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# ENDOGENOUS RELATIONSHIP OF ACCIDENT OCCURRENCE WITH SPEED, TRAFFIC HETEROGENEITY AND DRIVING ENVIRONMENT ON INTER-URBAN ROADS IN INDONESIA

***Martha Leni Siregar***
*Universitas Indonesia, Faculty of Engineering, Department of Civil and Environmental Engineering, West Java, Indonesia*

***Tri Tjahjono***
*Universitas Indonesia, Faculty of Engineering, Department of Civil and Environmental Engineering, West Java, Indonesia*

***Nahry***
*Universitas Indonesia, Faculty of Engineering, Department of Civil and Environmental Engineering, West Java, Indonesia*

***Key words:*** *speed, road geometry, IRI, fatality rates, accident rates, hilliness, bendiness, endogeneity, heterogeneous traffic*

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# ENDOGENOUS RELATIONSHIP OF ACCIDENT OCCURRENCE WITH SPEED, TRAFFIC HETEROGENEITY AND DRIVING ENVIRONMENT ON INTER-URBAN ROADS IN INDONESIA

*Martha Leni Siregar, Tri Tjahjono*, Nahry*

*Universitas Indonesia, Faculty of Engineering, Department of Civil and Environmental Engineering, West Java, Indonesia*

*Speed performances and characteristics of traffic have mostly been considered as homogeneous across vehicles. In countries where the roads are dominated by mixed types of vehicles, the heterogeneity needs to be considered. This study is aimed at modeling how traffic heterogeneity as captured in speed, speed deviation, and traffic volume determines the fatality rates and accident rates. Traffic volume, road geometry (bendiness, hilliness, bend density and hill density) and road surface condition (represented by IRI) become the independent variables in a simultaneous regression using structural equation model (SEM). SEM is adopted to represent the hierarchical causal effects between the independent variables and dependent variables. The data cover inter-urban roads in eight provinces in Indonesia from 2012-2016 and 2019. Speed is not significant in predicting accident rate, and speed deviation is not significant in predicting fatality rate. An increase in speed deviation lowers the accident rates; an increase in speed increases fatality rates. Road geometry and traffic volume negatively impact the speed deviations of all vehicle categories, indicating that when there is more traffic on the road, the speeds of all vehicle categories become more homogenous. Bend density, bendiness, hill density and hilliness negatively affect both the speed and the speed deviations of the vehicles of all categories The findings of the study can contribute to traffic policing and traffic safety improvement schemes for heterogeneous traffic.*

*Key words: speed, road geometry, IRI, fatality rates, accident rates, hilliness, bendiness, endogeneity, heterogeneous traffic*

## INTRODUCTION

Various studies have been conducted to investigate speed variations and the relationship between changes or variations of speed and the impacts on accident rate. The effects of speed variation on accidents, however, may vary among research results due to the different definitions adopted in different studies. Speeds of mixed traffic were mainly investigated in countries where traffic is strongly characterized by the mixture of vehicle categories such as China and India. A study by Roy [1] was carried out on mixed traffic under heavy flow while the previous study by Dhamaniya [2] focused on mixed traffic flow on urban arterials. Wang [3] investigated how speed and speed variations are related to accidents. Several studies defined speed variation as individual speed difference [4], as differences between 50 and 90 percentiles per lane [5], or as differences between lanes and within lanes [6], [7]. Wang [8] used speed variations based on segments and time, and Tanishita [9] used speed and change in mean speed. Studies on speed variations due to traffic heterogeneity and the effects on accident occurrence are still lacking. Traffic heterogeneity refers to traffic composition of different types of vehicles with nonuniform characteristics sharing the same lane. Heterogeneous traffic may result in distinct vehicle speed characteristics in terms of average speeds and speed deviations. The vehicles' different dimensions, speed and braking performances determine the stopping distances which characterize the roads with different vehicle performances due to vehicle speed behavior and maneuverability. As acceleration is inversely proportional to the mass, the maneuverability of heavy vehicles such as trucks are also influenced, which may contribute to the speed performance. It can, therefore, be expected that there is a significant gap between the average speed of categorized vehicles and the average traffic speed. Speed performances and characteristics of traffic have mostly been considered as homogeneous across vehicles. In this study, speed deviation refers to the speed variation of vehicles by categories. The present study applies six categories of vehicles to represent the heterogeneity: passenger cars (PC), angkots (A), pickups (PU), buses (B), trucks (T), and motorcycles (MC) which also include ojeks. Angkots are mini-van sized vehicles commercially operated for passengers, and ojeks are motorcycles operated for paid trips. The abbreviations apply in the naming and labelling of the related variables in the following sections.

The effects of road geometry on the accidents on specific road users was studied by Siregar [10], [11]. Traffic accidents figure in Indonesia by level of severity is shown in Fig. 1, the dotted lines are the linear regressions of total accidents and and number of fatality.

