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*Original research article*

# Effects of Sleep Deprivation on Probability of Traffic Violations in Motorcyclists; Analysis Using Bayesian Network

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**ABSTRACT**

This study focuses on the effects of sleep deprivation on the night before an accident on probability of traffic violation in motorcyclists. The accident rate for motorcyclists in Indonesia is quite high. This is based on statistical data that 70.93% of traffic accidents occurring from July to December 2015 in Indonesia involved motorcyclists. The study took place in Bekasci City, Indonesia. Samples consisted of 214 respondents who had had an accident. The probability of violation of motorcyclists was analyzied using a Bayesian network. Some variables affecting the probability of traffic violation are travel time, road side variability, road geometry, road conditions, driving time, fatigue, and travel distance for 1 year. The results of analysis show a probability of violation by 50% for motorcyclists sleeping 6 hours or less, 26% for those sleeping over 6 hours to 7 hours, and 24% for those sleeping over 7 hours.

**Keywords:** Accident; Bayesian; Network; Probability

## 1. Introduction

Fatigue will reduce a driver's ability to drive safely [1]. This fatigue is caused by several factors, including lack of rest, long travel times and monotonous roads [2]. In addition, fatigue and motorcyclist behavior on the road are also affected by driver's occupation, travel duration, work routines, driving at midnight, use of stimulants, work schedules and speed [3]. Motorcyclists must stop their vehicle when they feel tired. Another study shows that 80 minutes is a safe limit for driving on monotonous roads [4]. The fatigue felt by the driver can also be caused by the driver being sleep deprived.

Drivers who average less than 5 hours of sleep every night have a probability of having an accident almost 5 times greater

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than accidents caused by other factors [5]. In addition, drivers who experience collisions due to lack of sleep are likely to drive 20,000 miles or more per year, drive 2 hours or more per day, and drive at night or between midnight and 6 am [5]. Lack of sleep can result in a lack of concentration while driving. Car drivers who are sleep deprived will enter wrong lanes 8.1 times more often than those who sleep normally [6]. In another study related to traffic violations, motorcyclists who are more economically capable tend to commit more violations than those who are less economically capable [9]. Besides the fatigue factor, the road condition factor can also affect the alertness of the driver.

The level of alertness of drivers does not increase when driving on a straight road, but it will increase when driving around the bend [7]. Similarly, it is likely that fatigue will occur earlier in monotonous road conditions and low traffic volume [8]. Fatigue will result in reduced alertness of the rider, where driver reaction time has a correlation with variations of driver performance in driving [4]. Another study showed that with installation of the puppet police, the overall violations drop about twenty percent [11].

The location of this study is Bekasi City, Indonesia. The city of Bekasi is located not too far from the capital city of Indonesia. This study emphasizes on the impact of sleep deprivation on the probability of traffic violation in motorcyclists. Indonesia statistical data shows that the number of motorcycle vehicles is 61,078,188 or 79.42% of total vehicles [13]. Meanwhile, the average growth of vehicles in Indonesia is 13.43% annually. Accident cases in 2009 in Indonesia showed that there was one accident every 9.1 minutes and there was one life lost on the road every 20 minutes.

The maximum fatal accidents in 2014 occurred from June 2014 to September 2014 [10]. In the next period, cases of fatal accidents occurring in Indonesia from June 2015 to December 2015 showed the high number of fatal accident victims every quarter.

The distribution of types of accident injuries in Indonesia based on severity and age in the last quarter (from October 2015 to December 2015) shows that road users aged 15-19 years were most vulnerable to traffic accidents with 462 fatal accident and 531 injuries [10].

In addition, accident data from July 2015 to December 2015 based on types of vehicle throughout Indonesia shows the number of motorcycles involved in traffic accidents was relatively higher than other vehicles by 70.93% [10].

Meanwhile, data from the Police of Bekasi City showed that there were 484 motorcycle accidents case in Bekasi in 2011. Furthermore, in 2012 the number of accidents increased by 8.68% (526 cases). Meanwhile, in 2013, 2014 and 2015, the number of motorcycle accidents decreased by 12.55% (460 case), 9.57% (416 case) and 14.18% (357 case), respectively.

