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Original Article

Analyzing accident severity of motorcyclists using a Bayesian network

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Abstract

This paper focuses on the probability of crashes with severe and mild injuries in motorcyclists. The probability of crashes took human, road and environment, and vehicle factors into consideration. From July to December, 2015, 70.93% of the crashes that occurred in Indonesia involved motorcycles. The research took place in Bekasi City, Indonesia. The samples consisted of 184 respondents who had experienced crashes. The results indicated that the probability of severe injuries from the crashes was 13% and the probability of mild injuries was 87%. The mean absolute deviation of the model was 20.20%. Female drivers were more likely to be severely injured than males. Driving on roads which have road side variability and driving on curvy roads would be able to decrease the level of monotonous driving from 41% to 21%. Motorcycles which have engine capacity above 125 cm^3 were 14% more likely to experience crashes with severely injuries.

Keywords: accident severity, Bayesian network, Bekasi, motorcycle

1. Introduction

Age, sex, occupation, job status, vehicle type, license status, fatigue, speed, and location of accident were independently correlated to the severity of the accident (Boufous & Williamson, 2009). Elderly people were more likely to suffer fatal crashes or severe injuries rather than mild injuries. For the age group under 30 years old, the risk mild injuries was higher than fatal crashes or suffering from severe injuries (Vorko-Jovic, Kern, & Biloglav, 2005). An increased severity rate was found not only in younger motorcyclists who used higher engine capacity vehicles, but also in older motorcyclists who used lower engine capacity vehicles (Yannis, Golias, & Papadimitriou, 2004). Drivers younger than 20 years of age were almost 12 times more likely to suffer fatal crashes but decreases dramatically as the age of the driver increases and then rises again after the drivers pass the age of 65 (Clarke, Ward, Bartle, & Truman, 2009). Wearing a helmet lowers the average probability of a crash for motorcyclists and young motorcyclists on average are more likely to suffer from severe injuries or fatal crashes (Lapparent, 2005).

Males are 2.69 times more likely to die in a crash than females (Vorko-Jovic, Kern, & Biloglav, 2005). However, males are less likely to ignore traffic rules than females (Susilo, Joewono, & Vandebona, 2014).

The characteristics that are predictive to be causes of serious and fatal injury were driving in the darkness, between Friday and Sunday, on a road with a speed limit of 60 mph, on single carriageways, overtaking, skidding, hitting an object off the carriageway, and passing by previous accident sites (Gray, Quddus, & Evans, 2008).

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The experience of monotonous situations while driving is influenced by road design monotony and roadside variability, which may rapidly reduce the vigilance level of the driver. The level of vigilance does not increase when the road is straight, but vigilance increases on a turn (Laruea, Rakotonirainya, & Pettitt, 2011). Monotonous roads, long periods of driving, and the lack of rest can result in fatigue in drivers (Ma, Wiliamson, & Friswell, 2003). Monotonous road conditions and low-level traffic volume are likely to result in early fatigue (Thiffault & Bergeron, 2003a).

Sportbikes involved in fatal accidents were caused by excessive speed (Bjørnskau, Nævestad, & Akhtar, 2011). The difference in motorcycle performance will affect the risk in driving behavior and the risk of fatal crashes (Teoh & Campbell, 2010). Travelling to work by motorcycle is correlated with increased death in crash victims on the highway (Moeinaddini, Asadi-Shekari, Sultan, & Shah, 2014).

In 2011, 484 motorcycle accidents occurred in Bekasi City. This number increased to 526 in 2012, and decreased to 460, 416, 357 in the years of 2013, 2014, and 2015, respectively. Moreover, the number of those who sustained severe injuries in 2011 was 160. This decreased to 117 in 2012, and increased to 131 in 2013. However, it was found that in 2014 and 2015 the numbers of serious injuries were found to be 114 and 45, respectively. In 2011, 47 motorcyclists were involved in fatal accidents and in the following years of 2012, 2013, 2014, and 2015 the numbers decreased to 63, 38, 44, and 23, respectively. In the periods of 2011, 2012, and 2013 the number of motorcyclists who sustained mild injuries increased by 393, 453, and 483 respectively. However, the numbers decreased in 2014 and 2015 to 390 and 406, respectively (Bekasi Police Department, 2016).

This research aimed to analyze some factors which affected the probability of accident severity rate in motorcyclists. Three factors reviewed in this research were human factor, road and environment, and the condition of the vehicle. The factors were analyzed simultaneously to obtain the probability of accident severity in motorcyclists.