*tjahjono@eng.ui.ac.id

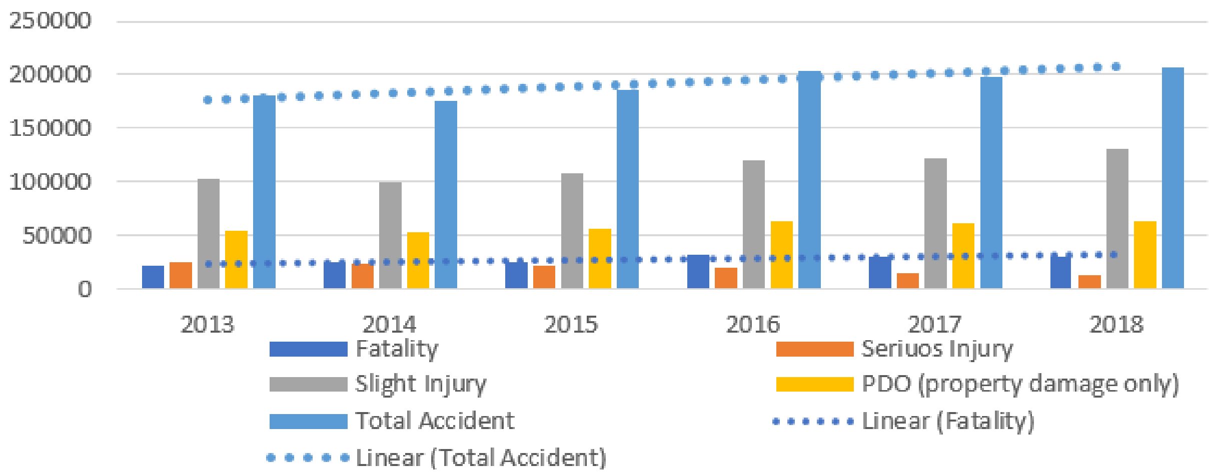


*Figure 1: Accident data in Indonesia (2013-2018). From [12]*

The number of fatalities is comparatively higher than the number of serious injuries. Both the total accident number and fatalities in Indonesia show increasing trends during 2013-2018, which necessitates comprehensive studies covering various factors. The traffic volume on the inter-urban roads under study ranges from 1,500 vehicles per day in NTB to 67,000 vehicles per day, with the average volume approximately 10,000 vehicles per day. Motorcycles contribute around 57% to the total traffic. [13]

Speed characteristics have been studied with a wide range of research objectives. This study is aimed at modeling how traffic heterogeneity as captured in speed, speed variation, and traffic volume determines the fatality rates and accident rates.

## METHODOLOGY

### Data

A set of time series data were obtained from both secondary data [10] and direct measurements in 2019 covering data from 5 provinces in the eastern parts of Indonesia: South Sulawesi, SE Sulawesi, NTB, West Kalimantan, South Kalimantan, Bali, and NTT, as shown in Fig. 2. This set of data is the most complete time-series traffic data of inter-urban provincial roads in Indonesia. Direct measurements were conducted on four roads in South Sulawesi for more updated data and to capture changes in driving environment conditions.

The International Roughness Index (IRI) values were measured using roughometer, three runs for each direction and data were recorded for segments of around 100 m. IRI is obtained from measured longitudinal road profiles, and bigger values of IRI indicate rougher roads and vice versa. Two kinds of speeds were measured; spot speed by types of vehicles, and floating speeds. Accident data were obtained from local police stations as well from the website of traffic police accident information system. As the survey roads have different lengths, the accidents occurrences are represented by fatality rates and accident rates.


