Effects of Sleep Duration on the Probability of Accident in Motorcyclists

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Abstract: This research focuses on the effects of duration of sleep the night before an accident on the probability of an accident on motorcyclists. Data of accidents occurring from July to December 2015 in Indonesia indicate that 70.93% of traffic accidents involved motorcycles. The research took place in Bekasi, Indonesia. The sample consisted of 202 respondents who had been involved in an accident. Attributes that affect the probability of an accident include: trip duration, road side variability, road geometry, road condition, driving time, age, fatigue, 1-year mileage. The results of analysis showed that the probability of accidents occurring for drivers who got 6 hours or less of sleep was 51%, and 27% for those who got sleep over 6 hours to 7 hours, and 22% for those who got sleep over 7 hours.

Keywords : Accident, Bayesian, Probability

1. INTRODUCTION

Based on the data of Statistics Indonesia (BPS) from 2010, 2011, 2012, the number of accidents increased in each period by 66,488 cases, 108,696 cases and 117,949 cases respectively (BPS, 2011; BPS, 2012; BPS, 2013). However, in 2013 the number of accidents declined by 100,106 cases of accidents BPS (2014). Road users in the 15-25 age group are highly vulnerable to traffic accidents in Indonesia as indicated by the number of accident victims, namely 462 victims of fatal accidents, 531 victims with serious injuries, 2,797 victims with slight injuries Korlantas Polri (2015). Based on vehicle type, the data of accidents occurring from July 1, 2015 until December 31, 2015 in Indonesia show that the number of motorcycles involved in traffic accidents was very high compared to other vehicles by 70.93% or 30,628 accidents Korlantas Polri (2015). Several factors may cause accidents, including: human error, road and environment, as well as vehicle condition. Of these three factors, 75% of accidents are caused by human error, one of which is due to fatigue suffered by the driver. Previous studies have examined the effects of duration of sleep the night before the accident on the accident in motorists. However, the study on the duration of sleep the night before the accident on the accident in motorcyclists has not been conducted, particularly in motorcyclists who do not take a rest on their trip before the accident. Therefore, it is necessary to conduct a research related to the reduction of the risk of accidents, particularly in motorcyclists. In addition, the research on the probability of an accident in drivers who get 6-hours and less of sleep the night before the accident has not been conducted, except for the drivers who get less than 5 hours of sleep the night before the accident. This research aims to reduce the risk of accidents in motorcyclists by identifying attributes that affect the probability of accidents due to the effects the duration of sleep the night before the accident.

2. LITERATURE REVIEW

A study in Northern California in 1998 with a sample size of 1403 people shows that drivers who had accidents due to falling asleep are likely driving 20,000 miles or more per year, driving 2 hours or more per day, and driving at night while it is dark outside or driving between midnight and 6 am Stutts *et al*. (2001). A study in Northern California in 1998 with a sample size of 1403 people, of which 312 participants had accidents due to falling asleep, 155 participants had accidents due to fatigue, 529 participants had accidents not related to sleep and fatigue, and 407 participants did not have accidents. Work factors related to the accidents due to falling asleep include: part-time job, night shift, work schedules, and working 60 hours or more per week. In addition, drivers who on average sleep less than five hours each night have nearly 5-fold higher of having accidents. Moreover, more than half of drivers who had accidents due to falling asleep had slept less than six hours before the accident, and a third had slept less than five hours, and almost 1 of 5 drivers who had accidents due to falling asleep reportedly stayed awake for 20 hours or more before the accident. Sleep disorders do not significantly affect the accidents due to falling sleeping, but high levels of sleepiness during the day will likely increase accidents due to falling asleep Stutts *et al*. (2001). A study conducted in a laboratory and on motorways in France in 2003 with a sample size of 20 men, where the subjects whose sleep was restricted used improper lane by 8.1 times compared to drivers whose sleep was normal, and there was no correlation between the number of trips a year with the number of violations Philip *et al.* (2003). Driving for long periods of time will reduce driver reaction time. Driver reaction time correlates with variations of driver performance in driving (pre-test) Ting *et al*. (2007). Samples of more than 2000 accidents involving drivers aged 60 years or older in the United Kingdom (UK) from 1994 to 2007 indicate that fatigue-related accidents in old drivers were concentrated in the afternoon, and almost half of the accidents occurred in 4 hours between noon to 4 pm Clarke *et al*. (2009). Driver fatigue is caused by several factors: lack of rest, long duration of trip, and monotonous road Ma *et al*. (2003). Monotonous while driving are influenced by: road design monotony and roadside variability, which can reduce the vigilance level of the driver rapidly. The vigilance will reduce when the road is straight, but the vigilance will increases on the turn Laruea *et al*. (2011). Monotonous roads, long duration of driving, and lack of rest can cause fatigue in drivers Ma *et al*. (2003). Monotonous road conditions and low-level traffic volume will likely cause fatigue earlier Thiffault and Bergeron (2003a).

Bayesian Network (BN) is based on Bayes' theorem. Bayesian Network (BN) is a Directed Acyclic Graph and is equipped with Conditional Probability distribution Table for each node. Node represents a variable domain and arrow between nodes represents a probabilistic dependency Pearl and Russel (2001). Bayes' is used to calculate the probability of the occurrence of an event based on the influence obtained from the observation. This theorem describes the correlation between the probability of occurrence of event A on condition that event B has occurred, which is formulated in the equation :

$$P(A|B) = \frac{P(B|A)\, P(A)}{P(B)} = \frac{P(B|A)\, P(A)}{P(B|A)\, P(A) + P(B|-A)\, P(-A)} \quad (1)$$

Some examples of pictures and Bayesian calculation are shown in Figure 1.
Probability of accident in Figure 1(a) can be calculated :

P(PAcc) = P(PAcc | ≤ 20 years) P(≤ 20 years) + P(PA | > 20 years) P(> 20 years).

Probability of Accident in Figure 1(b) can be calculated :
P(PAcc) = P(PAcc|Age ≤ 20 years, Female) P(Age ≤ 20 years) P(Female) + P(PA|Age ≤ 20 years, Male) P(Age ≤ 20 Years) P(Male) + P(PA|Age > 20 years, Female) P(Age > 20 years) P(Female) + P(PA|Age > 20 years , Male) P(Age > 20 years) P(Male).

