Study of Traffic Composition Relationship with Accident Risk Using Traffic Simulation

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This research tries to understand the relationship of traffic volume composition to accident risk in mixed-traffic condition, which such condition is prevalent in many South-East Asian Countries like Indonesia. The objective is to study the relationship of accident risk represented by surrogate safety measure with changes in traffic volume composition through-out the change traffic volume and with respect to urban road-traffic characteristic using traffic-simulation software VISSIM. The urban road-characteristic is captured through the following variables: road-side disturbance and access density. This research finds that traffic composition that makes mixed-traffic condition impose higher accident risk compared to traffic composition with balance proportion of motorcycle and other motor vehicle that represents non mixed-traffic situation. Road-side disturbance and access density is found also affect accident risk especially in medium values (i.e 0.018 and 17 per 200 m respectively). TTC and PICUD yields similar result regarding accident risk in regard to traffic composition, RSDI and AR. However, they are different in terms of frequency of identified crash risks on the observed traffic events.

Key Words: *mixed-traffic, surrogate safety measure, traffic simulation, VISSIM*

1. INTRODUCTION

One of the distinct traffic conditions in many South-East Asian Countries like Indonesia is the traffic has a mixed traffic condition. There is different situation that makes a mixed-traffic condition, however, in this case it is represented by the dominance of motorcycle in the traffic composition as presented in **Table 1**[1)].

Mixed-traffic is always associated with high accident-risk and segregation is often suggested as the main solution[1)]. Interestingly, there are other argument that mixed traffic can be relatively safe under certain condition, such as: appropriate traffic composition, low speed, and volume[2)]. Unfortunately, studies on this still can be considered insufficient[3)].

Mixed-traffic situation, at first occurs due to different characteristics of road users using the road in same time and space, which one or more of the road users considered to be a vulnerable road user. The situation become more complex as this vulnerable road user is dominating the traffic flow. In this case the vulnerable road user is motorcyclists. Due to this reason the decision to study relation between traffic composition in mixed-traffic situation, which furthermore encouraged by argument that accident is dependent on relative composition of the traffic flow[4].

This research tries to explore the relationship of traffic volume to accident risk in mixed-traffic condition in developing countries like Indonesia, especially in urban arterial roads where motorcycle dominance is prevalent. The limitation of high-resolution data and considering dynamic nature of traffic encourage the use of traffic simulation, hence surrogate safety measure to study the accident risk.

Three different simulation scenarios are developed to cater typical urban traffic characteristics. Time to collision (TTC) and Possibility Index for Collision with urgent deceleration (PICUD) were chosen as SSM targeted for rear-end location, which are the most dominant accident pattern in the study location.

The research able to find that traffic composition in mixed traffic composition where motorcycle proportion is high impose more accident risk compared to more balance traffic composition in non-mixed-traffic situation and disturbance to traffic flow by road environment factor also affect accident risk. TTC and PICUD gives similar conclusion, but TTC's results yield more accident risk events compared to PICUD's result.

Table 1 Vehicle Proportion (%) in some South-East Asian Countries.

Country	Motor cars	Motorized 2/3 wheelers	Heavy trucks	Buses
Indonesia	11.2	82.8	4.5	1.5
Bangladesh	32.6	60.1	5.0	2.3
India	13.3	71.7	5.3	1.3
Thailand	34.7	60.8	2.0	0.5
Srilangka	15.7	66.5	7.5	2.1
Myanmar	11.6	82.1	2.8	0.9
Nepal	11.4	75.6	4.1	3.0
Timor-Leste	17.4	76.3	6.1	0.2

2. LITERATURE REVIEW

Most accident studies are using aggregated data as source of information. However, this approach is thought to have downsides, namely, loss of information due to averaging of information due to aggregation[4]. Answer to this issue is real-time accident analysis that matches the time occurrence of accident and with the associated traffic flow situations in the same time. However, such study requires high resolution data, that even in developed countries mostly available in expressways compared to usual urban arterial road.

In order to overcome this challenge, an accident study using traffic simulation software like VISSIM to obtain high resolution traffic data that can be analysis for safety study purposes. The current advancement of VISSIM that allows simulation of mixed traffic[5] further encourage the approach.