After obtaining several attributes that could affect the probability of accident severity using the Bayesian network method, some scenarios could be developed to reduce the probability of accident severity on the motorcyclists. The scenarios could be developed by changing the percentage of the attribute, which would also affect the probability of accident severity. Therefore, the best prevention can be developed as early as possible to minimize the risk of fatal injury due to an accident.

2. Materials and Methods

The research took place in Bekasi City, Indonesia. Bekasi has the largest commuter trips in the Jabodetabek area at around 2.43 million compared to other cities in Jabodetabek. Motorcycles comprised 58.19% of commuter trips in Jabodetabek and 94.6% of the commuter trips in this city have a travel time greater than 30 min. Therefore, Bekasi City was appropriate to enroll respondents for this study. To validate the model, data were also collected outside Bekasi City in the cities of Bandung, Yogyakarta, Pekanbaru, and Pasir Pengaraian.

The inclusion criteria for the respondents were motorcyclists who had experienced traffic crashes and at least 17 years old. Some attributes calculated in this study were gender, age, speed, fatigue, engine capacity, road side variability, road monotonous design, duration of driving, road conditions, and visibility. The data were collected by respondent interviews that took approximately 30 min. The number of respondents was determined based on Solvin technique approach with the following formula:

$$n = \frac{N}{1 + Ne^2} \tag{1}$$

where n = sample, N = population, and e = margin of error. It was known that the number of accident victims (N) involving motorcycles in 2015 in Bekasi was 474 people (Bekasi Police Department, 2016) and e = 10%.

$$n = \frac{474}{1 + 474\,(0.1)^2} = 82.578 \text{ respondents}$$

The number of samples collected was 246 respondents that consisted of 184 respondents of motorcyclists who had an accident and did not take a break on the way before the accident. Thirty-five respondents had an accident and took a break on their way before the accident, while 27 respondents did not have complete data.

This research used 184 respondents of motorcyclists who had an accident and did not take a break on the way before the accident. The data were then analyzed using the Bayesian network method. The Bayesian network originated from Bayes' theorem. Bayesian network is more suitable to predict the severity of an accident than the regression model (Zong, Xu, & Zhang, 2013). There are fundamental differences between the Bayesian method and the classical method. In the classical method, the population parameter is regarded as an unknown quantity. The Bayesian method regards the population parameter as a variable that has a prior distribution. In addition, the regression model does not allow 2 variables that have a strong correlation, which does not apply in Bayesian network. The Bayesian network analysis in this study used Software GeNIe 2.0. The variables and statistics based on data can be seen in Table 1. This theorem describes the relationship between the probability of the incident of event A and the previous incident of event B, which is formulated in the equation:

$$P(A|B) = \frac{P(B|A)\,P(A)}{P(B)} = \frac{P(B|A)\,P(A)}{P(B|A)\,P(A) + P(B|-A)\,P(-A)} \tag{2}$$

where P = probability, P(A|B) = posterior probability of structure A, P(A) = prior probability distribution of B, P(B) = probability distribution of data set B.

The indicator to measure the accuracy of the model was the mean absolute deviation (MAD), with the equation:

$$\frac{1}{2}\,\Sigma\,\left|\text{Actual - Forcast}\right| \tag{3}$$

Table 1. Variables and statistics.

Number	Variables	Value	Percentage
1	Gender	Male	73.37
		Female	26.63
2	Age	≤20 years old	68.48
		>20 years old	31.52
3	Speed	<50 km/h	52.17
		50-70 km/h	38.04
		>70 km/h	9.78
4	Fatigue before to accident	Yes	46.20
		No	53.80
5	Engine capacity	≤125 cm^3	84.24
		>125 cm^3	15.76
6	Road side variability	Variable	81.52
		Unvariable	18.48
7	Road monotonous design	Flat and straight	84.24
		Hills and bends	15.76
8	Long duration of driving	30 min	77.72
		45 min	14.13
		60 min	8.15
9	Road condition	Monotonous	41.30
		Unmonotonous	58.70

