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MASTER'S THESIS

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Abstract

In the city of Jakarta, the students, working class or any people needing to commute within the city have the option to take the private-owned vehicle or the public mass transport. The private-owned vehicle consists of cars and motorcycles, with 75% of them are motorcycles. The main public transport in Jakarta is the commuter train and bus rapid transit (BRT) system, with BRT system have their own lane in the public roads. Unfortunately, the recorded number for accidents is still in the range of thousands for private vehicle, hundreds for bus rapid transit; and while the commuter train has low number of accidents, it still records some severe accidents. We would like to assess the risk attached to the commuting activities, and quantitative risk assessment (QRA) is used as the method.

To perform QRA within the transportation world, we first established the framework with the basis risk analysis principles from Aven (2012) and some studies on vehicle accidents. First, the context must be established, as this step contains the defining basis of the assessment. Then, the hazard should be identified for the starting point of accident cause and consequence analysis. In the cause analysis, three common main sources of accident should be included: human error, environmental factor and vehicle mechanical failure. Consequence analysis should include the intermediate events identified that may escalate the accident, some of the events are, vehicle speed, the functionality of safety feature, traffic situation and passenger condition on vehicle. The results from cause and consequence analysis are presented in the risk picture. Monitoring, review and update are important to keep the validity of the assessment, while communication and consultation are critical to understand the view of every stakeholder involved

As the results of QRA, 4 risk indices are calculated: the crash occurrence probability, potential injuries and loss of lives, individual injury risk and individual fatality risk. Our assessment result shows that the private vehicles have lower probability of crash (expected probability of 3.44×10^{-7} for cars and $3{,}81 \times 10^{-7}$ for motorcycles) than the BRT system ($5{,}36 \times 10^{-5}$) and commuter train ($6{,}26 \times 10^{-6}$). Potential injuries from commuter train (40) and BRT (5,2) are also the higher than the private vehicles, this is due to the maximum number of passengers the vehicle can carry. The same reason also applies to why the commuter train have the highest potential loss of lives, considering how much passengers the train can carry. These numbers imply that when a public transport is having an accident, the outcome will be more severe. Individual injury and fatality risk are the indices that shows the risk to one passenger/occupant of the vehicle when travelling one time. The results in individual injury risk for BRT system is the highest ($1{,}13 \times 10^{-5}$) almost 25 times more than motorcycles ($3{,}93 \times 10^{-7}$), the lowest in individual injury risk. Highest individual fatality risk is with the motorcycles ($5{,}84 \times 10^{-7}$) and the lowest is the commuter train ($1{,}02 \times 10^{-8}$). Overall, we have injury risk higher than the fatality risk for every individual.

We introduced some of the possible risk reducing measures with the focus to reduce the crash frequency. Violating traffic rule on the road (private vehicles) and bad systems (public transport) are the most significant in causing the crash. From this thinking, we understand that risk reducing measures for vehicle accident will be effective in the form of a more robust regulations (for private vehicles) and a better-designed system (for public mass transport).

Key words: Quantitative risk assessment, vehicle accident, transportation accident, commuting activities

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1 Introduction

1.1 Background

The city of Jakarta, capital of Indonesia is a home to 10 million people, and the number adds up to over 25 million if we take account the Greater Jakarta area (Jabodetabek area). The students, working class or any people needing to commute within the city have the option to take the private-owned vehicle or the public mass transport. The private-owned vehicle consists of cars and motorcycles, with 75% of them are motorcycles. The main public transport systems in Jakarta are the commuter rail and bus rapid transit (BRT) system, with BRT system have their own lane in the public roads. Both BRT and commuter rail system today can take a combined number of 2 million passengers per day, and this may leave the rest of the population of Jakarta to drive their private vehicle.

The people have their own preferences to choose how they commute and by the percentage, it shows that the majority chose motorcycles. Unfortunately, according to the Indonesian statistics bureau, motorcycles are involved in most accident happened within Jakarta. As risk assessment can give insight on decision analysis, we would like to give an insight into the modes of transport we are using from the risk perspective.

1.2 Problem definition

The number of registered motorcycles and private cars keeps growing for the past years in Jakarta while road accidents still happening frequently. At the same time, main public transportation such as bus rapid transit and commuter rail system are growing, and both modes of public transport also still susceptible to an accident. Many factors can cause the accident, and the consequences of the accident must be known; therefore we would like to do a risk assessment and establish risk knowledge on commuting in Jakarta.

1.3 Objectives

The main objective of this thesis is to establish risk knowledge on the situation considered, that is commuting using the private-owned vehicle and public transportation in Jakarta, Indonesia. The risk knowledge that is established here can benefit the community of Jakarta in general, to be risk-informed when choosing the modes of transport. In specific, this study can give insight to the operators of public transport on how they can improve the safety and service, as for the owner of private vehicle will be informed on what is needed for extra attention to increasing road safety.