*Figure 2: Locations of surveys, as marked with circles*

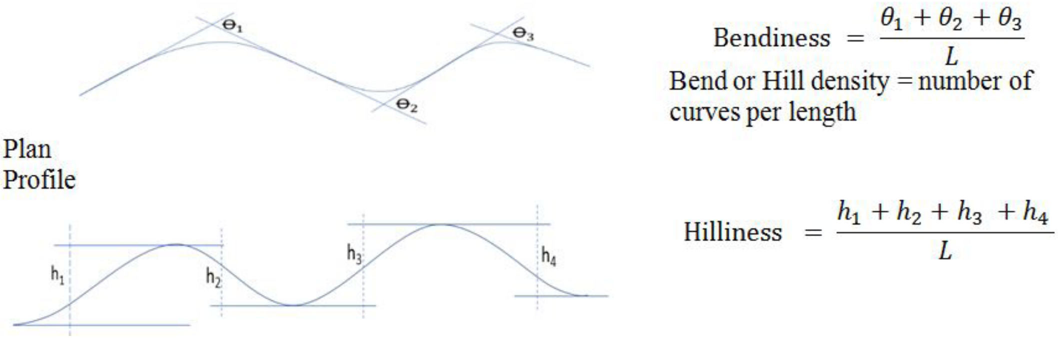


*Figure 3: Accident data in Indonesia (2013-2018). From [12]*

***Method***

Based on previous studies on speed characteristics and traffic safety [11], speed, safety and accident [12], [13], speed variation and safety [3], [9], [14], [15], accident severity [16] and crash risk factors and infrastuctures [17], the present study assumes that the traffic-related factors in accidents occurrences include the traffic volumes, vehicle speed deviations, and vehicle speeds, and the road-related factors include road geometry and IRI. The road geometry is represented by bendiness (B), bend density (BD, hilliness (H) and hill density (HD) as described in Fig. 3.

Accidents occurrence is represented by accident rate and fatality rate. Heterogenous traffic characterizes the traffic conditions on the survey roads. As different categorizations of vehicles were used in speed surveys and traffic volume surveys, some adjustments in the data were made for data compatibility. Traffic heterogeneity is reflected in the indirect correlations with the latent variables of geometric condition (Geom), volume (Vol), speed deviation (SD) and speed (S).

The Structural Equation Modelling (SEM) was adopted in this study and the analysis was carried out using IBM SPSS AMOS 23. The use of SEM allows exploratory purposes besides CFA and multiple regression[18], and it allows the possibility of the existence of latent variables. SEM is built on (1) the structural model and (2) the measurement model. As CFA is a confirmatory technique and the hypothesis is based on related theories, SEM can, therefore, be used to test various hypothetical relationships between the endogenous and exogenous variables. Exogenous variables are variables that influence the endogenous variables and that are independent of any other factors.

The causal relationship between the ith endogenous and exogenous latent variables with the ith indicators can be described as:[19]

$$x_i=\alpha_x+\lambda_x\xi_i+\delta_i \quad (1)$$

$$y_i=\alpha_y+\lambda_y\eta_i+\varepsilon_i \quad (2)$$

Relationship between the latent variables:

$$\eta_i=\alpha_\eta+B\eta_i+\Gamma\xi_i+\zeta_i \quad (3)$$

Where

$x_i$ = indicators of the exogenous variables

$y_i$ = indicators of endogenous variables

$\alpha$ = the vector of intercept

$\lambda_x$ = the matrix of coefficients that gives the expected effects of $\xi_i$ on $x_i$

$\lambda_y$ = the matrix of coefficients that give the expected effects of $\eta_i$ on $y_i$

$\xi_i$ = the vector of latent exogenous variable $\lambda_x$

$\eta_i$ = the vector of latent endogenous variable

$\delta_i$, $\varepsilon_i$, $\zeta_i$= the vector of equation disturbances that consists of all other influences of the dependent variables that are not included in the equation

$B$ = the matrix of coefficients that give the expected effect of the $\eta_i$

$\Gamma$ = the matrix of coefficients that give the expected effects of $\xi_i$ on $\eta_i$

The use of structural equation modeling (SEM) allows simultaneous analysis of the relationships. The structure is comprised of the direct and indirect effects of speed (S), speed deviations (SD), traffic volumes (Vol), road geometry (Geom) and road roughness index (IRI) on fatality rate (FR) and accident rate (AR). A two-level analysis is applied to explain the effects of the direct and indirect effects of independent variables.

***Level 1***

Level 1 model is constructed based on the hypotheses:

1. Accident rates and fatality rates are only directly determined by speeds and speed deviations of vehicles,
2. Speeds and speed deviations variables are correlated
3. Speeds and speed deviations are latent variables with vehicle categories as indicators.

The joint distribution of the model can be described as $P(x_1, x_2)=P(y|x_1, x_2)$ where X is exogenous variable to Y, $X_1$ is speed deviation (SD), $X_2$ is speed (S), Y is fatality rate (FR) or accident rate (AR).

***Level 2***

Level 2 model is constructed based on the hypotheses:

1. Accident rates and fatality rates are only directly determined by speeds and speed deviations of vehicles,
2. Traffic volumes road geometry and IRI directly determine speeds and speed deviations
3. Speed and speed deviations are correlated through errors and directly determine accident fatalities and rates
4. Speeds, speed deviations, road geometry and traffic volumes are latent exogenous variables with different indicators.

With more variables considered in the model, some changes in the magnitude of the relationship between the variable are expected. Keeping the structure and the direction of relationships the same, the inclusion of more exogeneity changes the speed deviation (SD) and speed (S) into endogenous variables and the two variables become correlated in their error terms. Both speed deviation (SD) and speed variables are endogenous towards fatality rate (FR) and accident rate (AR).