Consequence of using traffic simulation is that it could not be coupled directly with accident data, hence the use of SSM. Using SSM has several advantages. For example, non-crash events relatively easy to observe compared crash events that inherently rare, under-reporting in accident reports, limited information and prior condition of crash, it is a pro-active approach, and improvement of crash quality is still behind improvement of crash frequency[6]. Furthermore, the main idea of using SSM is that there is relation between different traffic events both in terms of frequency and severity.

This research uses time to collision (TTC) and possibility index for collision with urgent deceleration (PICUD). There are different types of SSM, which can be categorized to temporal based, spatial based, and deceleration based[7]. Approximately there are 19 types of SSM. Among them, TTC is the most widely used, at least in 90 published papers[6], this is mainly because of its theoretical and reliability aspect[7]. TTC has weakness that it assumes that the speed of vehicles is constant and does not account deceleration of vehicles, thus in this research, the analysis also uses PICUD that account vehicle deceleration to compared how both of them measures proxy value of accident occurrence.

Furthermore, both TTC and PICUD able to detect possible rear-end crashes, that are being targeted in this study. According to accident data obtained from the Indonesian National Police via Ministry of Public Works, dominant accident type in the city of Bandung's urban arterial roads are rear-end crashes.

Definition of TTC is available time until crash would have occurred if two vehicles does not change their course and speed. Formula of TTC is available in formula (1).

$$TTC(t) = \frac{X_{leader}(t) - X_{follower}(t) - l}{V_{follower}(t) - V_{leader}(t)} \tag{1}$$

X = vehicle position
V = vehicle speed
l = subject vehicle's length

Definition of PICUD is available distance between leading and following vehicles when they start to decelerate accounting deceleration rate of both vehicles and delayed reaction time of the following vehicle. Formula of PICUD is available in formula (2).

$$PICUD = \frac{{V_1}^2}{2a_1} - \left(V_2 \Delta t + \frac{{V_2}^2}{2a_2} \right) + S_0 \qquad (2)$$

V = vehicle speed

Δt = delayed reaction time

a = deceleration rate

S_0 = initial distance

3. DATA DESCRIPTION

This study uses two types of data. The first type is empirical data gathered from various sources and the second type is data produced through VISSIM. The empirical data mainly used as input for the simulation starting from the road environment, traffic data, and simulation scenario variation. The second type data which is a vehicle record data as a result of simulation used to analyze SSM.

(1) Road environment

This study focuses on urban arterial roads which modeled from the city of Bandung, Indonesia. The data is obtained from the Institute of Road Engineering (IRE) and Google maps. In summary, in the city of Bandung, there are several road type configurations, they are: 4/1; 2/2UD; 4/2D; 6/2D; and 8/2D. This study only focuses on 4/1 road.

Other than the above usage, road environment data is used to represent the typical situation that occurs on the field. This research introduced two variables, namely road-side disturbance (RSD) and access density (AD). RSD represents the typical situation that roadsides is being used for illegal parking or other activities, while AD represents situation that even though the road is an arterial road, there direct property access to the road.

a) RSD

The calculation of RSD used data from the survey vehicle of IRE of which the data contains visual imagery of the study location and location coordinates. A dedicated software package allows dimension (width and height) of an object to be measured and coordinate to be tagged. The coordinate location is used to calculate the length of disturbance. The formula of RSD is available in formula (3).

$$RSDI = \frac{\sum_{i=1,2,\ldots}^{n} (li \ x \ wi)}{Ls \ x \ Ws} \qquad (3)$$

From the calculation result of RSD from the study location's medium (0.018) and maximum (0.0578) value used for different simulation scenarios.

b) AD

AD is a simple variable. It denotes number of access to property in certain length of a road segment. In this case, AD is calculated per 200 m sections. The same procedure as RSD also conducted for AD. Medium (17 per 200 m) and maximum (71 per 200 m) value used for different simulation scenarios.

(2) Traffic data

The traffic data consists of traffic volume and composition data and speed data which being used as simulation input.

a) Traffic volume and composition

The traffic volume and composition data used as an input for the simulation is taken from a 4/1 road segment in the study location.

b) Speed distribution

To represents similar real situation speed distribution data is required. Speed distribution data from a road segment with similar characteristic used as an input for this purpose.