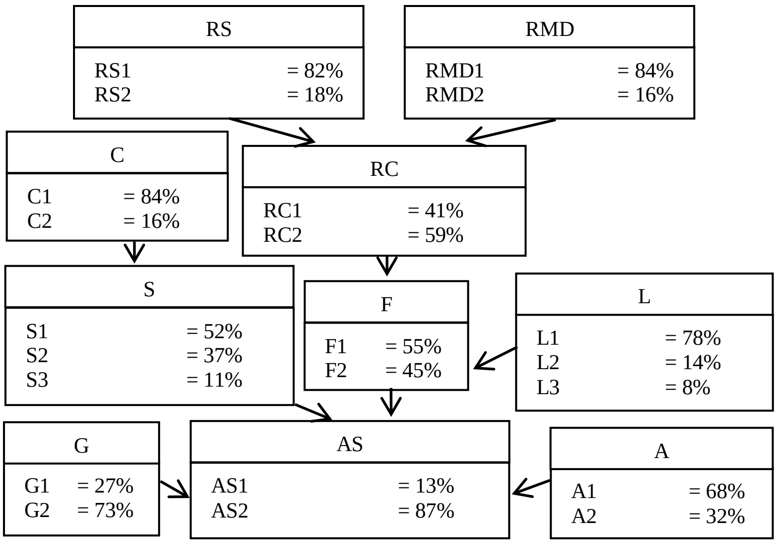
3. Results and Discussion

The structure of Bayesian network can be seen in Figure 1. Attributes that affected the probability crash included gender, age, speed, fatigue, engine capacity, road side variability, road monotonous design, duration of driving, and road condition. The results of the structure of the Bayesian network analysis indicated that the probability of a crash that resulted in severe injuries was 13%, whereas the probability of sustaining mild injuries was 87%. A calculation of probability crash severity for the existing model and scenario used the formula in the equation (Table 2).

The accuracy of the model in Table 2 was measured by calculating the mean absolute deviation (MAD). To calculate the value of MAD, new data were used that comprised 59 respondents (Table 3). For the validation of the 59 respondents, there were only 17 probabilities to occur. Meanwhile, the other 7 probabilities did not occur. In the Bayesian network method, the probability that does not occur, such as this probability could be assumed that the value fatal injury was 50% and minor injury was 50%. The validation process in this research used only the real value obtained from the respondents. The assumption value was not used in order to see the proximity between the actual value and the model value.

The probability calculation of the severity of accidents in Table 3 was directly affected by 4 variables, namely gender, fatigue, speed, and age. Therefore, the probability of accident severity was 48 possibilities that consisted of 24 possible severe injuries and 24 possible mild injuries. This was obtained from 2 options of gender response x 2 options of response to fatigue x 3 options of response to speed x 2 options of age response x 2 options of response to probability of accident severity.

The results of the model accuracy indicated that the value of MAD was 20.20% (Table 3). The deviations between the actual condition and the model were quite varied. The variations existed because the data used for validation were obtained from other cities outside Bekasi City such as Bandung, Yogyakarta, Pekanbaru, and Pasir Pengaraian cities. Meanwhile, the data used for analysis were from respondents



Where: RS=Road side variability, RS1=Variability, RS2=Unvariability, RMD=Road monotonous design, RMD1=Flat and Straight, RMD2=Hill and Bend, C=Engine capacity, C1 = ≤125 cm3, C2 = >125 cm3, RC=Road condition, RC1=Monotonous, RC2=Unmonotonous, A=Age, A1 = ≤ 20 years, A2 = > 20 years, L=Long duration of driving, L1=Time 30 min, L2=Time 45 min, L3=Time 60 min, G=Gender, G1=Female, G2=Male, F=Fatigue, F1=Not Fatigue, F2=Fatigue, S=Speed, S1 = ≤50 km/h, S2=50-70 km/h, S3 = >70 km/h, AS=Accident Severity, AS1=Severly injured, AS2=Mildly Injured

Figure 1. Structure of Bayesian Network

Table 2. Equations of probability accident severity.