The joint distribution of the model can be described as $P(x_1, x_2, z_1, z_2, z_3, y) = P(x_1 | z_1, z_2, z_3) P(x_2 | z_1, z_2, z_3) P(z_1) P(z_2) P(z_3) P(y | x_1, x_2)$ where X is the endogenous variable to Z and exogenous to Y, $X_1$ is speed deviation (SD), $X_2$ is speed (S), Z1 is surface condition (IRI), $Z_2$ is traffic volume (Vol), $Z_3$ is road geometry (Geom) and Y is fatality rate (FR) or accident rate (AR).

Road geometry, traffic volume and IRI are exogenous variables in this model which are directly related to speed and speed deviation and indirectly related to fatality rate and accident rate. Traffic volume is a latent variable with the volumes of all six vehicle categories as the indicators; road geometry (Geom): bend density (BD), hilliness (H) and hill density (HD) as the indicators. The road surface condition is represented by IRI (the international roughness index) value of the road surface (IRI). Speed (S) and speed deviation (SD) are correlated but in error terms as they become endogenous.

## RESULTS AND DISCUSSION

Meticulous reading and analysis on the as-built drawings were conducted to obtain geometric data which include road bendiness, bend density, hilliness and hill density. Road surface condition is indicated by IRI. Fatality rate is the number of accident deaths per 100 mn vehicle-km and accident rate is the number of total accidents per 100 mn vehicle-km. Bendiness is the total of deflection angles divided by the length (degree $km^{-1}$), hilliness is the sum of height gain and loss divided by the length (m $km^{-1}$). Bend density and hill density are the number of curves divided by the length ($km^{-1}$).

Fig. 4 shows that there are road sections with unfavorable conditions with a high density of bends and also large bendiness. Similar trends can be identified from Fig. 5 where there are sections with large values of hilliness as well as hill density. Flat lines show road sections of the same surveyed segments. The diagrams indicate that bendiness and bend density show similar patterns; large bendiness results from high density of bends. Hilliness and hill density, however, show some inconsistencies. Sections with hill densities but small hilliness may indicate that the roads are characterized with a number of vertical curves.

The speed distribution in Fig. 6 indicates that there are some road segments where speeds of all types of vehicle converge giving small speed differences as in segment 49, while some segments show distinct speeds. In general, the distribution shows a pattern with obvious changes of speeds on different segments, however, the speed consistency of a certain type of vehicle are not reflected. This implies that the different characteristics of driving environments influence the vehicle speed behaviors. Table 1 shows the descriptive analysis of the data.