Where, P=Probability, PAcc=Probability of Accident.

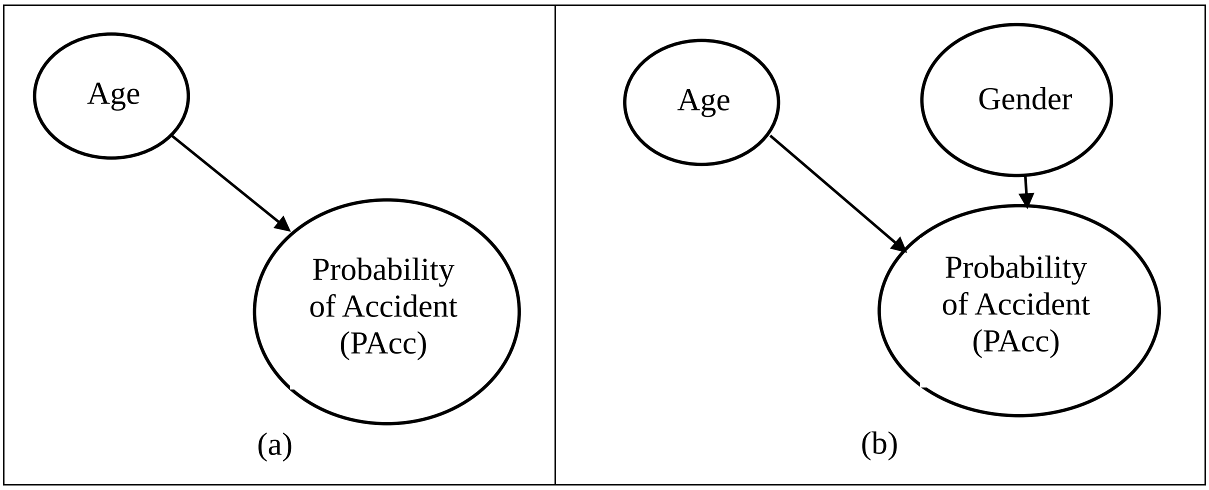

Figure 1. Examples Bayesian Network

The accuracy of model is measured by considering the value of error, which is a deviation between the results of model and actual data. The type of error in this research used as an indicator to measure the accuracy of the model was the Mean Absolute Deviation (MAD), with the formula :

$$\frac{1}{n} \Sigma \left| \text{Actual - Forecast} \right| \qquad (2)$$

3. METHOD

The research took place in Bekasi, Indonesia. Bekasi was chosen as the location for the study because it has the largest commuter line in Jabodetabek, around 2.43 million compared to other cities in Jabodetabek (Indonesia). Approximately 58.19% of commuter trips in Jabodetabek use the mode of motorcycles. In addition, 94.6% of commuter trips in the city of Bekasi have a travel time of over 30 minutes. Therefore, the city is appropriate to look for respondents for this study. The data were collected from April to June 2016. Criteria for the respondents are motorcyclists who had experienced a traffic accident with a minimum age of 17 years old. The data were collected by interviews where each respondent took time approximately 30 minutes. Several attributes calculated in this research were: long duration of driving, road side variability, road geometry, road condition, age, driving time, fatigue, miliage for 1 year, and sleep duration before accident. The calculation of samples use solvin technique approach with formula :

$$n = \frac{N}{1+Ne^2} \qquad (3)$$

Where: n = samples, N = populationt (the number of accident victims involved motorcycle in

Bekasi City in 2015 are 474 victims (Polresta Bekasi, 2016), and e (margin of error) = 10%

$$n = \frac{474}{1 + 474\,(0,1)^2} = 82.578 \text{ respondents}$$

The samples of this study consisted of 202 respondents who had experienced an accident. The data then, were analyzed using the Bayesian Network method, which indicates a causal relationship between the variables contained in the structure of Bayesian network and this Bayesian network was built with the conditional probability approach. The Bayesian Network analysis in this research used Software GeNIe 2.0. Meanwhile, in order to validate the model, data were also collected outside Bekasi. The characteristics of respondents and accident location based on the perception of respondents are shown in Table 1. Accidents occured more frequently on a 30 minute trip duration than those on other trip duration.

Table 1. Variables and statistics

Number	Variable	*Value*	Persentase
1	Long duration of driving	30 Minute	76.73
		60 Minute	20.30
		> 60 Minute	2.97
2	Road side variability	Variability	79.70
		Not variability	20.30
3	Road geometry	Flat and straight	85.15
		Hilly and winding	14.85
4	Road Condition	Monotonous	42.08
		Unmonotonous	57.92
5	Age	< 20 Year	48.51
		20 Year ≤ Age <30 Year	48.02
		≥ 30 Year	3.47
6	Driving time	06.00 s/d 12.00	36.63
		12.00 s/d 18.00	41.58
		18.00 s/d 24.00	17.82
		24.00 s/d 06.00	3.96
7	Fatigue	Yes	46.80
		No	53.20
8	Mileage for 1 year	> 20000 mile	5.45
		< 20000 mile	94.55
9	Sleep duration	≤ 6 hour	50.5
		6 hour < x ≤7 hour	27.23
		x ≥7 hour	22.28

4. RESULTS AND DISCUSSION

Bayesian Network structure in this research has several attributes that affect the probability of accidents, namely: long duration of driving, road side variability, road geometry, road condition, age, driving time, fatigue, miliage for 1 year, and sleep duration before accident.