P	P(G)	P(F)	P(A)	P(S)	P(AS)
1	G1	F1	A1	S1	P(AS)1 = P(AS|G1,F1,A1,S1,C,RC,L,RS,RMD) P(S1|C) P(F1|RC,L) P(RC|RS,RMD)
2	G1	F1	A1	S2	P(AS)2 = P(AS|G1,F1,A1,S2,C,RC,L,RS,RMD) P(S2|C) P(F1|RC,L) P(RC|RS,RMD)
3	G1	F1	A1	S3	P(AS)3 = P(AS|G1,F1,A1,S3,C,RC,L,RS,RMD) P(S3|C) P(F1|RC,L) P(RC|RS,RMD)
4	G1	F1	A2	S1	P(AS)4 = P(AS|G1,F1,A2,S1,C,RC,L,RS,RMD) P(S1|C) P(F1|RC,L) P(RC|RS,RMD)
5	G1	F1	A2	S2	P(AS)5 = P(AS|G1,F1,A2,S2,C,RC,L,RS,RMD) P(S2|C) P(F1|RC,L) P(RC|RS,RMD)
6	G1	F1	A2	S3	P(AS)6 = P(AS|G1,F1,A2,S3,C,RC,L,RS,RMD) P(S3|C) P(F1|RC,L) P(RC|RS,RMD)
7	G1	F2	A1	S1	P(AS)7 = P(AS|G1,F2,A1,S1,C,RC,L,RS,RMD) P(S1|C) P(F2|RC,L) P(RC|RS,RMD)
8	G1	F2	A1	S2	P(AS)8 = P(AS|G1,F2,A1,S2,C,RC,L,RS,RMD) P(S2|C) P(F2|RC,L) P(RC|RS,RMD)
9	G1	F2	A1	S3	P(AS)9 = P(AS|G1,F2,A1,S3,C,RC,L,RS,RMD) P(S3|C) P(F2|RC,L) P(RC|RS,RMD)
10	G1	F2	A2	S1	P(AS)10 = P(AS|G1,F2,A2,S1,C,RC,L,RS,RMD) P(S1|C) P(F2|RC,L) P(RC|RS,RMD)
11	G1	F2	A2	S2	P(AS)11 = P(AS|G1,F2,A2,S2,C,RC,L,RS,RMD) P(S2|C) P(F2|RC,L) P(RC|RS,RMD)
12	G1	F2	A2	S3	P(AS)12 = P(AS|G1,F2,A2,S3,C,RC,L,RS,RMD) P(S3|C) P(F2|RC,L) P(RC|RS,RMD)
13	G2	F1	A1	S1	P(AS)13 = P(AS|G2,F1,A1,S1,C,RC,L,RS,RMD) P(S1|C) P(F1|RC,L) P(RC|RS,RMD)
14	G2	F1	A1	S2	P(AS)14 = P(AS|G2,F1,A1,S2,C,RC,L,RS,RMD) P(S2|C) P(F1|RC,L) P(RC|RS,RMD)
15	G2	F1	A1	S3	P(AS)15 = P(AS|G2,F1,A1,S3,C,RC,L,RS,RMD) P(S3|C) P(F1|RC,L) P(RC|RS,RMD)
16	G2	F1	A2	S1	P(AS)16 = P(AS|G2,F1,A2,S1,C,RC,L,RS,RMD) P(S1|C) P(F1|RC,L) P(RC|RS,RMD)
17	G2	F1	A2	S2	P(AS)17 = P(AS|G2,F1,A2,S2,C,RC,L,RS,RMD) P(S2|C) P(F1|RC,L) P(RC|RS,RMD)
18	G2	F1	A2	S3	P(AS)18 = P(AS|G2,F1,A2,S3,C,RC,L,RS,RMD) P(S3|C) P(F1|RC,L) P(RC|RS,RMD)
19	G2	F2	A1	S1	P(AS)19 = P(AS|G2,F2,A1,S1,C,RC,L,RS,RMD) P(S1|C) P(F2|RC,L) P(RC|RS,RMD)
20	G2	F2	A1	S2	P(AS)20 = P(AS|G2,F2,A1,S2,C,RC,L,RS,RMD) P(S2|C) P(F2|RC,L) P(RC|RS,RMD)
21	G2	F2	A1	S3	P(AS)21 = P(AS|G2,F2,A1,S3,C,RC,L,RS,RMD) P(S3|C) P(F2|RC,L) P(RC|RS,RMD)
22	G2	F2	A2	S1	P(AS)22 = P(AS|G2,F2,A2,S1,C,RC,L,RS,RMD) P(S1|C) P(F2|RC,L) P(RC|RS,RMD)
23	G2	F2	A2	S2	P(AS)23 = P(AS|G2,F2,A2,S2,C,RC,L,RS,RMD) P(S2|C) P(F2|RC,L) P(RC|RS,RMD)
24	G2	F2	A2	S3	P(AS)24 = P(AS|G2,F2,A2,S3,C,RC,L,RS,RMD) P(S3|C) P(F2|RC,L) P(RC|RS,RMD)
					Σ P(AS)