*Figure 4: Bendiness and Bend Density of Road Sections*

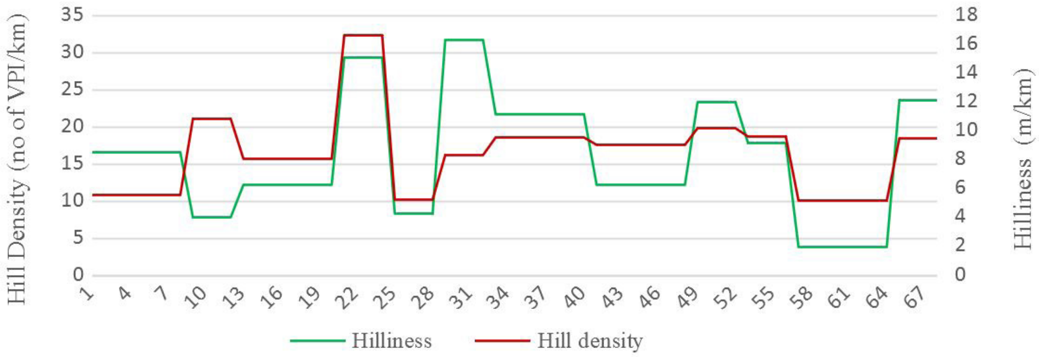


*Figure 5: Hilliness and Hill Density of Road Sections*

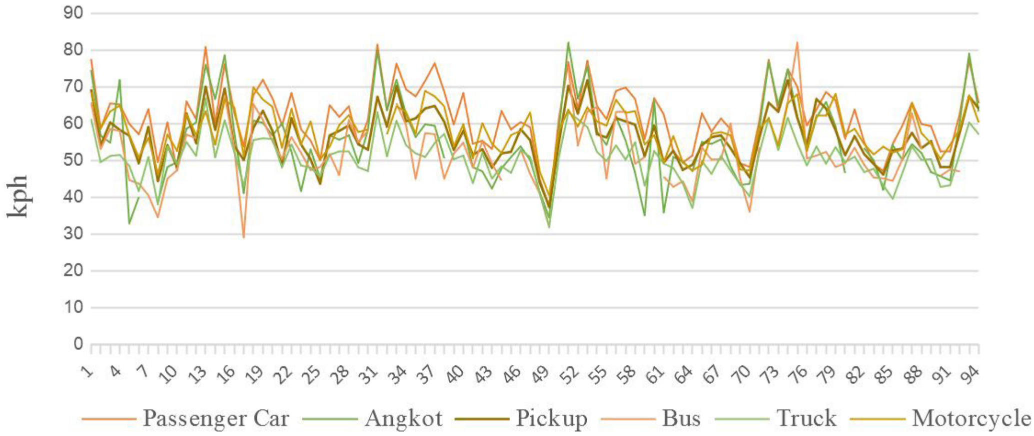


*Figure 6: Speed Distribution of Different Categories of Vehicles*

*Table 1: Descriptive Statistics of the Data*

| | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|
| IRI | 1.9 | 3.8 | 2.71 | 0.47 |
| Vol PC | 193 | 5,373 | 1,449 | 1,226 |
| Vol A | 13 | 4,799 | 604 | 812 |
| Vol PU | 94 | 2,139 | 661 | 479 |
| Vol B | 0 | 606 | 71 | 80 |
| Vol T | 50 | 2,873 | 853 | 756 |
| Vol MC | 593 | 10,881 | 4,104 | 2,465 |
| SD PC | 8.6 | 18.6 | 13.1 | 2.31 |
| SD A | 0 | 24.3 | 10.2 | 4.22 |
| SD PU | 8.2 | 20.2 | 12.9 | 2.56 |
| SD B | 0.7 | 24.7 | 10.1 | 5.82 |
| SD T | 8 | 17.5 | 11.5 | 2.25 |
| SD MC | 9.3 | 50.9 | 12.5 | 4.97 |
| S PC | 47.1 | 81.5 | 61.9 | 8.64 |
| S A | 0 | 82 | 55.1 | 13.83 |
| S PU | 43.6 | 71.8 | 56.4 | 7.30 |
| S B | 0 | 82 | 49.2 | 21.94 |
| S T | 43.1 | 63.1 | 50.5 | 5.93 |
| S MC | 49.4 | 68.1 | 58.1 | 5.17 |
| Bend Density | 2.2 | 8.4 | 4.8 | 1.46 |
| Hill density | 5.2 | 16.7 | 8.6 | 2.79 |
| Bendiness | 32 | 331.2 | 109.7 | 71.90 |
| Hillness | 3.9 | 31.8 | 16.2 | 8.05 |
| Fatality Rates | 0 | 59.51 | 9.1 | 10.69 |
| Acc Rate | 0 | 152.8 | 26 | 31.04 |

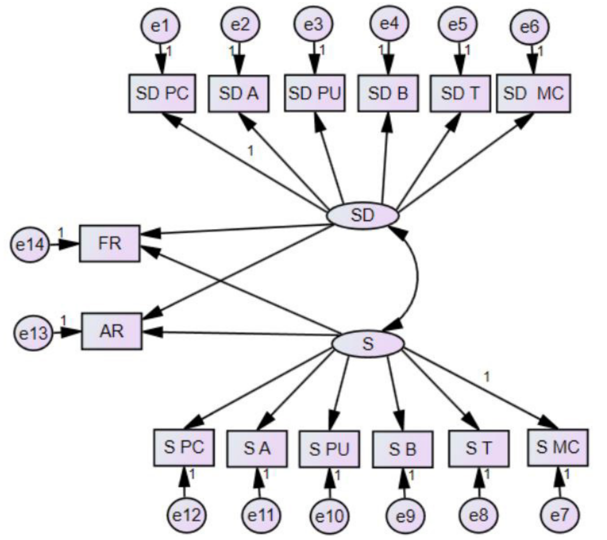


*Figure 7: Level 1 Path Diagram*

The mean value of passenger cars speed is the highest, followed by the speed of motorcycles.

The results of Level 1 path analysis based on the path diagram in Fig. 7 show that both speed (S) and speed deviation (SD) are found to be significant in the prediction of fatality rate (FR) and accident rate (AR). The regression weights of speed (S) on fatality rate (FR) and accident rate (AR) are 0.515 and 0.461; the regression weight of speed deviation (SD) on fatality rate (FR) and accident rate (AR) are -0.464 and -0.548.