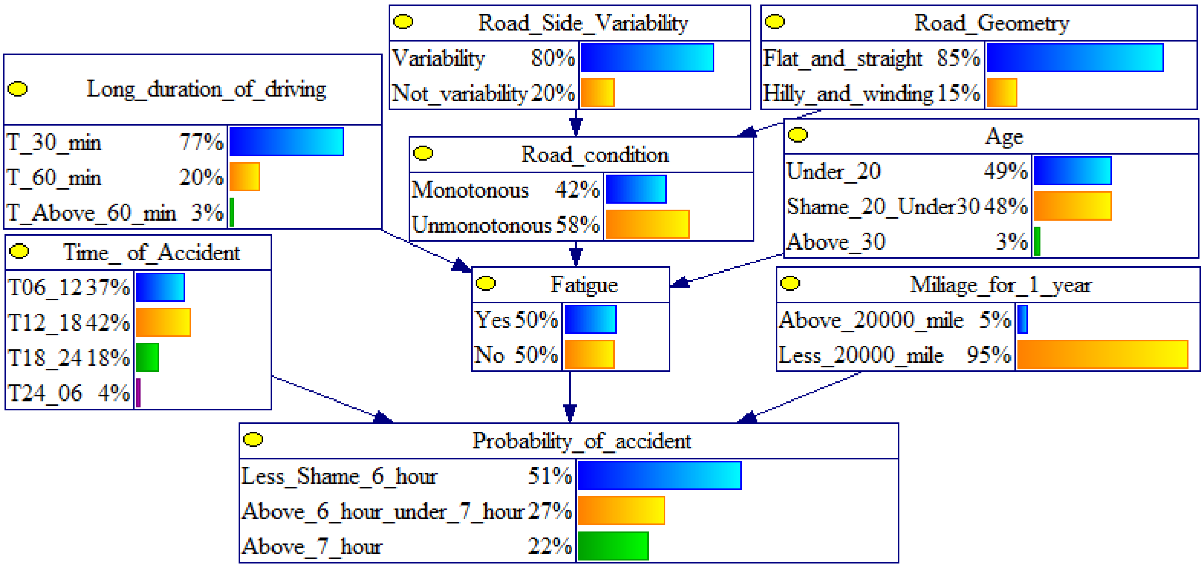

Figure 2. Structure of bayesian network

Beside the bayesian network analysis in this study used Software GeNIe 2.0, the calculation of probability of accident for existing model and scenario of model can use equation, as shown in Table 2. Several attributes influenced probability of accident namely : driving time (4 answer), fatigue (2 answer), miliage for 1 year (2 answer). Therefore, there are 48 probability of accident (16 probability of accident for drivers who got 6 hours and less of sleep the night before the accident, 16 probability of accident for those who got over 6 hours to 7 hours of sleep the night before the accident and 16 probability of accident for those who got over 7 hours of sleep the night before the accident).

Table 2. The equation of probability of accident

P	P(T)	P(F)	P(M)	P(Acc)
1	T1	F1	M1	P(Acc)1 = P(Acc|T1,F1,M1,A,RC,L,RS,RG) P(F1|L,RC,A) P(RC|RS,RG)
2	T1	F1	M2	P(Acc)2 = P(Acc|T1,F1,M2,A,RC,L,RS,RG) P(F1|L,RC,A) P(RC|RS,RG)
3	T1	F2	M1	P(Acc)3 = P(Acc|T1,F2,M1,A,RC,L,RS,RG) P(F2|L,RC,A) P(RC|RS,RG)
4	T1	F2	M2	P(Acc)4 = P(Acc|T1,F2,M2,A,RC,L,RS,RG) P(F2|L,RC,A) P(RC|RS,RG)
5	T2	F1	M1	P(Acc)5 = P(Acc|T2,F1,M1,A,RC,L,RS,RG) P(F1|L,RC,A) P(RC|RS,RG)

6	T2	F1	M2	P(Acc)6 = P(Acc|T2,F1,M2,A,RC,L,RS,RG) P(F1|L,RC,A) P(RC|RS,RG)
7	T2	F2	M1	P(Acc)7 = P(Acc|T2,F2,M1,A,RC,L,RS,RG) P(F2|L,RC,A) P(RC|RS,RG)
8	T2	F2	M2	P(Acc)8 = P(Acc|T2,F2,M2,A,RC,L,RS,RG) P(F2|L,RC,A) P(RC|RS,RG)
9	T3	F1	M1	P(Acc)9 = P(Acc|T3,F1,M1,A,RC,L,RS,RG) P(F1|L,RC,A) P(RC|RS,RG)
10	T3	F1	M2	P(Acc)10 = P(Acc|T3,F1,M2,A,RC,L,RS,RG) P(F1|L,RC,A) P(RC|RS,RG)
11	T3	F2	M1	P(Acc)11 = P(Acc|T3,F2,M1,A,RC,L,RS,RG) P(F2|L,RC,A) P(RC|RS,RG)
12	T3	F2	M2	P(A)12 = P(A|T3,F2,M2,A,RC,L,RS,RG) P(F2|L,RC,A) P(RC|RS,RG)
13	T4	F1	M1	P(Acc)13 = P(Acc|T4,F1,M1,A,RC,L,RS,RG) P(F1|L,RC,A) P(RC|RS,RG)
14	T4	F1	M2	P(Acc)14 = P(Acc|T4,F1,M2,A,RC,L,RS,RG) P(F1|L,RC,A) P(RC|RS,RG)
15	T4	F2	M1	P(Acc)15 = P(Acc|T4,F2,M1,A,RC,L,RS,RG) P(F2|L,RC,A) P(RC|RS,RG)
16	T4	F2	M2	P(Acc)16 = P(Acc|T4,F2,M2,A,RC,L,RS,RG) P(F2|L,RC,A) P(RC|RS,RG)
				Σ P(Acc)

Where: P=Probability, Acc=Accident, T=Time of accident, T1 ≤ 30 minute, T2 > 30 minute and ≤ 60 minute, T3 > 60 minute, F=Fatigue, F1=Not Fatigue, F2=Fatigue, M=Miliage for 1 year, M1>20000 mile, M2<20000 mile, A=Age, L=Long duration of driving, RC=Road condition, RS=Road side variability, RG=Road geometry.

The results of analysis with 202 respondents indicated that the probability of accidents was 51% for drivers who got 6 hours and less of sleep the night before the accident, and 27% for those who got over 6 hours to 7 hours of sleep the night before the accident, and 22% for those who got over 7 hours of sleep the night before the accident as shown in Figure 2. The motorcyclists who sleep more than 6 hours to 7 hours and over 7 hours did not indicate significant difference in the probability of accidents.