P = Probability; AS = Accident Severity; G = Gender; G1 = Female; G2 = Male; F = Fatigue; F1 = Not Fatigued; F2 = Fatigue; A = Age; A1 = ≤20 years; A2 = >20 years; S = Speed; S1 = ≤50 km/h; S2 = 50-70 km/h; S3 = >70 km/h; C = Engine capacity; RC = Road condition; L = Long duration of driving; RS = Road side variability; RMD = Road monotonous design.

in Bekasi City. In addition, the differences in motorcyclist characters and behaviors in one region were highly likely to affect the probability of accident severity.

Females were more likely to suffer severe injuries than males (Figures 2 and 3). The data indicated that 66.67% of female drivers violated traffic regulations before the accident, while 33.33% of male drivers violated traffic regulations before the accident. Males are less likely to ignore the traffic rules than females (Susilo, Joewono, & Vandebona, 2014). This result was not in accordance with the studies conducted by (Vorko-Jovic, Kern, & Biloglav, 2005).

Table 3. The Calculation of the mean absolute deviation (MAD) value.

Probability	Gender	Fatigue	Speed (Km/h)	Age	Number of respondents		Probability of severely injured		Deviation %
					Severely injured (respondent)	Mildly injured (respondent)	Actual %	Model %	
1	F	No	< 50	≤ 20	1	1	50.00	12.00	38.00
2	F	No	< 50	> 20	5	10	33.33	32.00	1.33
3	F	No	50-70	≤ 20	1	4	20.00	13.00	7.00
4	F	No	50-70	> 20	0	2	0.00	50.00	50.00
8	F	Yes	< 50	> 20	0	1	0.00	7.00	7.00
9	F	Yes	50-70	≤ 20	0	1	0.00	3.00	3.00
10	F	Yes	50-70	> 20	0	1	0.00	50.00	50.00
13	M	No	< 50	≤ 20	0	2	0.00	5.00	5.00
14	M	No	< 50	> 20	1	2	33.33	13.00	20.33
15	M	No	50-70	≤ 20	0	2	0.00	9.00	9.00
16	M	No	50-70	> 20	0	7	0.00	6.00	6.00
19	M	Yes	< 50	≤ 20	0	4	0.00	12.00	12.00
20	M	Yes	< 50	> 20	0	4	0.00	13.00	13.00
21	M	Yes	50-70	≤ 20	0	5	0.00	9.00	9.00
22	M	Yes	50-70	> 20	2	1	66.67	1.00	65.67
23	M	Yes	> 70	≤ 20	0	1	0.00	18.00	18.00
24	M	Yes	> 70	> 20	0	1	0.00	29.00	29.00
Number of Respondent 10 + 49 = 59					10	49			
Mean Absolute Deviation (MAD)									20.20