In addition, in 2011, the number of motorcyclists who suffered serious injuries in Bekasi was 160 people and in 2012 it decreased to 117 people or by 26.88%. However, in 2013 the number of motorcyclists who suffered serious injuries increased to 131 people or by 11.97%. While in the period of 2014 and 2015 the number of motorcyclists who suffered serious injuries in each period by 114 people or reduced by 12.98%, and 45 people or decreased by 60.53% [12]. Such a high number of accidents in motorcyclists is caused by the high number of motorcycle users and the high rate of growth of this vehicle annually. Based on this, it is necessary to conduct a study to reduce the the risk of accidents among motorcyclists.

This paper aimed to analyze three factors which affect the probability of traffic violation in motorcyclists. The three factors reviewed in this paper were human factor, road and environment. These factors were analyzed simultaneously to get the probability of traffic violation in motorcyclists. After that, the best prevention can be developed as early as possible to reduce the risk of accident.

## 2. Materials and Methods

The study took place in Bekasi City. The statistical data show that 14.8% of the 2.43 million people who commute to the Greater Jakarta area are domiciled in Bekasi City. This percentage is the highest compared to other cities in the Greater Jakarta. In addition, 58.19% of commuter trips in the Greater Jakarta area use motorcycles and 51.79% of commuter trips in Bekasi City to the location of activities use motorcycles.

This study employed a quantitative method. Data were collected from interviews with motorcyclists. The criteria for respondents were motorcyclists and at least 17 years old.

Several questions were asked of respondents including:

1. Age of the driver when the accident occured?
2. What time did the accident occur? (06:00 a.m - 12:00 p.m, 12:00 p.m - 06:00 p.m, 06:00 p.m - 12:00 a.m, 12:00 a.m - 06:00 a.m)
3. Long duration of driving before accident?
4. Roadside variability around location of accident? (varied, not varied)
5. Road geometry around location of accident? (Flat and straight, Hilly or Bending)
6. Feeling monotonous before the accident happen? (Monotonous, Unmonotonous)
7. You feel tired before accident happen? (Yes, No)
8. The average distance drive for each day?
9. License?
10. Violate traffic rule before accident? (Yes, No)
11. If yes, what kind of traffic violation was conducted? (violation in the traffic light, not use helmets, violation of road marking)

Several variables were analyzed in the model of Structure of Bayesian Network including: roadside variability, road geometry, road conditions, long duration of driving, fatigue, driving time, length of driving for one years, and traffic violation. Roadside variability and road geometry affect road conditions, whether monotonous or not. Roadside variability is variation of the view on the side of the road, where the road with roadside variability can reduce the level of monotony of the driver, as well as the conditions of geometric of the road, such as a straight road that is too long can cause motorists to experience monotonous conditions and drowse [7].

Driving too long can affect the level of monotony and driver fatigue [2], so it is necessary to limit the maximum travel time in order to avoid the risk of accidents.

The variable driving time and length of driving for one year can affect fatigue of driver, and even make the driver unable to concentrate properly, which will lead to driver conduct traffic violations, both intentional and unintentional.

Data were analyzed using the Bayesian Network method, which shows a causal correlation between variables existing in the Bayesian Network structure. The Bayesian Network Structure Analysis in this study used GeNIe 2.0 Software.

A Bayesian Network (BN) is derived from the Bayes theorem, which is an approach to uncertainty. This theorem explains the correlation between the probability of event A and the condition for event B to have occurred, which is formulated in the following equation:

$$P(A|B) = \frac{P(B|A)P(A)}{P(B|A)P(A) + P(B|-A)P(-A)}, \tag{2.1}$$

note: $(-A) = A$ complement.

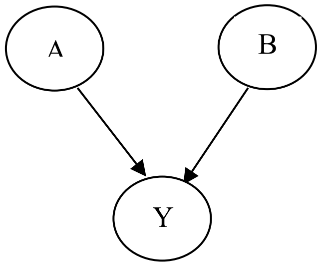


**Fig. 1.** Example of analysis of bayesian network with 3 variables.

Analysis of Bayesian Network in Fig. 1 (with 3 variables) can be calculated with the formula:

$$P(Y)=P(Y|A,B)\times P(A)P(B)$$
$$+P(Y|A,-B)\times P(A)P(-B)$$
$$+P(Y|-A,B)\times P(-A)P(B)$$
$$+P(Y|-A,-B)\times P(-A)P(-B).$$

