT^{1,2}$= driver reaction time; $SSD^{1,2}$= Sight stopping distance; distance= length from perceive to the final velocity

5. Discussion

Two unexpected crossing scenarios were conducted based on truck driver rig, anthropometry driver through 90%ile DHM, vision, and perception driver time. This study result shows that the DHM vision was blocked by pillar A, and the motorcycle did not appear on the DHM vision. Another study by Summerskill et al. (2016) revealed that using mirror projection on a truck's side convex mirror helped understand the truck's blind spot.

The driver perception time found that trucks at a speed of 70 km/h at a distance of 8 and 5 meters before the curving road generated hard deceleration and took time for the truck driver to react (6.93 sec). Manggala et al. (2015) and Widianty et al. (2019) found that reducing speed using rumble strips significantly reduced accidents on a curving road. This study emphasizes how decreasing velocity is governed by a vital thing on the curving road with an unexpected crossers lane since the driver's vision was a failure to identify a motorcycle object behind another. However, this study did not explore the convex mirror projection from driver sight.

CONCLUSION AND FURTHER RESEARCH

This study of unexpected crossing lanes on the curving road has been investigated in previous results and discussions. In summary, DHM of truck driver vision cannot see the motorcycle behind another vehicle. It is dangerous to Overspeed before on a curving road if there are crossing lane geometry and activity. Several algorithms have been developed from a method that generates the perspective of DHM truck drivers on curving road situations and how a truck driver should be aware of speed and distance. The comparable results using DHM truck driver sight combined with driver perception time are occasionally better in time and cost than in an experiment. However, it cannot guarantee data precision.

The perception time of the truck driver from distance and velocity scenario indicates that the truck cannot decelerate hardly. A speed trap shall be applied before the curving zone to increase safety by decreasing the truck's speed in both lanes. Furthermore, adding and assessing how the convex mirror at the side of the curving road effectively projects and helps the driver see beyond the corner at the range of speed is a challenge for further research.

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