(3) Vehicle record data

Vehicle record data in VISSIM basically produce record of vehicle position and movement in each time step and of the simulation. Other related information can be customized according to the user needs. For example, lane, speed, acceleration, lane change, etc. The information mainly used in this study is vehicles coordinate, position, lane, and speed.

4. METHODOLOGY

(1) Road environment in VISSIM

The length of the road created in the VISSIM simulation environment in total is 1 km consist of 200 m link segments. An intersection is created between the 4th and 5th segment. The scenario variation in regard the road environment, incorporated in different available segments. The road environment model is available in **Fig.1**.

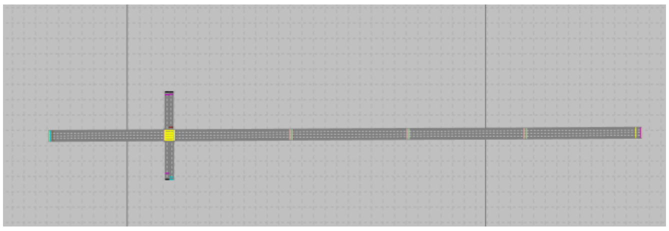

Fig. 1 Road environment model.

(2) Simulation scenario

This research developed three simulation scenarios for analysis. The information of the scenario is available in **Table 2**.

Table 2 Simulation scenarios.

Scenario	Road environment variation	Volume	Composition
1	Straight + intersection	Associated volume varied every 15 minutes	Composition A. Composition B.
2	Straight + intersection + RSD + AD (medium value)	Associated volume varied every 15 minutes	Composition A. Composition B.
3	Straight + intersection + RSD + AD (maximum value)	Associated volume varied every 15 minutes	Composition A. Composition B.

The simulation period is set for two hours divided into 15-minute intervals. From 0 to 1 hour, the volume is increased 5% each interval from the original input. From 1 to 2 hours is decreased 5% each interval to the original input. Detailed process available in **Table 3**. The vehicle classification in the simulation is motorcycle (including scooter), car occupants (e.g. sedan, and SUV), and heavy vehicle (bus).

Table 3 Traffic volume simulation input.

No	Simulation period (seconds)	Traffic volume
1	0-900	2963
2	900-1800	3764
3	1800-2700	4445
4	2700-3600	5185
5	3600-4500	5926
6	4500-5400	5185
7	5400-6300	4445
8	6300-7200	3764
9	7200-max	2963

As for vehicle composition, composition A is the associated composition of the road where motorcycle is dominant and composition B is where motorcycle and car occupants have similar composition. Detail value in **Table 4**.

Table 4 Traffic composition input.

Vehicle	Composition A	Composition B
Motorcycle	0.626	0.519
Car occupants	0.358	0.472
Heavy vehicle	0.016	0.009

(3) SSM

As mentioned before, this research used two types of SSM (e.g. TTC and PICUD) of which different characteristics. TTC is temporal based SSM, while PICUD is spatial based SSM. The result presented in form of a heat map plotted to the road environment. The plotted TTC values is < 10/second of inverse TTC value. On the other hand, the plotted PICUD values is between -100 m to 50 m (negative PICUD value shows crash risk).

5. RESULT AND DISCUSSION

(1) TTC

TTC results from each scenario is available in **Fig. 2**, **Fig.3**, **Fig.4**, **Fig.5**, **Fig.6, and Fig.7**. In scenario 1 and scenario 2, composition A has higher frequency of high TTC values. This result suggests high proportion of motorcycle (i.e. composition A) impose higher collision risk compared to composition B. The decrease trend of TTC value in scenario 3, where RSD and AD values is the highest, suggest the effect of both variables on collision risk peaked around the medium values in scenario 2 and decreased towards the maximum values.

The explanation for decrease of TTC value in scenario 3 may due to the traffic already in the state of platoon/congested state when disturbance on the road around the maximum value. In such state speed of traffic flow considerably low.

The location of high TTC values does not have distinct patterns across the road environment, it scattered along the road environment. This hold for each scenario and its variation.