Table 3. The Calculation of the value of Mean Absolute Deviation (MAD)

Probability	Time of Accident	Fatigue	Mileage for 1 year	Probabity of accident		Difference %
				Actual	Model	
				≤ 6 hour	≤ 6 hour	
2	06.00 s/d 12.00	Yes	< 20000	85.71	71.00	14.71
4	06.00 s/d 12.00	No	< 20000	22.22	55.00	32.78
6	12.00 s/d 18.00	Yes	< 20000	33.33	50.00	16.67
8	12.00 s/d 18.00	No	< 20000	62.50	38.00	24.50
12	18.00 s/d 24.00	No	< 20000	100.00	50.00	50.00
Mean Absolute Deviation						27.73

The accuracy rate of Bayesian Network Model was measured by calculating the Mean Absolute Deviation (MAD). In calculating the value of MAD, new data used 32 respondents who had been involved in accidents, which were obtained from outside Bekasi City. The results of the model calculation accuracy indicated that the MAD value was 27.73%, or the average absolute deviation of the model was 27.73%, as shown in Table 3. The correlation between trip duration and the probability of accidents and the correlation between trip duration and the probability of fatigue can be seen in Figure 3, 4, and 5.

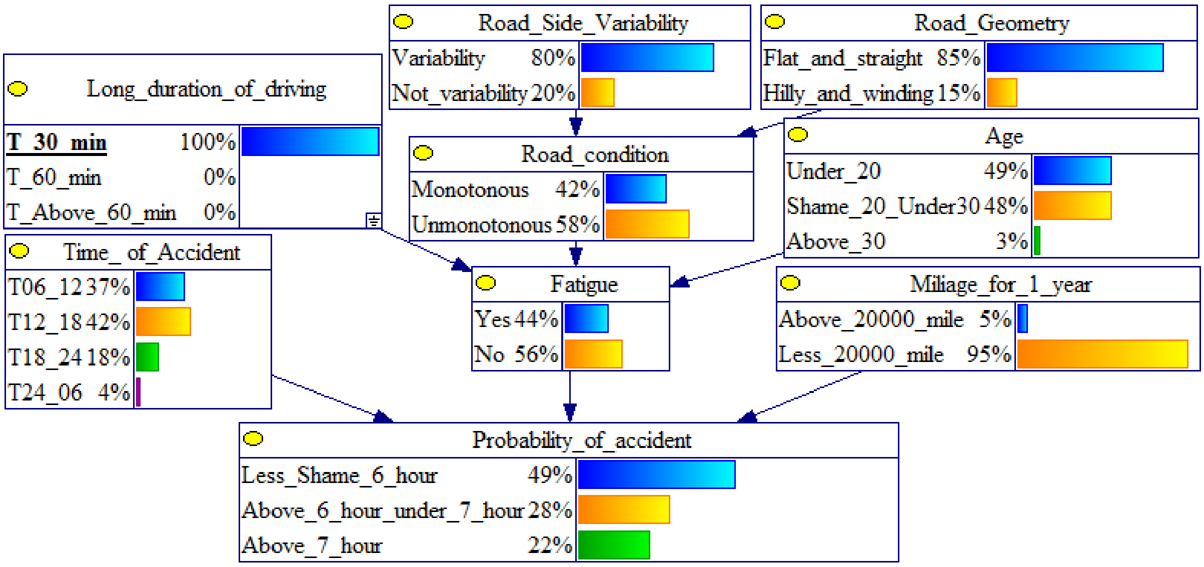

Figure 3. Correlation between the probability of accident and 30 minute and below long duration of driving

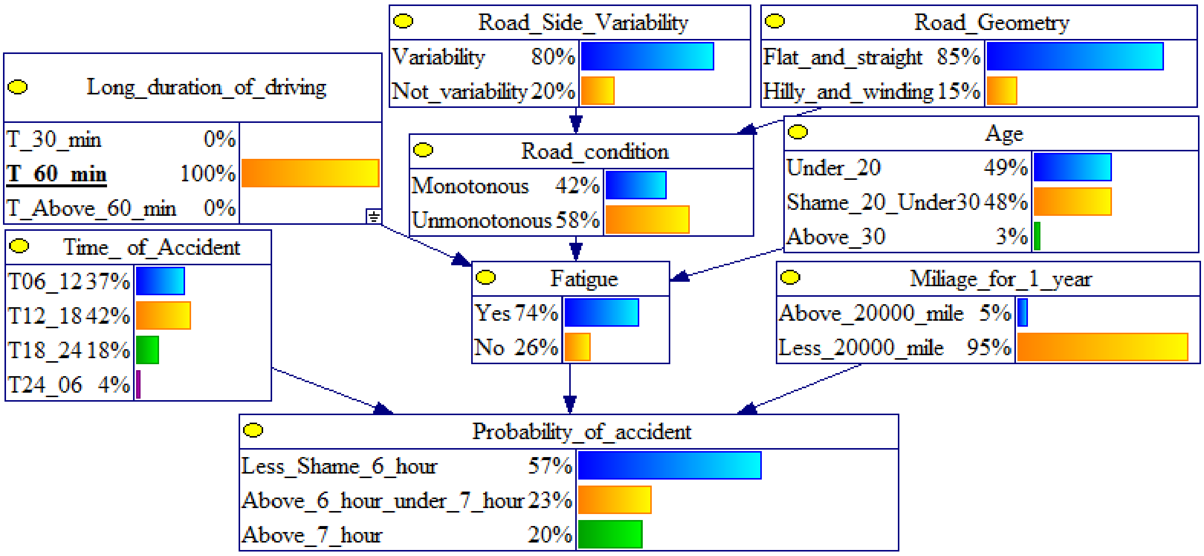

Figure 4. Correlation between the probability of accident and above 30 minute and 60 minute and below long duration of driving