Analysis of Bayesian Network in Fig. 2 (with 4 variables) can be calculated with the formula:

$$P(Y)=P(Y|B,C,A)\times P(B|A)\times P(C|A)$$
$$+P(Y|B,-C,A)\times P(-B|A)\times P(-C|A)$$
$$+P(Y|-B,-C,A)\times P(-B|A)\times P(C|A)$$
$$+P(Y|-B,-C,A)\times P(-B|A)\times P(-C|A).$$

Samples in a population were taken using purposive sampling, a method for determining respondents based on certain criteria. The sample size was determined using equation (2), and the calculation results indicated a minimum sample size of 83 respondents. Note: $n$ = sample, $N$ = population, $e$ = margin of error. The number of motorcycle accidents in Bekasi City = 474 people [12], and the value of $e$ = 10%.

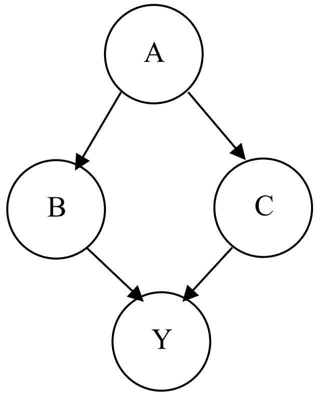


**Fig. 2.** Example of analysis of bayessian network with 4 variables.

$$n=\frac{N}{1+Ne^2}, \tag{2.2}$$

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

The number of respondents in this study was 214 respondents.

## 3. Results and Discussion

The variables affecting the probability of violation before the accident related to the sleep duration of the driver on the night before the accident are: travel duration, roadside variability, road geometric, driving time, fatigue, road conditions and travel distance for 1 year. Variables and statistics based on data can be seen in Table 1.

**Table 1.** Data Variables and Statistics.

| No | Variable | Value | Percentage |
|---|---|---|---|
| 1 | Accident Time (W) | 06:00 a.m. - 12:00 p.m (W1) | 35.05 |
| | | 12:00 p.m.- 06:00 p.m (W2) | 47.66 |
| | | 06:00 p.m.- 12:00 a.m (W3) | 13.08 |
| | | 12:00 a.m. - 06:00 a.m (W4) | 4.21 |
| 2 | Age | ≤ 20 year. | 79.44 |
| | | > 20 year. | 20.56 |
| 3 | Travel Duration (LP) | 30 minutes (LP1) | 77.57 |

| | | | |
|---|---|---|---|
| | | 60 minutes (LP2) | 20.09 |
| | | 90 minutes (LP3) | 2.34 |
| 4 | Road Side Variability (SJ) | Varied (SJ1) | 63.55 |
| | | Not varied (SJ2) | 36.45 |
| 5 | Road Geometry (GM) | Flat and straight (GM1) | 85.51 |
| | | Hilly or Bending (GM2) | 14.49 |
| 6 | Road Conditions (KJ) | Monotonous (KJ1) | 45.79 |
| | | Not monotonous (KJ2) | 54.21 |
| 7 | Fatigue (L) | Yes (L1) | 50.00 |
| | | No (L2) | 50.00 |
| 8 | Travel distance for 1 year (JP) | > 20000 miles (JP1) | 1.87 |
| | | ≤ 20000 miles (JP2) | 98.13 |
| 9 | Probability of traffic violations (PP) | Sleep duration ≤ 6 hours (PP1) | 50.00 |
| | | 6 hours < Sleep duration ≤7 hours (PP2) | 26.17 |
| | | Sleep duration > 7 hours (PP3) | 23.83 |

The probability of traffic violation was calculated using the equations in Table 2, where the probability of traffic violation is directly affected by 3 variables: driving time, fatigue, and travel distance in 1 year. Therefore, there are 48 probabilities of traffic violation, consisting of 16 possible traffic violations by motorcyclists who slept on the night before the accident for 6 hours or less, 16 possible traffic violations by motorcyclists who slept on the night before the accident for over 6 hours to 7 hours, and 16 possible traffic violations by motorcyclists who slept more than 7 hours on the night before the accident. This was obtained from 4 choices of answers for driving time variable (06:00a.m.-12:00p.m., 12:00p.m.-06:00p.m., 06:00p.m.-12:00a.m., 12:00a.m.-06:00a.m.) x 2 choices of answers for fatigue variable (tired, not tired) x 2 choices of answers for travel distance for 1 year variable ( ≤ 20,000 miles,> 20,000 miles) x 3 choices of answers for the probability of traffic violation due to the sleep duration on the night before accident (sleep duration ≤ 6 hours, 6 hours < sleep duration ≤ 7 hours, sleep duration >7 hours).