To reach the objective of the thesis, we will perform a quantitative risk assessment using the current method of risk assessment. This means, in addition of the main objective, we can extend the possible field of application for the current method of risk assessment in transportation and we may identify what parts need to be modified to suit the field related.

1.4 Methodology

Indonesian statistics bureau releases “Jakarta in figures” and “Jakarta transportation statistics” every year and it consists of some road accidents historical data. Data that might be useful for this study are, for example, number of road accidents, the consequences of the accidents, type of vehicle involved, the total number of vehicles in Jakarta, data for bus rapid transit and some others. The data is openly available.

We will conduct a quantitative risk assessment method using the data available and other relevant knowledge. Based on principles of risk analysis, we develop a framework for quantitative risk assessment specific to transportation accident. In risk analysis, to understand the situation of interest, we need to analyse the cause and consequence of the events considered, and for that, we need to establish models. In order to establish the models to assess the causes and consequences, we may use fault tree and event tree method. And to assess and quantify the uncertainties in the models, we use probabilities as the measure. In the models, we may identify some existing barrier, or we may suggest some risk-reducing measures as the result of these studies.

We use the settings of commuting in Jakarta, Indonesia when using the private-owned vehicle and public mass transport, and here are the steps of the methods when doing the quantitative risk assessment:

1. Identify initiating events
2. Perform cause analysis and establishing model using fault tree
3. Conduct consequence analysis and establishing a model using event tree
4. Calculate uncertainties in the model using probabilities and other uncertainty measure needed for every scenario identified
5. Establish risk picture based on the cause and consequence analysis

1.5 Contents

The report will be structured as the following: Introducing the study in section 1, summarizing the theories from the literature in section 2, presenting the Jakarta transportation in section 3. In section 4, we develop a framework for our study, meanwhile, in section 5 we conduct the risk assessment and the result will be presented in section 6, the risk picture. Section 7 will cover the conclusion and discussion from the result of the studies.

2 Theoretical foundation

2.1 Risk analysis

Risk analysis is a study for risk. By doing risk analysis, we can express the risk of a situation considered. But how to express this risk? What is it exactly expressing risk means? For that we must understand the principles and where to focus when doing risk analysis, Aven (2012) provide us with the answer for these questions. Two essential things to focus and understand in doing risk analysis is the background knowledge, where we base all our understanding regarding the risk considered and the observable quantities, conveying the state of the world in the analysis.

2.1.1 Principles

We focus on the concept of risk from Aven (2015), risk comprises of two elements, the consequences *C*, and the uncertainties *U* related to it. In this sense Risk = *(C, U)* or *(A, C, U)* with addition of events *A* which are the initiating events leading to *C*. The concept explains that we are uncertain on the size of the consequences, or the occurrence of the consequence itself.

For a better understanding, we apply the concept to what this study focuses on, the activity of commuting in Jakarta. Commuting means we travel around the city from a specific point to another by any means of transportation. We focused on the accident risk when doing the activity with a different kind of transportation. Here, *C* means the consequences of the commuting activity, occurrence of an accident or no occurrence and what is the consequence of the accident. Then, the uncertainties *U* related to the consequences are we do not know whether an accident will happen or not and we do not know what will happen as the consequence.

The product of risk analysis is that we describe the risk itself. This involves specifying the concept *(A, C, U)*. We specify the consequences, the uncertainties are measured and specified, and this brings us to risk description = *(A', C', Q, K)*. *A'* and *C'* are the specified events and specified consequences respectively, *Q* is a measure of uncertainties and when using probabilities *P,* we may write *P* instead of *Q* in the description. *K* is the background knowledge all other components are based on; this may include all relevant information regarding any kind of assumptions and data available that is used in the risk analysis.

Based on the risk concept above, Aven (2012) established four principles to hold when conducting a risk analysis. The four principles are:

1. Specifying consequences must be focused on the state of the world, meaning it is the quantity of interest of why we are doing the risk analysis. This is what we call the *observable quantities.* These quantities are potentially observed in the future and true number of these numbers exist.
2. The observable quantities are predicted.
3. Uncertainty of the observable quantities is measured by knowledge-based probabilities (also known as subjective probabilities), an expression of belief from the assessor towards the uncertainties of an event/consequences using all relevant information and knowledge available, hence it is an *epistemic uncertainty*.
4. Models in risk analysis are specifying the link between the observable quantities and the details behind. Models should be treated as a simplified state of the real world.

These principles are illustrated in Figure 1.