M=Male, F=Female

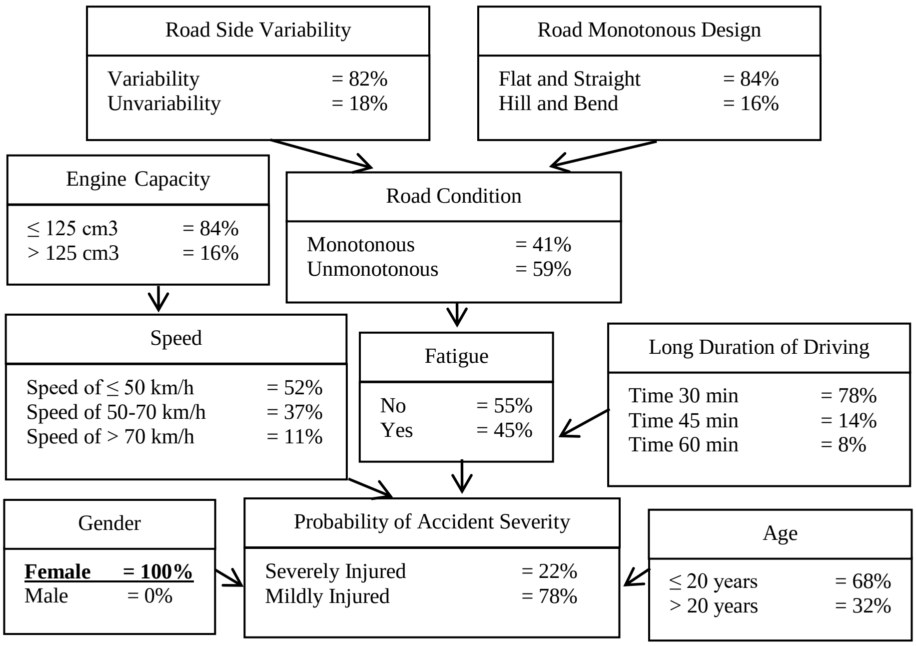


Figure 2. Scenario 1

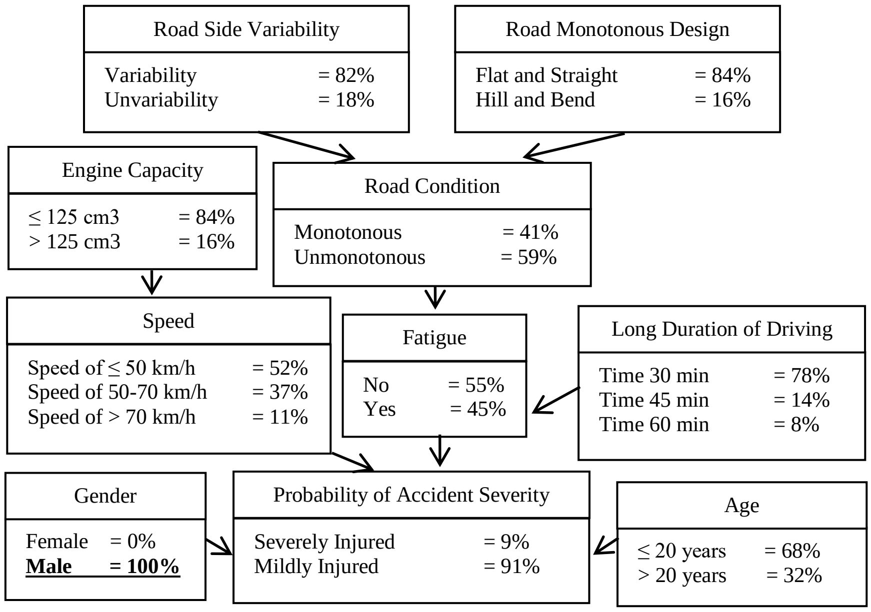


Figure 3. Scenario 2

Drivers aged 20 years and older were more likely to suffer severe injuries than those aged 20 years and younger (Figures 4). This study is in accordance with the studies conducted by (Vorko-Jovic, Kern, & Biloglav, 2005; Yannis, Golias, & Papadimitriou, 2004). This study is in not accordance with the studies conducted by (Clarke, Ward, Bartle, & Truman, 2009; Lapparent, 2005). In addition, the data indicated that 35.29% of drivers aged 20 years and older had experienced fatigue before the crash, and 33.8% of drivers aged 20 years and younger had experienced fatigue before the crash. Other research related to this study was conducted (Clarke, Ward, Bartle, & Truman, 2009; Dotzauer, Waard, Caljouw, Pöhler, & Brouwer, 2014). Drivers who were 25 years old were less likely to perceive their risk of crash while 30%-70% of middle-aged drivers were likely to perceive the risk of crash. Drivers aged between 60 and 64 and above were more likely to contribute to a crash and in general it was a right-turn crash at an intersection (Clarke, Ward, Bartle, & Truman, 2009). Young drivers have a maximum velocity which is significantly higher than older drivers (Dotzauer, Waard, Caljouw, Pöhler, & Brouwer, 2014). In addition, the data indicated that 35.29% of drivers aged 20 years and older had experienced fatigue before the crash, and 33.8% of drivers aged 20 years and younger had experienced fatigue before crash.