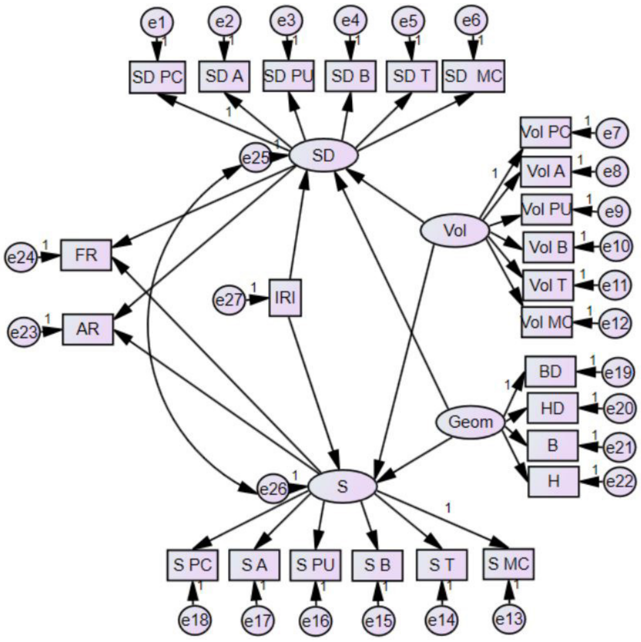


*Figure 8: Level 2 Path Diagram*

As the number of accidents includes the number of fatalities, it can be inferred from the model that serious and non-serious injuries are more likely to be determined by the speed deviation. Bus speed deviation (SD B), bus speed (SB) and motorcycle speed deviation (SD MC) indicators are found to be not significant. However, all variables are kept in the model to see how the relationships change with the inclusion of more variables into the model. The results of Level 2 path analysis based on the path diagram in Fig. 8 are shown in Table 2.

The standardized effects of the variables of Level 2 model can be summarized as follow:

S = – 0.329 Vol – 0.559 Geom

SD = – 0.422 Vol – 0.672 Geom

FR = 0.473 S – 0.421SD

AR = 0.396 S – 0.491SD

While holding the other variables fixed, a 1 kph increase in speed leads to an increase of 0.473 accident deaths per 100 mn vehicle-km, and a 1 kph increase in speed deviation results in an increase of 0.421 accident death per 100 mm vehicle km. The indirect effects of a variable is the direct effect of the variable to the mediating variable x the direct effect of the mediating variable to the dependent variable. The indirect effects of traffic volume (Vol) on fatality rate (FR) is (-0.422)(-0.421) + (-0.329)(+0.473) = +0.022.

In both models, the negative values of the regression weights of speed deviation (SD) to both fatality rate (FR) and accident rate (AR) indicate that an increase in speed deviations results in decreases in both FR and AR. Contradictory effect was shown by speed (S) with positive regression weight to predict the fatality rate (FR) the accident rate (AR). An increase in speed causes more accidents and fatalities; and bigger speed deviation decreases both the number of accidents and fatalities. The present finding is in line with that of Islam & El-Basyouny which was conducted in urban environment. It was found that when speed is reduced there is a reduction in crashes. [20]. However, it is contrary to that of Baruya (23) that stated average speed negatively influences collisions. Despite the difference in the definition of speed variation, the results of the present study are in line with that of Quddus [22] which found that speed variation was

*Table 2: Standardized Effects of Variables of Level 2 Model*

| | Standardized Indirect Effect | | | | Standardized Direct Effects | | | | Standardized Total Effects | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Vol | Geom | S | SD | Vol | Geom | S | SD | Vol | Geom | S | SD |
| S | | | | | -.329 | -.559 | | | -.329 | -.559 | | |
| SD | | | | | -.422 | -.672 | | | -.422 | -.672 | | |
| FR | .022 | .019 | | | | | .473 | -.421 | .022 | .019 | .473 | -.421 |
| AR | .077 | .109 | | | | | .396 | -.491 | .077 | .109 | .396 | -.491 |

statistically and positively associated with accident rates. The average speeds, however, were not associated with accident rates. The significance of speed variations was also revealed by Choudhary [23] who studied the speed variation right before accidents and concluded that when speed variance was not considered, the mean speed was not significantly related to accident occurrence.

In Level 2 model, changes are noticed in the regression weights as the speed deviations (SD) become an insignificant variable to fatality rate (FR) and the speed (S) becomes insignificant to accident rate (AR). Based on CR and p values, however, the regression between speed deviation (SD) and fatality rate (FR), and between speed (S) and accident rate (AR) are not significant in the prediction.

Speed deviation (SD) of all vehicle categories is also determined by road geometry (Geo) and traffic volume (Vol) with regression weights -0.329 and -0.559, indicating that when there is more traffic in the road, the speeds of all vehicle categories become more homogenous. It is also shown that the speed characteristics of buses (SD B and SB) and motorcycle speed deviation (SD MC) are not significant indicators. This implies that the indicators do not give indirect effect to fatality rate (FR) and accident rate (AR) through the latent variables of speed (S) and speed deviation (SD). This might be due to the fact that the number of buses in the surveyed roads is relatively smaller than other vehicles.