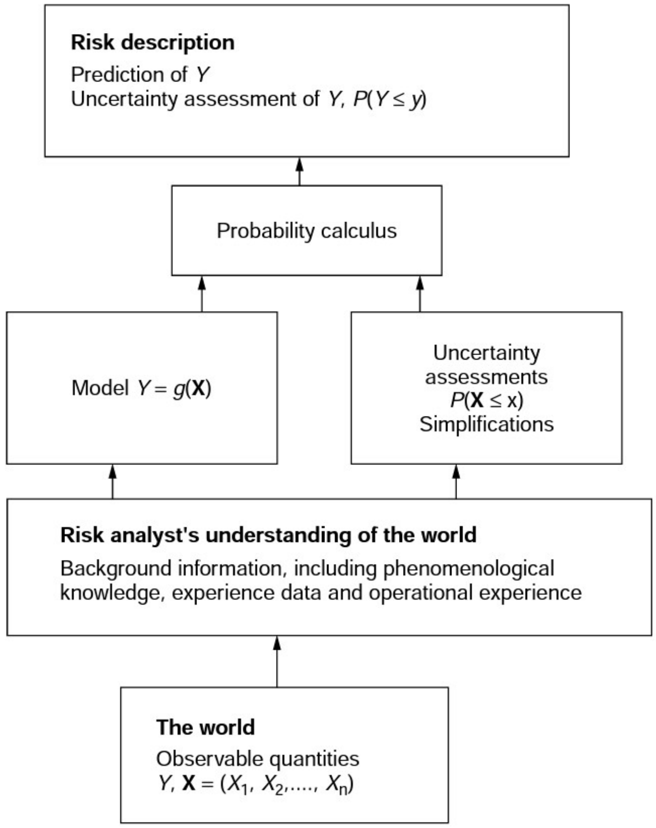


Figure 1 Basic principles in risk analysis (Aven, 2012)

The fourth principle, models help us to understand the predicted state of the world, in a simplified form. Models in risk can be written as $Y = g(X)$ with Y is the high-level observable quantities and X is the low-level observable quantities. The assessor must identify the link between Y and X and put it all together in the model $Y = g(X)$, so this way we understand in the model how X can affect Y, our quantities of interest.

2.1.2 Background knowledge

Assessing uncertainties have an objective to measure the uncertainties itself. To measure the uncertainties, we need a specific measure and it is very common to use probabilities, but we do not narrow it to only probabilities, if it is a suitable measure for risk analysis then we can make use of it. To explain *background knowledge,* we will use the probabilities as a measure.

When specifying probabilities, it is important to note that all the value will be based on a certain knowledge at the time we are quantifying the uncertainties (Aven, 2012). Meaning the probabilities are always conditional on a set of knowledge behind it. Knowledge here can be all relevant information we have available related to the uncertainties considered. This information can be historical data, set of regulation, understanding about phenomena, models of a system and everything related to the situation assessed. Models are considered as a knowledge, and as we understand, it means the “simplified representation of the world”. Simplified may mean there are assumptions regarding the state of the world in the model, and these assumptions are important to notice as it will not perfectly represent the situation assessed.

Let us consider the focus of our study, commuting in Jakarta using different type of vehicles. We may deal with assessing the occurrence of vehicle crash for a certain type of vehicle in the road of Jakarta. With various background knowledge, we may end up with $p(a|b)$ = 0,01 with a is the occurrence of vehicle crash and b is the assumption that all the traffic light in Jakarta working properly without any defect. This means that the uncertainty about the conditions of traffic light is not reflected in our assigned probability. Some groups may point out that this is a major issue and we cannot longer use the assumption about the traffic light in our probability. This means that knowledge about the traffic light must be sought and once it is established, it may change our probability. We may understand now that a great number of traffic lights are defected, and it could increase our probability, or we may know that some knowledge about the traffic light might make us consider reducing the probability.

The main point of background knowledge is we must be specific on it when assigning probabilities. An uncertainty in the background knowledge of assigned probabilities does not mean we have an uncertainty in the probabilities itself, but the knowledge we have now is inadequate. That is why it is an *epistemic uncertainty* – an uncertainty caused by lack of knowledge. As Aven (2012) emphasized, the uncertainty we have in risk analysis is only related to the observable quantities, we never have an uncertainty in the probabilities assigned.

2.1.3 Observable quantities

In risk analysis, based on the principles covered in the section before, we must give our focus to the quantities our analysis interested in and these quantities must be observable hence the term *observable quantities.* Being observable means that the quantities of interest must be distinct, it is clear on how to observe the quantities or there is an established convention about the quantities and ambiguity cannot exist (Aven, 2012). For example, fatalities of an accident are clear, no ambiguity is present on the definition of fatality. But when we consider a component defect, it is not very clear on what it means. Criteria must be specified on how a component can be considered "defected", a convention must be established, and then after that we can take into consideration that a certain component is defected when it met our criteria.