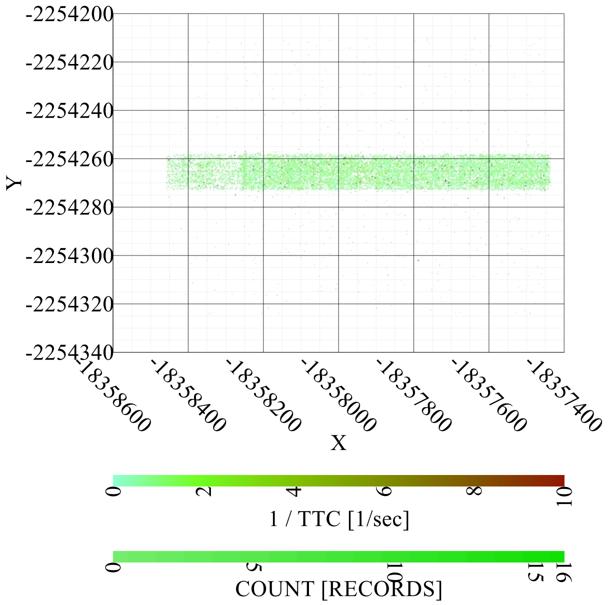

Fig. 2 TTC Scenario 1 – composition A.

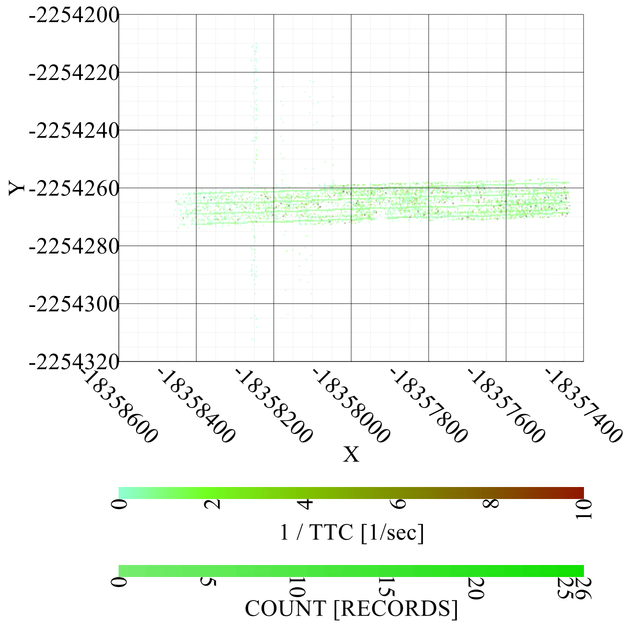

Fig. 4 TTC Scenario 2 – composition A.

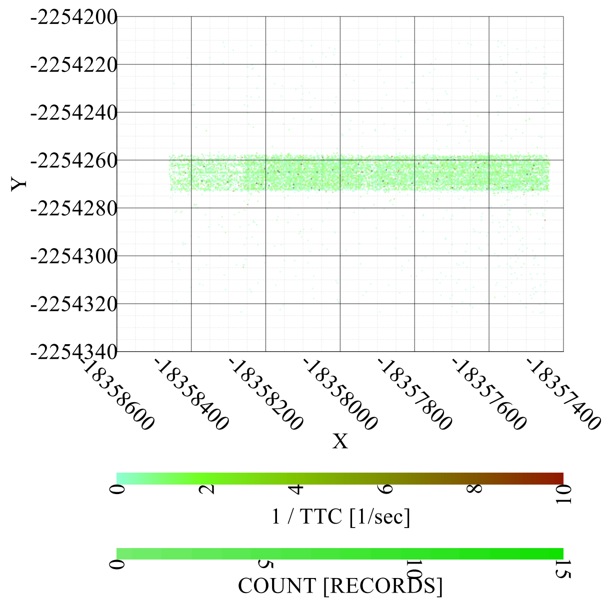

Fig. 3 TTC Scenario 1 – composition B.