The results of the analysis of the study on 214 respondents show that the probability of traffic violation is 50% for motorcyclists whose sleep duration on the night before the accident is 6 hours or less, and 26% for above 6 hours to 7 hours, and 24% for above 7 hours as shown in Fig. 3.

As an example of the calculations in Table 2, the equation for the probability 1 for drivers who sleep 6 hours or less the night before an accident:

P(PP)1=P(PP|W1,L1,JP1,SJ,GM,KJ,LP)x P(KJ|SJ,GM) x P(L|LP,KJ)
P(PP|W1,L1,JP1,SJ,GM,KJ,LP) =100 %
P(W1) = 35.05%; P(L1) = 50%;
P(JP1) = 1.87%
P(PP)1= 0.1 x 0.3505 x 0.5 x 0.0187
P(PP)1= 0.032% (meaning that the motorcyclists who drive from 06:00 a.m. - 12:00 p.m, driver was in fatigue condition, driver drive > 20000 miles per year, this driver had experienced accident, the percentage of the motorcyclists as above mentioned in the sample was 0.032%).

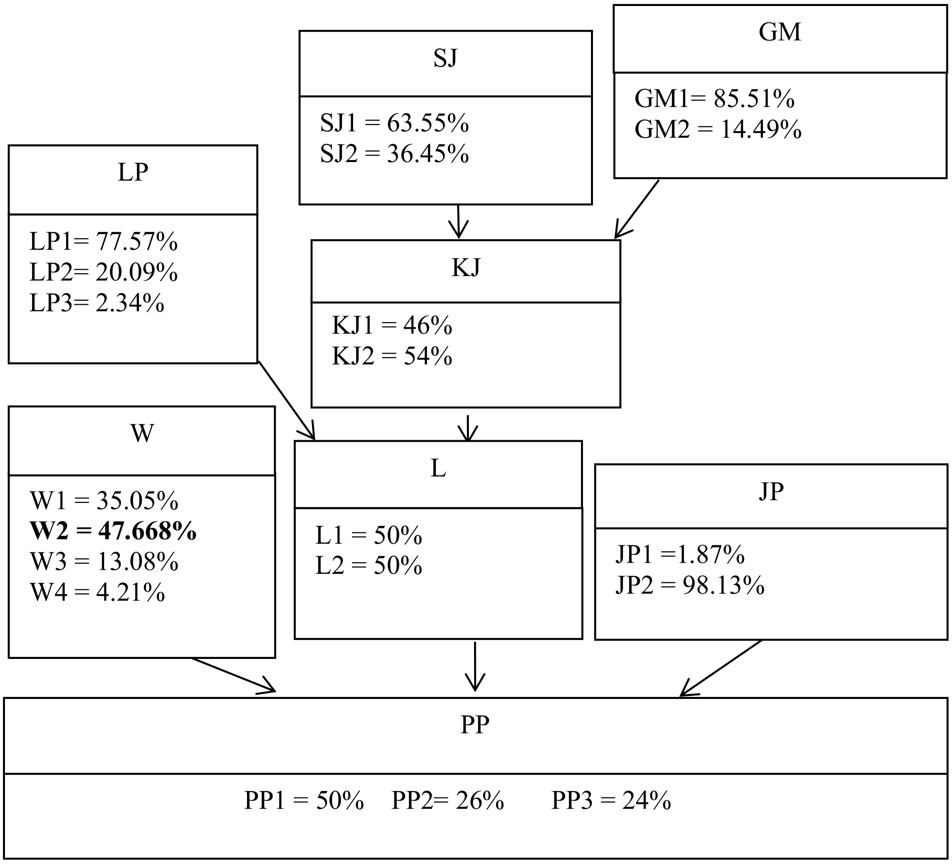


**Fig. 3.** Bayesian network structure on the probability of traffic violations.

Note : SJ = Road Side Variability, SJ1 = Varied, SJ2 = Not varied, GM = Road geometry, GM1 = Straight and flat, GM2 = Turn or bend, KJ = Road condition, KJ1 = Monotonous, KJ2 = Not monotonous, LP = Travel duration , LP1 = ≤30 minutes, 30 <LP2 ≤60, 60 <LP3 ≤90, L = Fatigue, L1 = Tired, L2 = Not tired, W= Accident Time, W1 = 06:00 a.m. - 12:00 p.m, W2 = 12:00 p.m.- 06:00 p.m, W3 = 06:00 p.m.- 12:00 a.m, W4 = 12:00 a.m. – 06:00 a.m, **JP = Travel distance for 1 year, JP1 > 20000 miles, JP2 ≤ 20000 miles**, PP = Probability of violation, PP1 for sleep duration ≤ 6 hours, PP2 for 6 < sleep duration ≤7, PP3 for sleep duration > 7 hours.