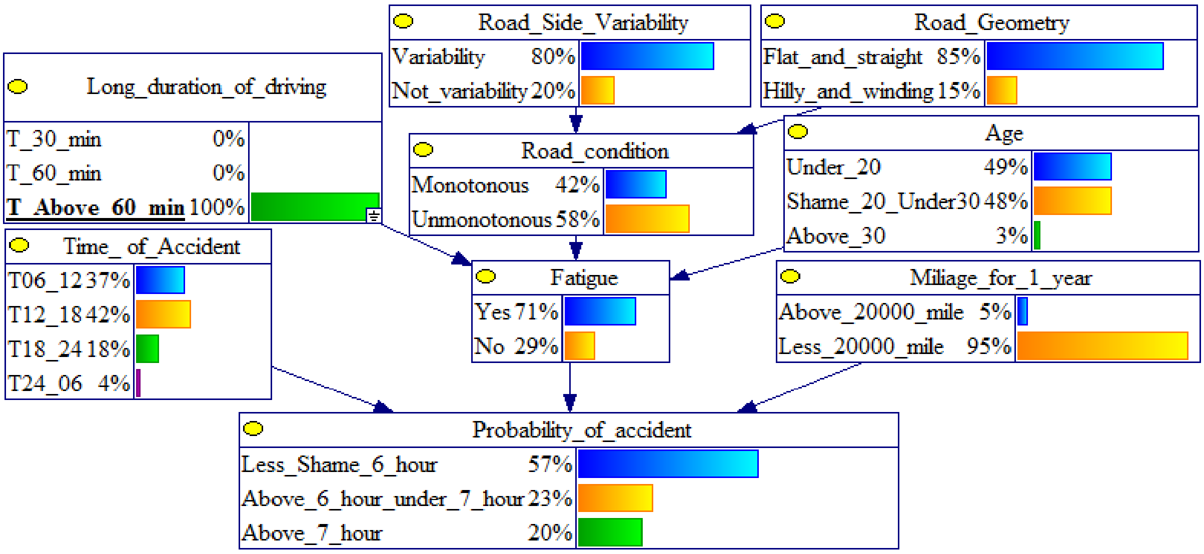

Figure 5. Correlation between the probability of accident and above 60 minute long duration of driving

The longer the trip duration is, the higher the probability of accidents and the higher the probability of fatigue in the driver will be. Previous related research states that driving in long periods of time will reduce driver reaction time. Driver reaction time correlates with variations in the driver performance in driving Ting *et al*. (2007).

Table 4. Correlation between long duration of driving with the probability of accident and probability of fatigue

Long duration of driving	Probability of Fatigue	Probability of accident		
		≤ 6 hour	6 hour < Sleep ≤ 7 hour	> 7 hour
30 min	43.5	49.2	28.5	22.3
60 min	73.9	57.5	22.7	19.8
> 60 min	70.5	56.5	23.4	20.1

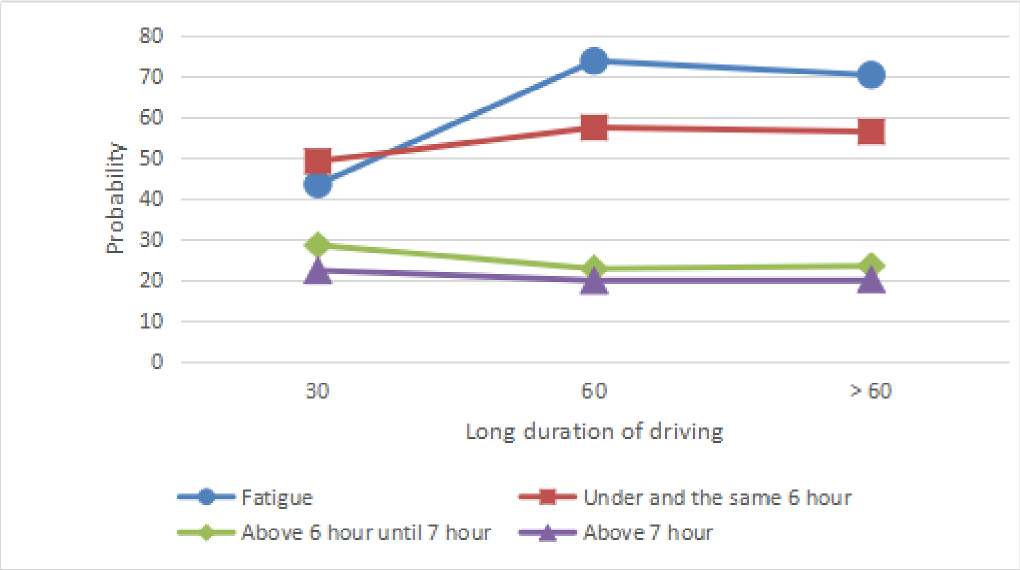

Figure 6. Correlation between long duration of driving with the probability of accident and probability of fatigue

The recapitulation of the correlation between trip duration and the probability of accidents and the correlation between trip duration and the probability of fatigue is shown in Table 4 and Figure 6. A 60-minute trip duration in the Bayesian network structure indicates a probability of maximum fatigue by 73.9%.

Motorcyclists who had an average annual total trips of over 20,000 miles had a probability of accidents by 73% for those who got 6 hours and less of sleep the night before the accident, and 16% for those who got over 6 hours to 7 hours of sleep the night before the accident, and 11% for those who got over 7 hours of sleep the night before the accident as shown in Figure 7.