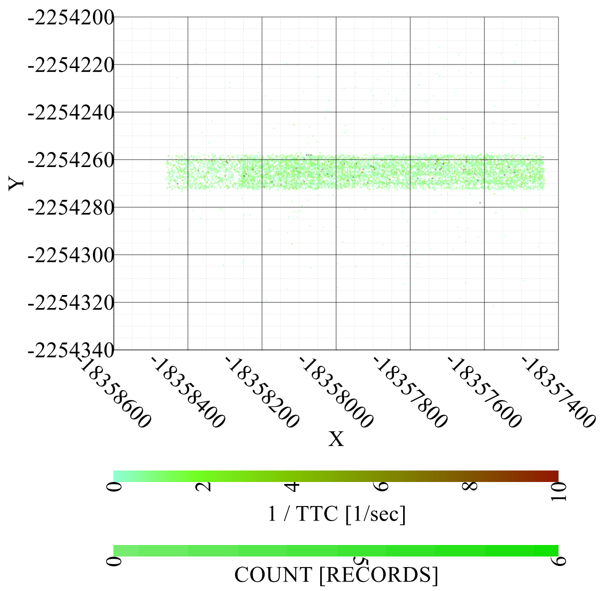

Fig. 5 TTC Scenario 2 – composition B.

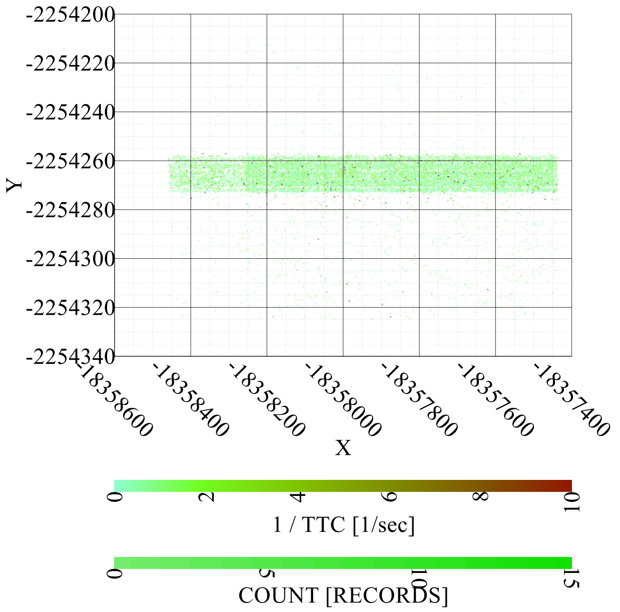

Fig. 6 TTC Scenario 3 – composition A.

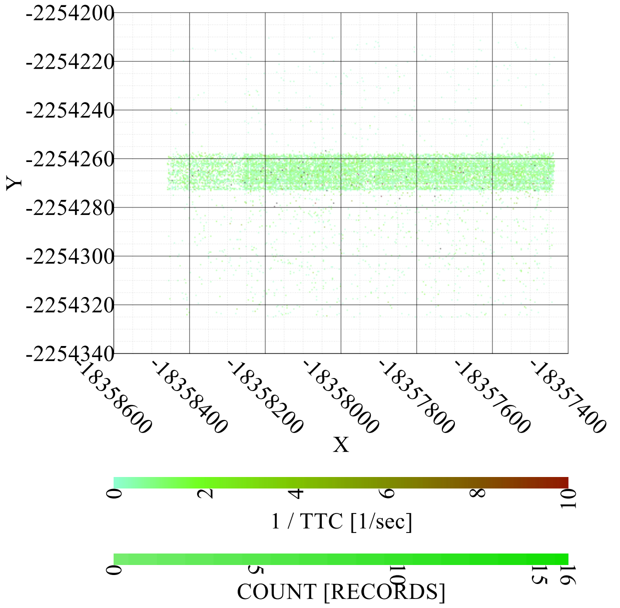

Fig. 7 TTC Scenario 3 – composition B.

(2) PICUD

PICUD results from each scenario is available in **Fig. 8**, **Fig.9**, **Fig.10**, **Fig.11**, **Fig.12, and Fig.13**. In general, the result of PICUD in regard to vehicle compositions and road environment factors (RSD and AD) has the same pattern with the result of TTC. High proportion of motorcycle impose higher collision risk than of more balance composition (i.e. composition B) between motorcycle and car occupants. Furthermore, the collision risk represents by PICU also decreased as value of RSD and AD peaked.

Similar with TTC values, high PICUD values also does not have distinct patterns across the road environment, it scattered along the road environment, which hold for each scenario and its variation.