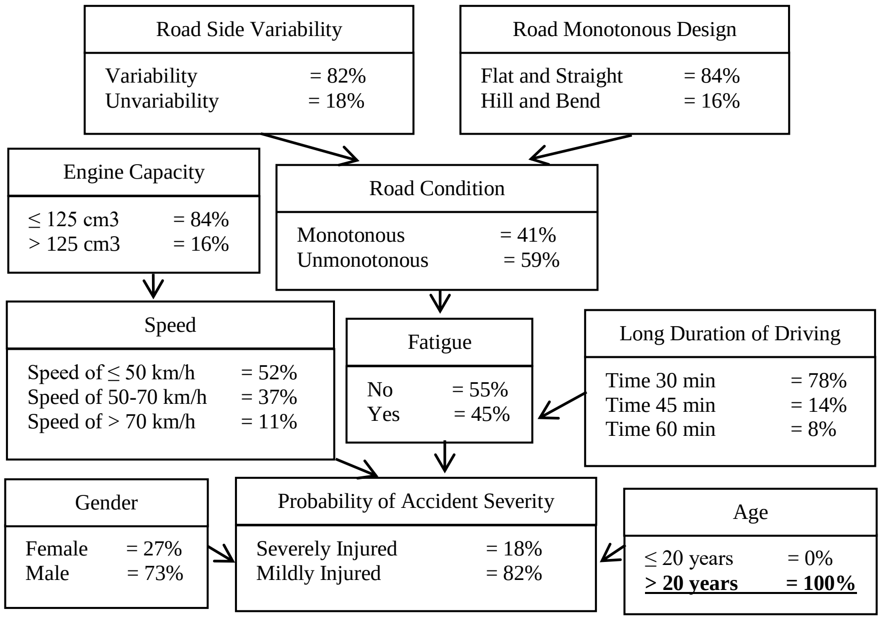


Figure 4. Scenario 3

Motorcycles which have engine capacity above 125 cm3 were 14% more likely to experience crashes with severe injuries and motorcycles with engine capacity 125 cm3 and below were 12%. In the scenario of a motorcycle with an engine capacity > 125 cm3, the probability of drivers at a speed < 50 km/h decreases from 56% to 29%, while the probability of drivers with a speed of 50-70 km/h increases from 35% to 50%, and so is for drivers at a speed > 70 km/j increasing from 9% to 21%, as shown in Figure 5 and 6. This study is in accordance with the studies conducted by (Teoh & Campbell, 2010; Yannis, Golias, & Papadimitriou, 2004; Gray, Quddus, & Evans, 2008; Bjørnskau, Nævestad, & Akhtar, 2011).

Driving on roads which have road side variability and driving on curvy roads would be able to decrease the level of monotonous driving from 41% to 21%, and decrease the probability of fatigue from 45% to 44% (Figure 7). This study is in accordance with the studies conducted by (Laruea, Rakotonirainya, & Pettitt, 2011; Thiffault & Bergeron, 2003a).