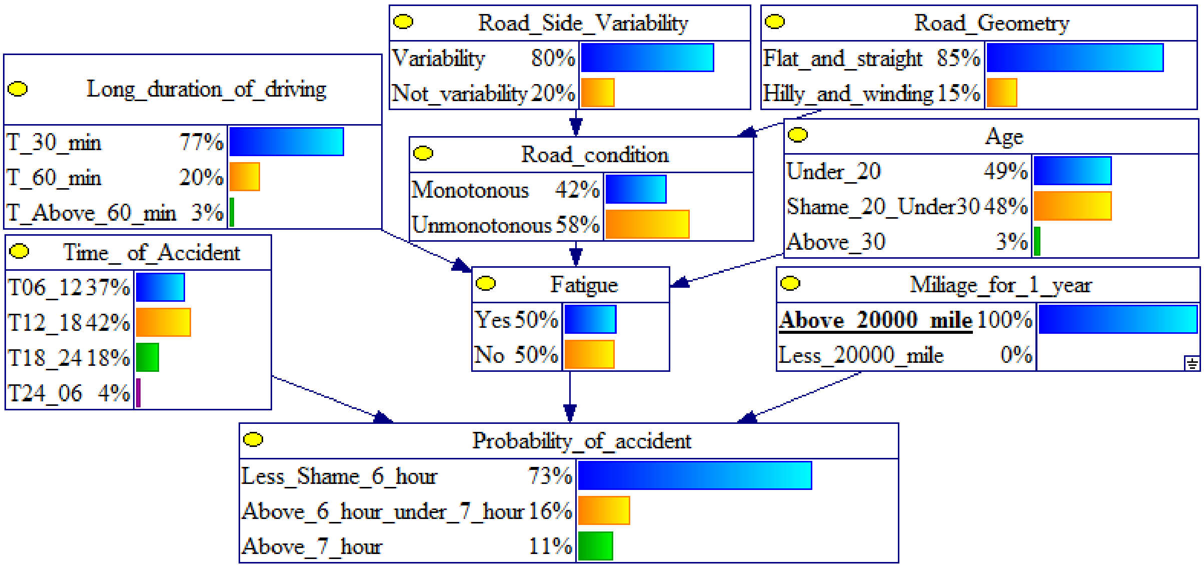

Figure 7. Correlation between mileage for above 20000/year mile year with the probability of accident

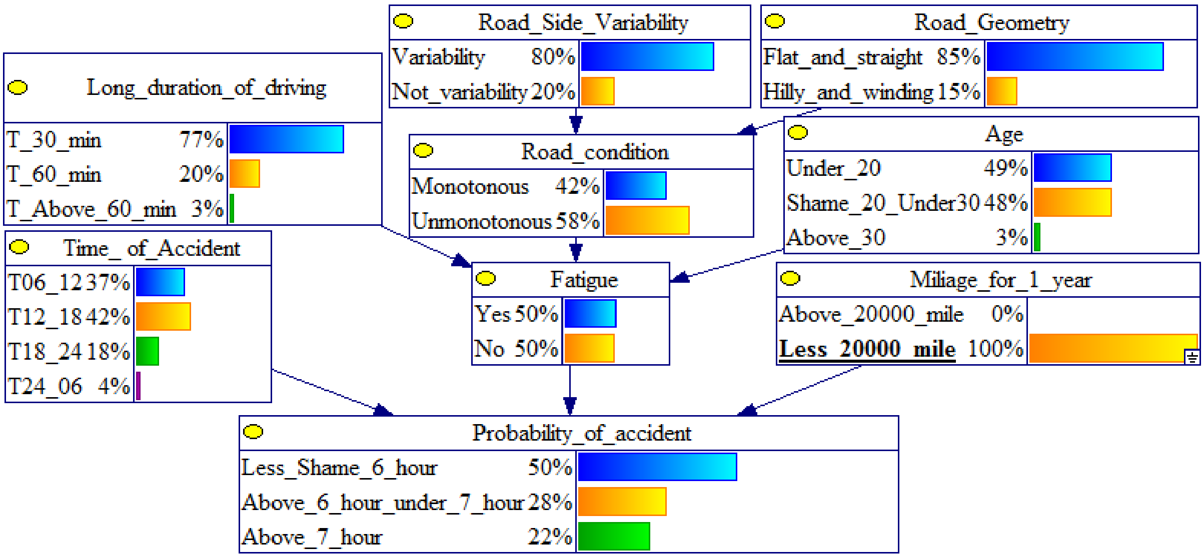

Figure 8. Correlation between mileage for less 20000 mile/year with the probability of accident

On the contrary, the motorcyclists who had an average annual total trips of less than 20,000 miles had a probability of accidents by 50% for those who got 6 hours and less of sleep the night before the accident, and 28% for those who got over 6 hours to 7 hours of sleep the night before the accident, and 22% for those who got over 7 hours of sleep the night before the accident as shown in Figure 8. Another related study states that the drivers who had been involved in accidents due to falling asleep are likely driving 20,000 miles or more per year, driving 2 hours or more per day, and driving at night while it is dark outside or driving between midnight and 6 am Stutts *et al*. (2001).

Drivers aged 20 and below and drivers aged between over 20 years and 30 years indicate the same probability of the accidents and the same probability of fatigue as shown in Figure 9 and 10. However, the probability of accidents and the probability fatigue increase in the drivers aged over of 30 years as shown in Figure 11. Related research states that fatigue-related accidents in old drivers are concentrated in the afternoon, and almost half of the accidents occur within 4 hours between noon to 4 pm Clarke *et al*. (2009).