Traffic volume (Vol) has negative direct effects on speed (S) and speed deviation (SD). The indirect effect on fatality rate (FR) through SD, therefore, becomes positive and through S becomes negative. The indirect effect on accident rate (AR) is positive through speed deviation (SD) and negative through speed (S). An increase in road geometry causes a decrease in both speed deviation (SD) and speed (S). This indicates that when a road has more bends and hills, the traffic speed and the speed deviation become smaller, leading to more convergent lower speeds. This is supported by the finding of Sadia [14] which shows that drivers choose lower speed along horizontal curves. With S and SD as the mediation variables, a one-unit increase in road geometry results in a 0.019 decrease, in fatality rate (FR) and a 0.109 decrease in accident rate (AR). Hilliness (H), Hill Density (HD), Bendiness (B) and Bend Density (BD) are all positive and significant indicators of road geometry (Geom). Some indicators in Level 2 are not significant to the latent variables, i.e. bus speed (SB), bus speed deviation (SD B), speed deviation of motorcycle (SD MC) and road surface condition (IRI). Although different from the results of Tjahjono [24] who also investigated the effects of IRI on fatality rate, the present finding shows some linearity. The present study was conducted on roads with IRI values ranging form 1.9 to 3.8, while the study by Tjahjono was conducted on roads with higher IRI values ranging from 3.6 to 10.4.

***Model fit***

The inclusion of more independent variables in Level 2 model changes the goodness-of-fit. With CFI 0.696, the complete model goodness-of-fit is lower than that of Level 1 model, which is 0.818. The model results in some non-significant indicators, i.e. SD B, SB, and SD MC. The omission of the non-significant indicators results in higher CFI but lower Chi-sq. The relatively smaller number of buses compared to other types of vehicles may

*Table 3: Comparison of Goodness of Fit*

| | Level 1 | Level 2 | Level 2 with only significant indicators |
|---|---|---|---|
| Chi-sq | 237.460 | 978.556 | 695.156 |
| P | 0.000 | 0.000 | 0.000 |
| Df | 74 | 267 | 182 |
| CFI | 0.793 | 0.623 | 0.696 |
| RMSEA | 0.182 | 0.199 | 0.205 |

*Table 4: Regression Weights*

| | | | Estimate | S.E. | C.R. | P | Label |
|---|---|---|---|---|---|---|---|
| SD | <-- | Geom | -1,069 | ,131 | -8,190 | *** | |
| S | <-- | Geom | -1,687 | ,318 | -5,311 | *** | |
| S | <-- | Vol | -,001 | ,000 | -3,590 | *** | |
| SD | <-- | Vol | -,001 | ,000 | -5,236 | *** | |
| SDPC | <-- | SD | 1,000 | | | | |
| SDA | <-- | SD | 1,283 | ,181 | 7,104 | *** | |
| SDPU | <-- | SD | 1,013 | ,086 | 11,742 | *** | |
| SDT | <-- | SD | ,699 | ,095 | 7,367 | *** | |
| BD | <-- | Geom | 1,000 | | | | |
| HD | <-- | Geom | 1,338 | ,174 | 7,695 | *** | |
| B | <-- | Geom | 42,366 | 3,413 | 12,412 | *** | |
| H | <-- | Geom | 4,651 | ,397 | 11,716 | *** | |
| VolPC | <-- | Vol | 1,000 | | | | |
| VolA | <-- | Vol | ,563 | ,082 | 6,892 | *** | |
| VolB | <-- | Vol | ,035 | ,008 | 4,154 | *** | |
| VolT | <-- | Vol | ,554 | ,075 | 7,350 | *** | |
| VolMC | <-- | Vol | 2,236 | ,293 | 7,630 | *** | |
| VolPU | <-- | Vol | ,516 | ,041 | 12,430 | *** | |
| FR | <-- | SD | -1,909 | 1,003 | -1,904 | | Not significant |
| SMC | <-- | S | 1,000 | | | | |
| ST | <-- | S | 1,374 | ,125 | 10,951 | *** | |
| SPU | <-- | S | 1,674 | ,156 | 10,767 | *** | |
| SA | <-- | S | 2,686 | ,324 | 8,304 | *** | |
| SPC | <-- | S | 2,029 | ,181 | 11,199 | *** | |
| AR | <-- | SD | -6,585 | 2,920 | -2,255 | ** | |
| AR | <-- | S | 2,838 | 1,538 | 1,845 | | Not significant |
| FR | <-- | S | 1,146 | ,532 | 2,156 | ** | |

account for the insignificance of both the speed deviation and the speed. The speed of motorcycles are kept in the model while the speed deviation is omitted as it is insignificant. Removing of the insignificant indicators of the latent variables results in better model fit as indicated by higher CFI. However, when the model is analyzed in two steps, it is revealed that the basic model with only speed and speed deviation variables has the goodness of fit close to the acceptable values. As the analysis aims to explore the magnitude of effects of different variables of speed, speed deviation, traffic volume and road surface condition on accidents, the model is acceptable.

The basic relationship between speed, speed deviation and accidents as in Level 1 model gives the smallest Chi-sq, probability and RMSEA, and the biggest value of CFI. Additional of hypothesized variables of road geometric (GEOM), traffic volume (VOL) and road surface condition (IRI) affect the estimates and goodness of fit as in Table 3. The significance of variables in the prediction is shown in Table 4.