**Table 2.** The equation of probability of violation.

| P | P(W) | P(L) | P(JP) | P(PP) |
|---|---|---|---|---|
| 1 | W1 | L1 | JP1 | P(PP\|W1,L1,JP1,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 2 | W1 | L1 | JP2 | P(PP\|W1,L1,JP2,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 3 | W1 | L2 | JP1 | P(PP\|W1,L2,JP1,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 4 | W1 | L2 | JP2 | P(PP\|W1,L2,JP2,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 5 | W2 | L1 | JP1 | P(PP\|W2,L1,JP1,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 6 | W2 | L1 | JP2 | P(PP\|W2,L1,JP2,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 7 | W2 | L2 | JP1 | P(PP\|W2,L2,JP1,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 8 | W2 | L2 | JP2 | P(PP\|W2,L2,JP2,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 9 | W3 | L1 | JP1 | P(PP\|W3,L1,JP1,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 10 | W3 | L1 | JP2 | P(PP\|W3,L1,JP2,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 11 | W3 | L2 | JP1 | P(PP\|W3,L2,JP1,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 12 | W3 | L2 | JP2 | P(PP\|T3,L2,JP2,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 13 | W4 | L1 | JP1 | P(PP\|W4,L1,JP1,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 14 | W4 | L1 | JP2 | P(PP\|W4,L1,JP2,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 15 | W4 | L2 | JP1 | P(PP\|W4,L2,JP1,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| 16 | W4 | L2 | JP2 | P(PP\|W4,L2,JP2,SJ,GM,KJ,LP) x P(KJ\|SJ,GM) x P(L\|LP,KJ) |
| | | | | Σ P(PP) |

where P = Probability

### 3.1 Discussion of the Results

The value of driving time variable shows that 35.05% of motorcyclists have accidents at 06:00 a.m. -12:00 p.m., 47.66% at 12:00 p.m. - 06:00 p.m. and 13.08% at 06:00 p.m. - 12:00 a.m. and 4.21% at 12:00 a.m. - 06:00 a.m. The percentage of accidents at 06:00 a.m. -12:00 p.m. and 12:00 p.m. - 06:00 p.m. is high. Driving time affects the level of driver fatigue and also affects the situation on the road and the surrounding passed by such as traffic jams. In addition, driving time also affects air temperature, especially when driving during the day that air temperature is hotter than other times. Fatigue conditions coupled with traffic conditions and hot temperatures will certainly make motorcyclists more fatigued so that they will be at risk of accidents.

The value of the travel duration variable in the model shows that 77.57% of motorcyclists have accidents on a maximum travel duration for 30 minutes and 20.09% between 30 minutes to 60 minutes and 2.34% between 60 minutes and 90 minutes. The percentage of accidents on a maximum trip of 30 minutes is quite high, which is caused by the high number of trips for drivers in 2 periods of time, namely 06:00 a.m. -12:00 p.m. and 12:00 p.m. - 06:00 p.m. Approximately 80.12% of accidents occurring within the duration of ≤30 minutes occur at 06:00 a.m. -12:00 p.m. and 12:00 p.m. - 06:00 p.m.

The value of the Road Side Variability variable in the model shows that 63.55% of motorcyclist have accidents on road sections with a road side variability and 36.45% on road sections without road side variability. Road side variability is not directly correlated with the potential for an accident, but is more correlated to the level of monotony experienced by the motorcyclist, which later will have an impact on the level of driver fatigue.

The value of geometric condition variable in the model shows that 85.51% of motorcyclists have accidents on flat and straight roads and 14.49% of motorists have accidents on hilly or bending roads. The percentage of motorcyclists who have accidents on straight roads is very high compared to accidents that occur on hilly or bending roads because motorcyclists will feel monotonous when passing straight and long roads. Monotonous situations experienced by motorcyclists can cause drowsiness and this condition will certainly reduce the level of alertness of the driver. Eventually, this condition will endanger the safety of the motorcyclists and the safety of other drivers. Meanwhile, motorcyclists who drive around bends tend to get rid of monotonous situations and even the level of alertness tends to increase when passing bends.