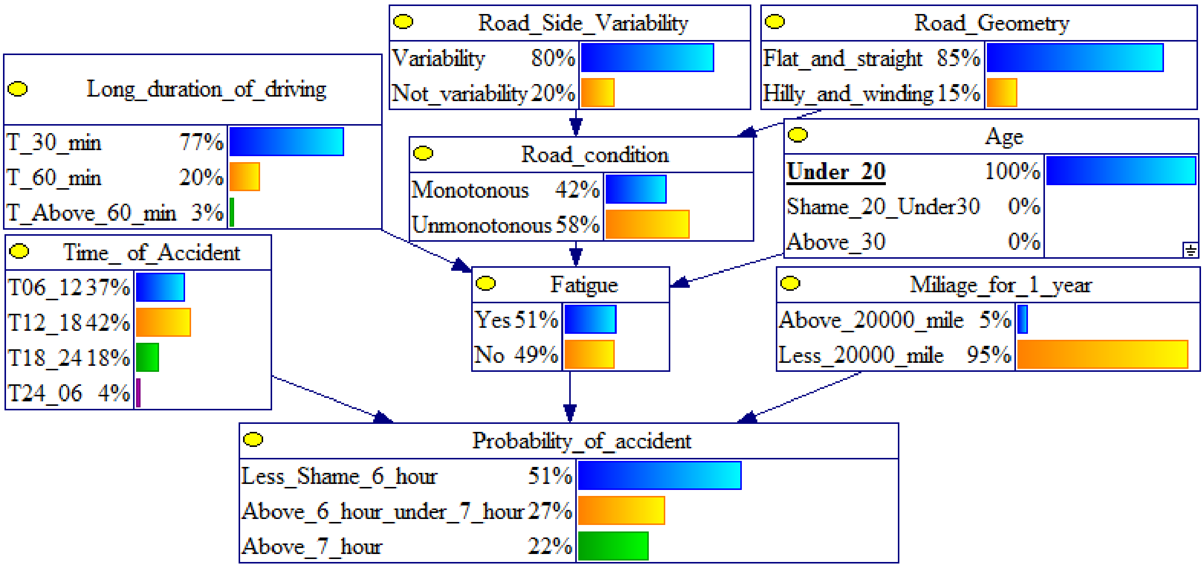

Figure 9. Correlation age under 20 years with probability of accident

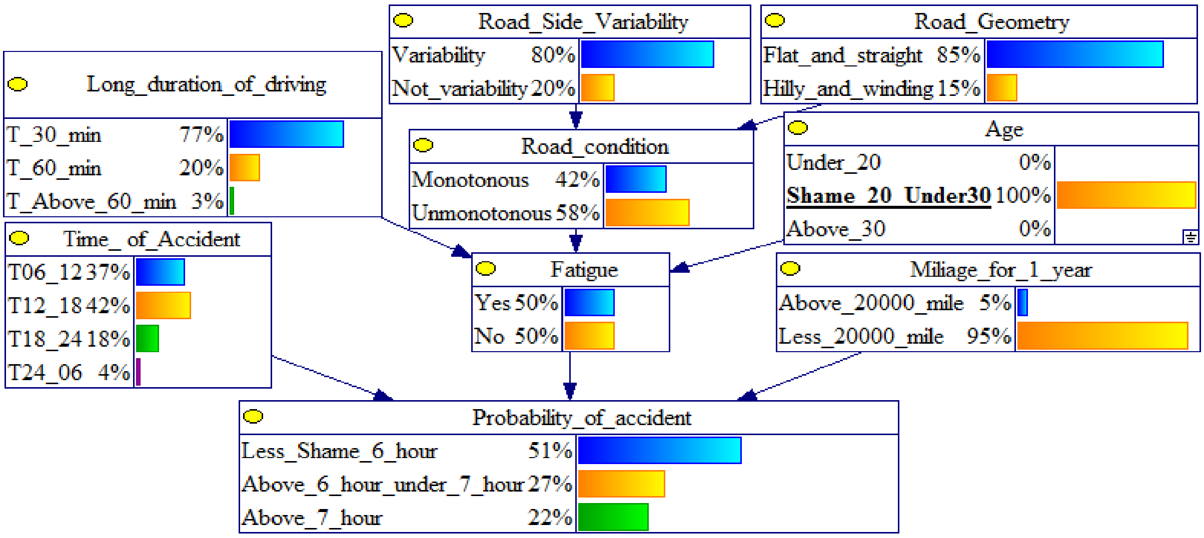

Figure 10. Correlation driver age 20 years and under 30 years with probability of accident