With positive values of regression weights, road geometry condition affects accident rates more than fatality rate. This implies that improvements in road geometry by reducing the vertical and horizontal curves densities and hilliness and bendiness can be expected to give positive effects on accident rate and fatality rates. Smaller weights on fatality indicates that more non-fatal accidents can be prevented by changing and improving the road geometry. This classification of road geometry, however, does not take into account the vertical and horizontal curves coordination which can be expected to relate to driver's reaction during driving. The road surface condition represented by IRI is not significant in predicting fatality rate and accident rate. One possible reason is that data were taken after road improvements, and there have been relatively small changes in the surface condition during the survey periods. In general, the findings are in line with the results of previous studies where average speed, volume and horizontal curves have significant effects on collisions. [25]

### *Traffic heterogeneity*

Table 5 shows the effects of heterogeneity of significant indicators. Standardized coefficients show the hierarchy of importance of the variables to the dependent variables based on numerical values.

The total effects of traffic volume and road geometry on the indicators show how the changes in the two variables are associated with the change in speed and speed deviation of different categories of vehicles.

A one-unit increase in traffic volume causes 0.322 units decrease in passenger car speed (S PC), 0.270 units in motorcycle speed (S MC). The most affected decrease in speed deviation by an increase of one unit of traffic volume is the speed deviations of passenger cars (SD PC), which is 0.400 units, and the least is the speed deviation of angkots with 0.293 units decrease. In general, the effects of traffic volume changes are smaller compared to those of road geometry. Indicator Vol PU has regression weight bigger than 1, which may result from some multi-collinearity with other indicators. As the pick-up functions and characteristics are basically unique and not comparable with other vehicle categories, the PU indicator is kept in the model. The road geometry negatively affects both the speed and the speed deviations of the vehicles of all categories. One unit increase in road geometry variable lowers the speed of passenger cars by 0.548 units and the speed deviation by 0.636 units. In general, higher values of road geometry indicators, bendiness, bend density, hilliness and hill density, result

*Table 5: Standardized Effects of Traffic Heterogeneity*

| | Standardized Indirect Effects | | Standardized Direct Effects | | | | Standardized Total Effects | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Vol | Geom | Vol | Geom | S | SD | Vol | Geom | S | SD |
| SPC | -.322 | -.548 | | | .981 | | -.322 | -.548 | .981 | |
| SA | -.271 | -.460 | | | .824 | | -.271 | -.460 | .824 | |
| SPU | -.316 | -.537 | | | .960 | | -.316 | -.537 | .960 | |
| ST | -.319 | -.542 | | | .969 | | -.319 | -.542 | .969 | |
| SMC | -.270 | -.459 | | | .821 | | -.270 | -.459 | .821 | |
| SDT | -.294 | -.468 | | | | .697 | -.294 | -.468 | | .697 |
| SDPU | -.370 | -.589 | | | | .877 | -.370 | -.589 | | .877 |
| SDA | -.293 | -.467 | | | | .695 | -.293 | -.467 | | .695 |
| SDPC | -.400 | -.636 | | | | .947 | -.400 | -.636 | | .947 |
| VolT | | | .721 | | | | .721 | | | |
| VolB | | | .430 | | | | .430 | | | |
| VolPU | | | 1.058 | | | | 1.058 | | | |
| VolA | | | .684 | | | | .684 | | | |
| VolPC | | | .803 | | | | .803 | | | |
| SD | -.422 | -.672 | | | | | -.422 | -.672 | | |
| S | -.329 | -.559 | | | | | -.329 | -.559 | | |

in lower and more homogenous speed by vehicle categories.

## CONCLUSION

In this study of Indonesian inter-urban roads, it has been found that speed deviation and speed, both individually and collectively contribute to the accident occurrences. The two-level modeling reveals that the inclusion of variables of road geometry, traffic volume and road surface condition which have indirect effects on accidents results in changes in the estimates. In both models, the fatality rate is significantly determined only by speed, while the accident rate is significantly determined by speed deviation. When traffic volume increases, the speed and speed deviation decrease and the speed of the vehicles from the same category becomes more homogenous. Traffic volume also indirectly increases the fatality rate and decreases the accident rates. The road surface condition was not found to be significant in accident occurrences. Road geometry contributes more to accident rates than to fatality rate.

### Limitations of the study

The calculation of horizontal and vertical curves (bends and hills) was based on the segments between intersections, and the effects of the intersections and turns were not considered.. Further investigations should, therefore, consider the two features to be road geometric indicators.

### Practical implications

The results of this study can be expected to contribute to accident and fatality reduction, traffic policing and traffic management schemes in roads characterized with heterogenous traffic.

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