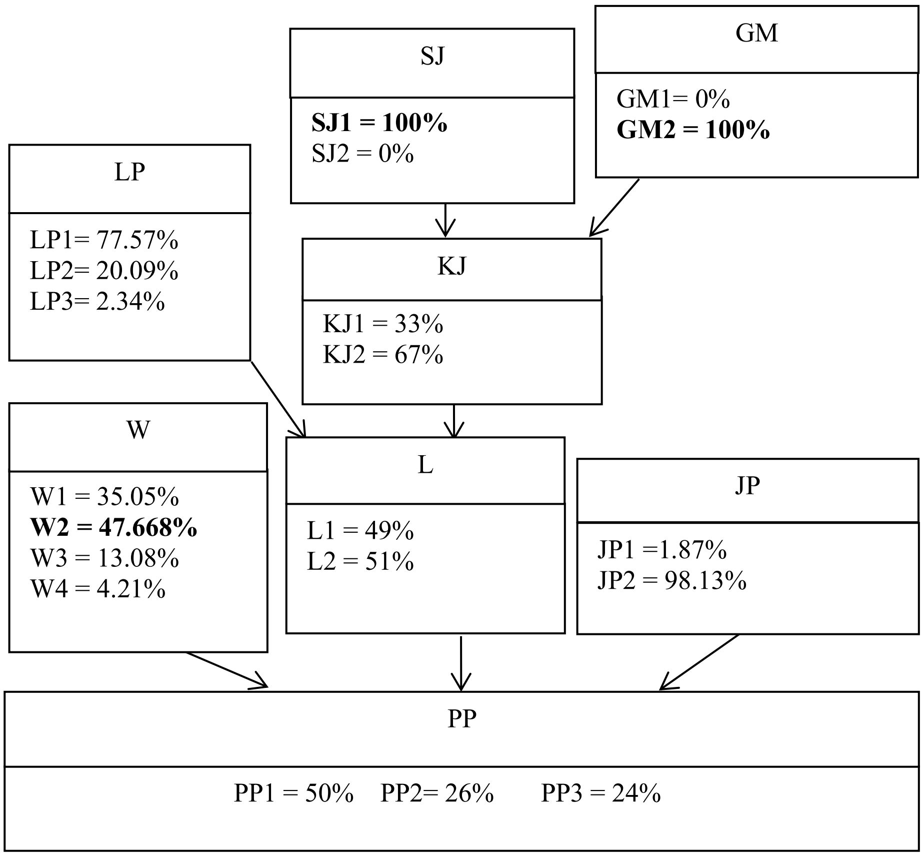


**Fig. 4.** Scenario 1 of the model.

The value of travel for a year variable shows that respondents who traveled > 20,000 miles per year had an accident of 1.87%, while respondents who traveled ≤ 20,000 miles per year had experienced an accident of 98.13%. This shows that the average motorcyclists' daily travel is not so far or below 88 km per day.

Scenario 1 of the model shows motorcyclists driving on road sections with road side variability and driving on bending roads will reduce the monotony level from 46% to 33%, and this condition can also reduce the probability of fatigue from 50% to 49% as shown in Fig. 4. Road sections with road side variability tend to make the motorcyclists more focused, avoiding drowsiness and monotonous situations. Similarly, road sections that are only flat and varied in the form of descent and ascent road will reduce the level of monotony in the motorcyclists. In addition, straight and long roads can cause drowsiness in the motorcyclists. Drowsiness occurring when driving on a straight road is caused by the monotonous situation experienced by the motorcyclists [8]. Monotony felt by the motorcyclist can reduce the level of alertness. The level of alertness of the motorcyclist does not tend to increase when on a straight road, but will tend to increase at a bend [7]. Furthermore, geometric conditions and road side variability can affect the level of monotony felt by the motorcyclists [7]. Monotonous road conditions and low levels of traffic volume will likely result in early fatigue for motorcyclists [8].