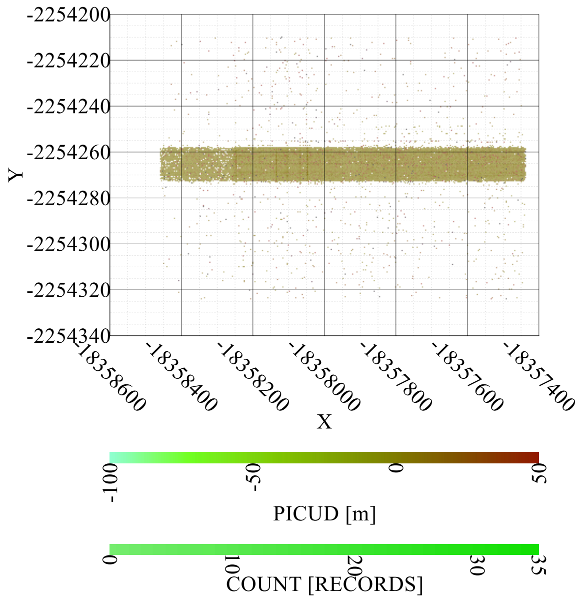

Fig. 8 PICUD Scenario 1 – composition A.

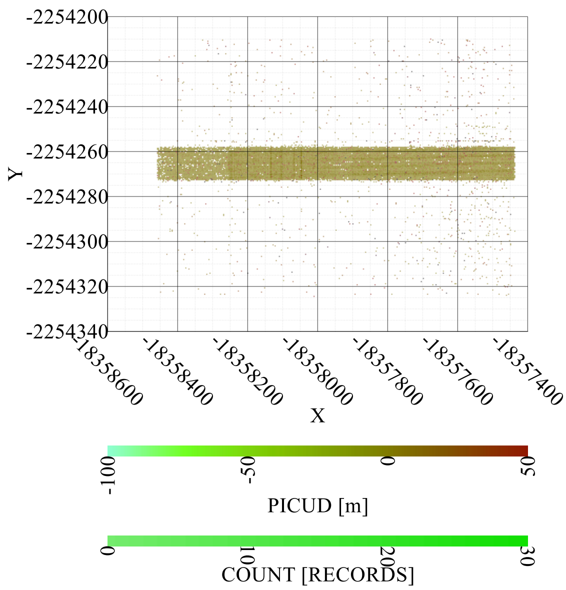

Fig. 9 PICUD Scenario 1 – composition B.

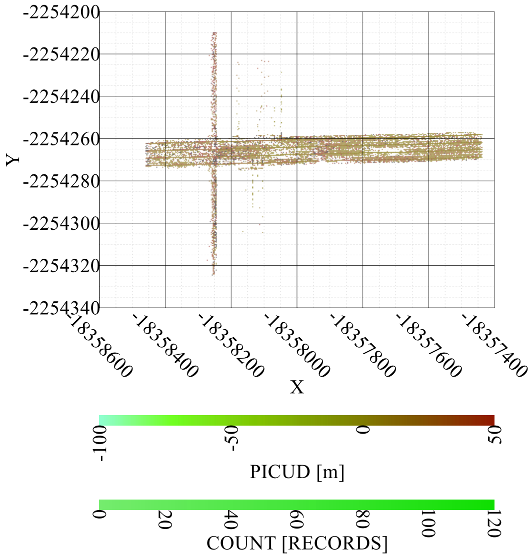

Fig. 10 PICUD Scenario 2 – composition A.

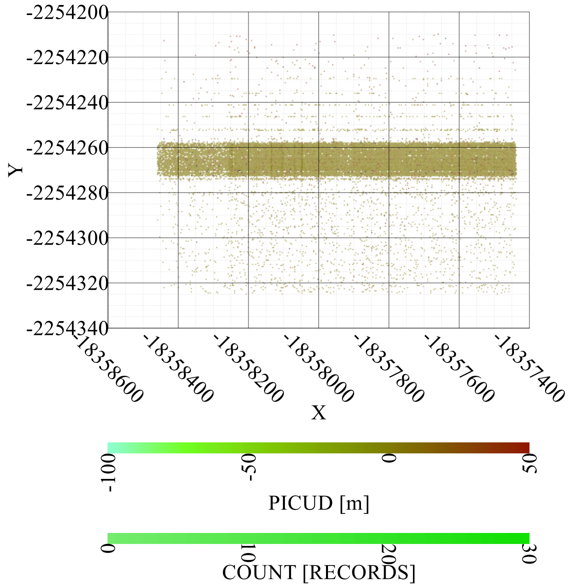

Fig. 12 PICUD Scenario 3 – composition A.