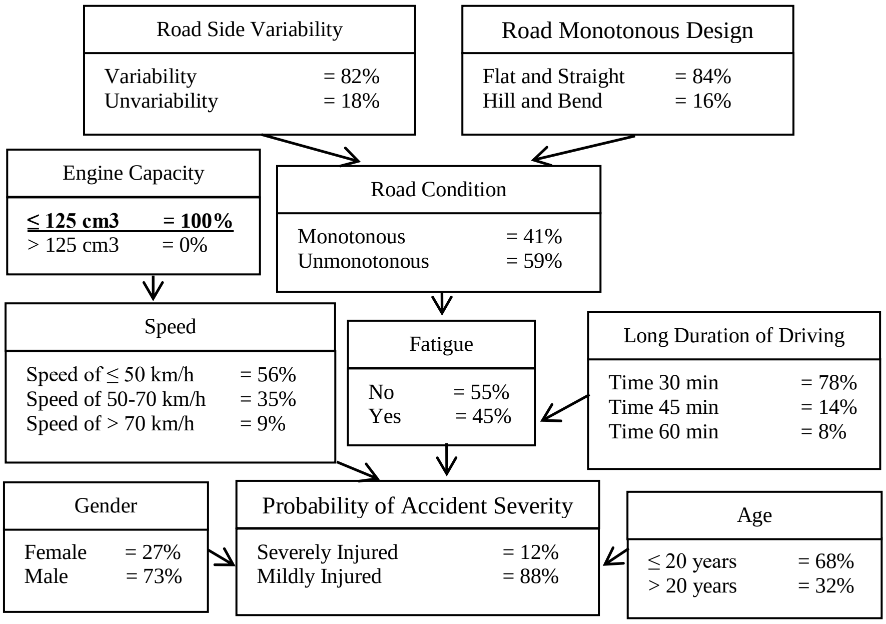


Figure 5. Scenario 4

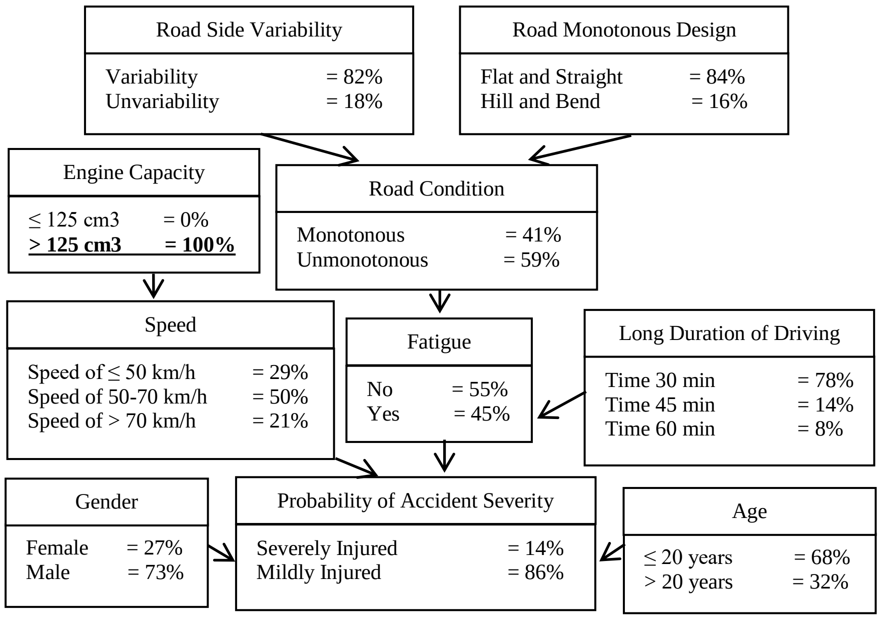


Figure 6. Scenario 5

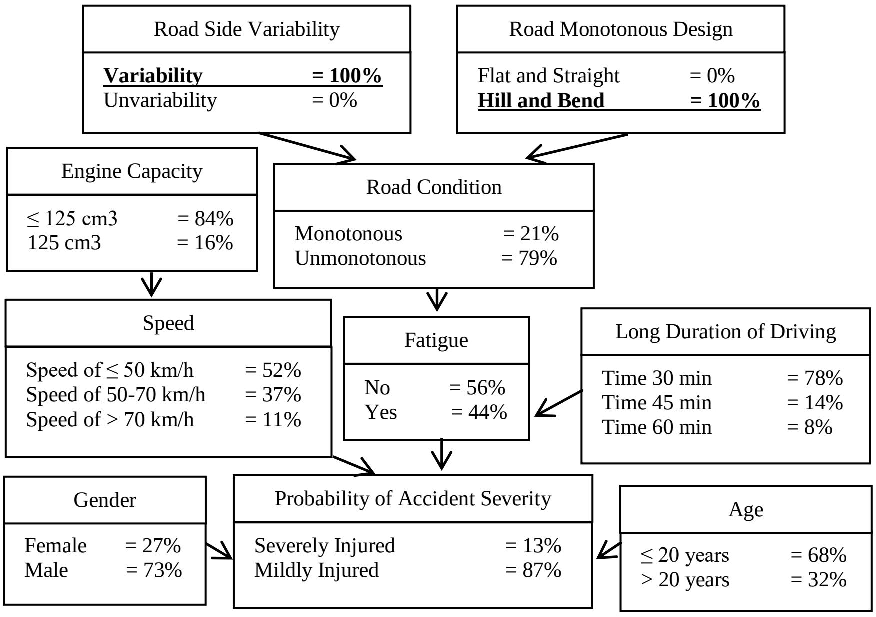


Figure 7. Scenario 6

4. Conclusions

Attributes that affect the probability of severe crashes are caused by human, road and environment, and vehicle factors that include gender, age, speed, fatigue, machine capacity, road side variability, road monotonous design, duration of driving, and road condition. The results of the analysis indicated that the probability of a crash resulting in severe injuries was 13%, while the probability of sustaining mild injuries was 87%. Driving on roads which have road side variability and driving on curvy roads would be able to decrease the level of monotonous driving from 41% to 21%. Motorcycles with an engine capacity above 125 cm^3 are more likely to suffer severe injuries than motorcycles with an engine capacity 125 cm^3 and below. Approximately 46.20% of crashes took place due to fatigue and 68.48% of crashes involved motorcyclists aged 20 years and younger. In addition, speeding is more likely to increase the probability of crash severity.

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