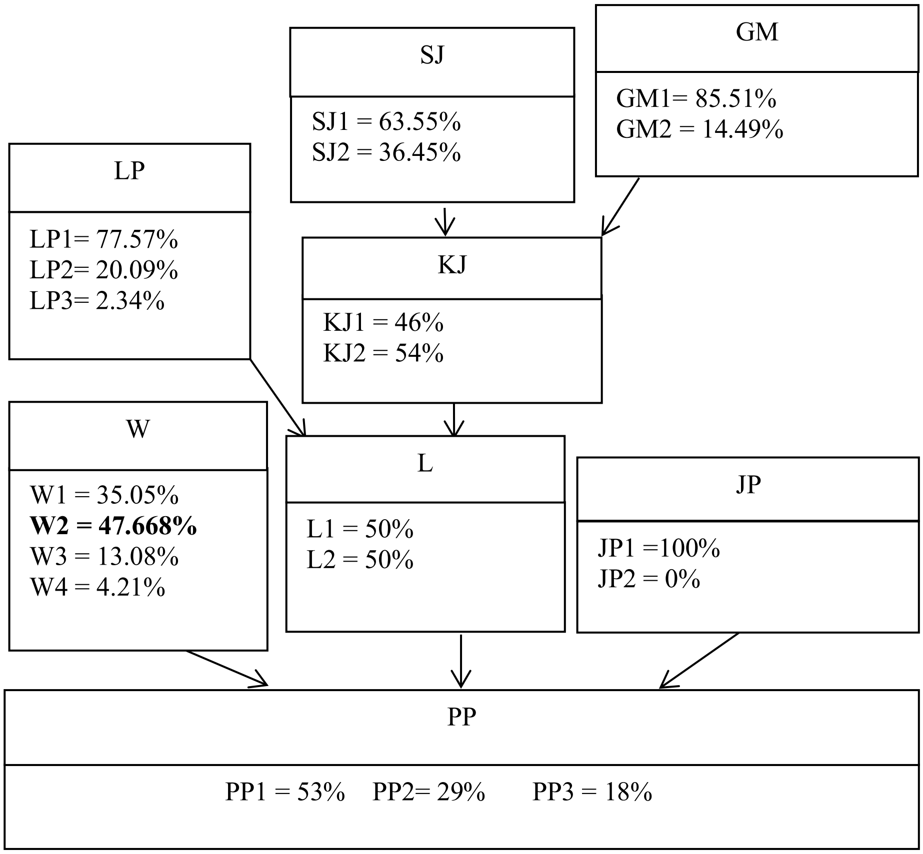


**Fig. 5.** Scenario 2 of the model.

Scenario 2 models show motorcyclists with an average total travel each year of > 20000 miles have a 53% of probability for committing violations in motorcyclists who sleep on the night before the accident for ≤ 6 hours, and 29% for the sleep duration on the night before the accident for above 6 hours to 7 hours, and 18% for the sleep duration on the night before the accident for > 7 hours as shown in Fig. 5. Motorcyclists who lack sleep can have drowsiness when driving. Drowsiness occurring when driving can reduce the concentration and this even will result in reduced driver reaction time. Therefore, it will affect the ability to make a decision when danger comes suddenly. Previous studies suggest that motorcyclists who sleep less than 5 hours every night have the probability to have an accident due to sleep nearly 5 times greater than accidents caused by other factors [5]. The same study shows that motorcyclists whose sleep was deprived would enter wrong lanes 8.1 times more frequently than those who sleep normally [6]. Motorcyclists who sleep 6 hours or less on the night before the accident have an accident probability 2.3 times greater than those who sleep for more than 7 hours on the night before the accident [14].

## 4. Conclusion

Several conclusions can be drawn as follows:

a. Attributes affecting the probability of traffic violation correlated with sleep duration on the night before the accident are: travel duration, road side variability, road geometry, road conditions, driving time, fatigue, travel distance for 1 year

b. The probability of traffic violation is 50% for motorcyclists sleeping 6 hours or less, and 26% for those sleeping over 6 hours to 7 hours, and 24% for those sleeping over 7 hours.
c. Increased travel duration increases the probability of an accident and increases the probability of fatigue.
d. Motorcyclists who have a total annual travel of more than 20,000 miles have probability of violation by 53% for those whose sleep duration is for 6 hours or less on the night before the accident.
e. Motorcyclists who drive on road sections with road side variability and drive on bending roads will be able to reduce the monotonous driving level from 46% to 33%, and reduce the probability of fatigue from 50% to 49%.

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