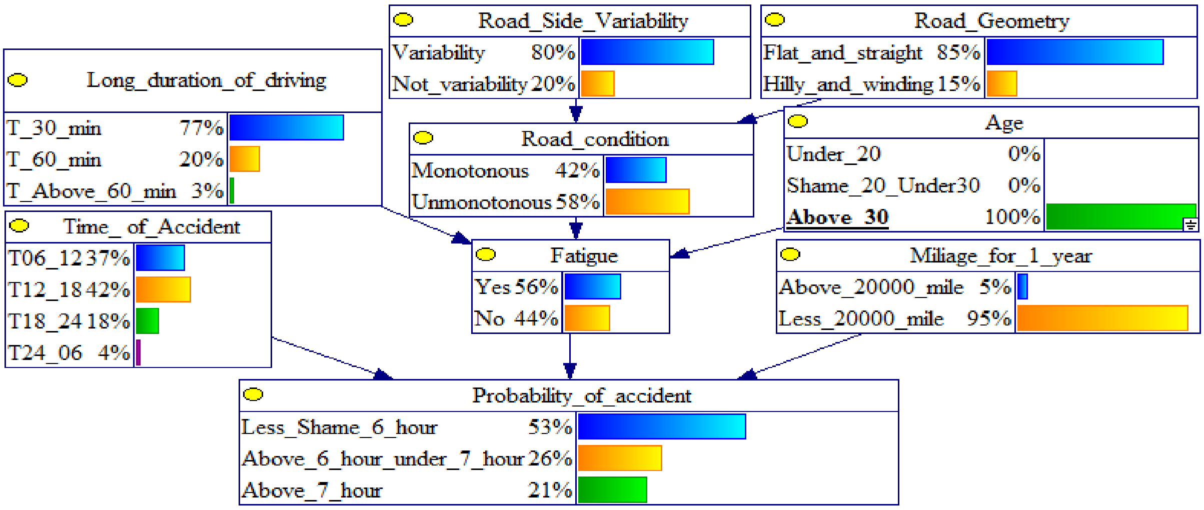

Figure 11. Correlation driver age above 30 rears with probability of accident

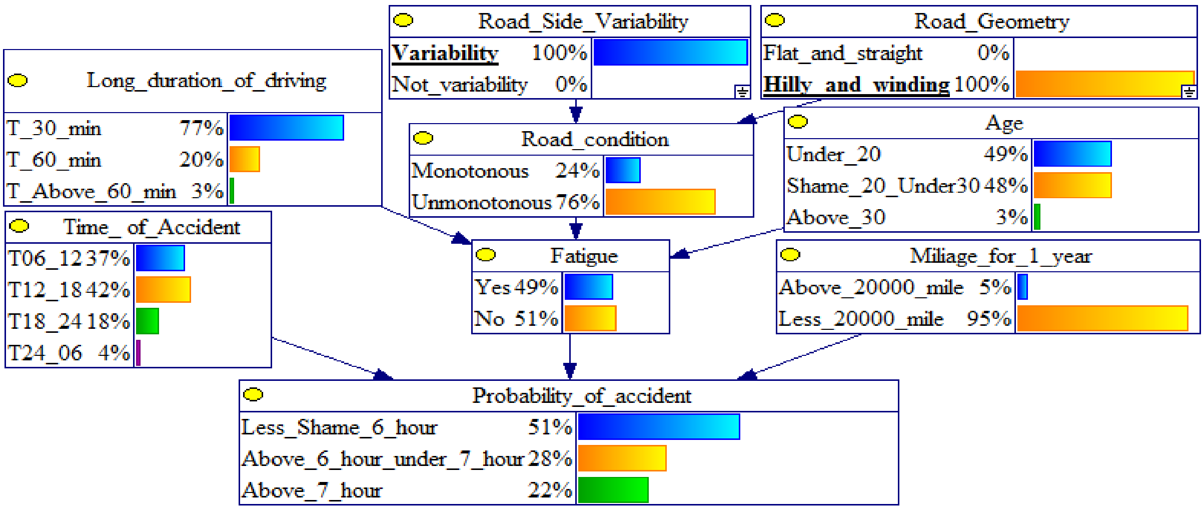

Figure 12. Correlation road side variability with variability, road geometry with hilly and winding, road condition, fatigue, and probability of accident

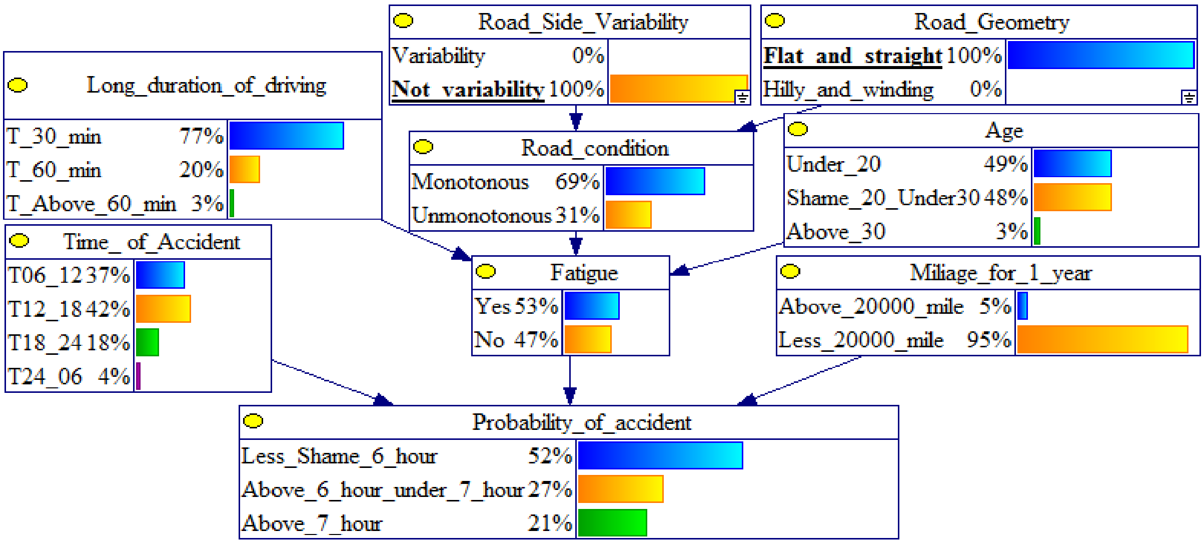

Figure 13. Correlation road side variability with not variability, road geometry with flat and straight, road condition, fatigue, and probability of accident

Driving on roads which have road side variability and driving on curvy roads would be able to reduce the level of monotonous driving from 42% to 24%, and reduce the probability of fatigue from 50% to 49% as shown in Figure 12. However, driving on roads that do not have road side variability and driving on non-curvy roads would increase the level of monotonous driving from 42% to 69%, and increase the probability of fatigue from 50% to 53%, and increase the risk of accidents from 51% to 52% as shown in Figure 13. This result is in accordance with the studies conducted by (Laruea et al 2011; Ma et al, 2003; Thiffault and Bergeron, 2003a). Monotonous while driving are caused by: road design monotony and roadside variability. The vigilance reduce when the road is straight, but the vigilance increases on the turn Laruea *et al.* (2011). Monotonous roads, and long duration of driving, and lack of rest can cause fatigue in drivers Ma et al. (2003). Monotonous road conditions and low-level traffic volume will likely cause fatigue earlier Thiffault and Bergeron (2003a).

5. CONCLUSION

Based on the above investigation, several conclusions can be drawn as follows:

a. The attributes that affect the probability of accidents related to duration of sleep the night before the accident include: trip duration, road side variability, road geometry, road conditions, driving time, age, fatigue, mileage for 1 year.
b. The probability of accidents is 51% for drivers who get 6 hours and less of sleep on the night before the accident, and 27% for those who get more than 6 hours to 7 hours sleep the night before the accident, and 22% for those who get more than 7 hours of sleep the night before the accident.
c. The longer the trip is, the higher the probability of accidents and the probability of exhaustion will be.
d. Drivers who have an annual total trip of over 20,000 miles has a probability of accidents by 73% for drivers who get 6 hours and less of sleep the night before the accident, while the drivers have an annual total trip of less than 20,000 miles has a probability of accidents by 50% for drivers who get six hours of sleep the night before the accident.
e. Drivers aged 20 years and below and drivers aged between over 20 years and 30 years indicate the same probability of accidents and the same probability of fatigue, while the

probability of accidents and the probability of fatigue increase in the driver aged over 30 years.

f. Driving on roads that have road side variability and driving on curvy roads will reduce the level of monotonous driving from 42% to 24%, and reduce the probability of fatigue from 50% to 49%.

g. On the contrary, driving on roads that do not have road side variability and driving on non-curvy roads will increase the level of monotonous driving from 42% to 69%, and increase the probability of fatigue from 50% to 53%, and increase the risk of accidents from 51% to 52%.

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