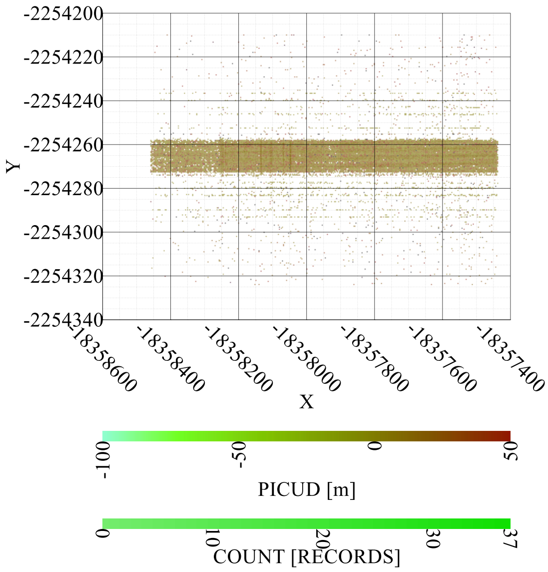

Fig. 11 PICUD Scenario 2 – composition B.

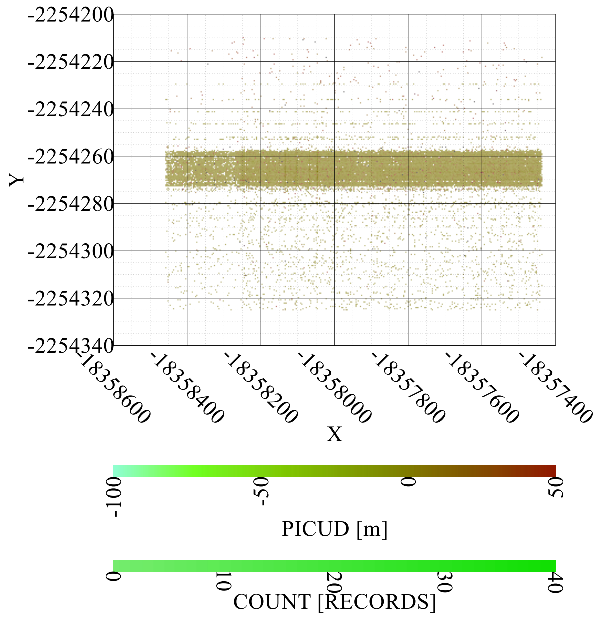

Fig. 13 PICUD Scenario 3 – composition B.

(3) TTC and PICUD result comparisons

TTC and PICUD in general gives similar trend in regards of different composition of traffic and road environment factors. However, there are several noticeable different from the analysis result.

TTC and PICUD is difficult to be directly compared due to it is different characteristics. However, from the analysis result, there is noticeable different in terms of frequency of the identified crash risks. Result of TTC shows high frequency of small TTC which means that there is high risk of collision compared to high TTC values, while for PICUD is the opposite. Negative value or small PICUD values that yield higher risk of collision has less frequency than high PICUD values.

Through investigation on how these two different SSM assess same traffic events or targeted crash type on the same pair of vehicle interaction or aggregated would give better understanding on the decision in what circumstances these types of SSM should be applied.

6. CONCLUSION

In the same traffic flow input, vehicle composition affects crash risk, represents by both TTC and PICUD, even the frequency of TTC and PICUD is different. A high disparity between proportion of motorcycle with other vehicles impose more dangerous interaction between road users that may lead to real crash events. Road environment factor represents by RSDI and AD shows contribution to risk of collision, which shows that in medium value of such disturbances when the traffic state between the state of free flow to platoon and congestion impose higher risk compared to higher disturbance values.

Further, detail research on much more varied composition, traffic flow input, and different road types is still needed to study how risk of collision occurs in relation to traffic composition, to find out whether the trend found in this study may hold or varies across such variation.

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