Aven (2012) highlighted the need to understand relative frequency in the case of observable quantities. Is relative frequency an observable quantity or not? The key is to recognize whether a population existed or not in the relative frequency considered. Let us consider a situation of offshore production facility – we want to analyze the occurrence of an accident in the facility for a specific time of 1 year. In this case, if we want to calculate a relative frequency, then we will need to have some number of similar facilities to calculate a relative frequency. Of course, in this setting, in practice will never happen, there will never be a population of similar facilities in large number therefore, it is not an observable quantity. However, if such population can be defined, then it can be regarded as an observable quantity. It is important to distinguish between a fictional population and the real-world population. Other cases like a mass production of products, a relative frequency in proportion of defected product is an observable quantity as the population is clear, the total product produced. The main point is the population, whether it can be clearly defined or not to be counted as observable.

2.1.4 Risk analysis steps

Risk analysis is based on the principles covered in the previous sections; we understand that we do not estimate the risk (in the sense of classical approach, where we estimate the correct value of risk), but we are doing the analysis to predict the proper value in observable quantities. We must give focus especially on the observable quantities, and with model we could have prediction on the quantity of interest. Another thing to note is the uncertainty measurement; all of uncertainty measurement must be based on some information – a knowledge-based probabilities.

Aven (2012) summarizes the steps of risk analysis based on the principles and key focus above with 5 steps:

1. Identify the overall system performance measures or we may refer this as the high-level observable quantities
2. Establish a model linking the high-level observable quantities and the more detailed level of observable quantities (low-level observable quantities)
3. Gather information about the low-level observable quantities and process this information systematically with regards to the high-level observable quantities
4. Assess uncertainties related to the low-level observable quantities and specify the probabilities
5. Calculate the uncertainty distribution for the performance measure/high-level observable quantities and define the prediction of the quantity of interest

2.2 Quantitative risk assessment

Risk as a concept is a set of initiating events (A), consequences (C) and uncertainty (U). This can be written Risk = *(A, C, U)*. The uncertainty can be related to both A and C. What kind of initiating events can occur? what consequences can happen? or how big the magnitude of the consequences? For a specific situation considered, we must describe what kind of risk can come up and therefore, we must do a risk assessment. Risk assessment is covered by several different kind of activities: identification of initiating, cause analysis and consequence analysis (Aven, 2015). And from those activities we form the risk description of the situation considered.

Although there is no formal classification, Apostolakis (2004) differs risk assessment into two types: traditional (safety analysis) and quantitative risk assessment (QRA) with the latter viewed as the more “modern” view of risk assessment.

Probabilities is often used as a measure of uncertainty; it quantifies our uncertainty towards events or consequences. It is vital to understand that even a traditional approach of risk assessment needs to measure the uncertainty but unlike QRA, it is not using numbers as measures.

QRA is a top-down approach, starting with the definition of end states, we specify the initiating events. From the initiating events, we modelled scenarios for the cause and consequence, usually using fault and event trees with uncertainties quantified for each scenario. The quantification of uncertainty is assessed by using available data (evidence) and expert judgement (Apostolakis, 2004). The assessment of every possible scenario identified is the one of the main benefits of using QRA method, even the scenario involves a unique event.

In assessing the situation of vehicle accident, the data should be available from year to year, with the reporting system authorities have. The data may include whose fault or which component that caused the accident. However, the data recorded may not reflect the behaviour of the driver on driving and maintaining the car or their attitude towards traffic rules and safety. In this case, a judgement or assumption should be done based on the available information.

2.3 Studies on vehicle accidents

2.3.1 Vehicle accidents statistics

Analyzing historical data can give information about the picture of how vehicle accident affecting the population in an area. Jusuf, Nurprasetio, and Prihutama (2017) and collected the data of traffic accidents in Indonesia and try to relate the accident with other issues, like vehicle growth and road infrastructure. While Santosa, Mahyuddin, and Sunoto (2017) focused on the severity of accidents in Indonesia.

Jusuf et al. (2017) relate the traffic accident and injury level severity, financial costs, vehicle growth, road growth and occurrences in main provinces of Indonesia. In 2004 to 2014, the data trend for number of vehicle accident is increasing, but the ratio between the severity of injury and fatality seems to be consistent. The 200% vehicle growth in Indonesia coincide with the 200% increased fatality rate per 100,000 population in 10 years, with motorcycle dominating the number. Jusuf et al. (2017) noted that motorcycle is popular in Indonesia due to their image as the most "effective" vehicle to beat the traffic. The other important data is that the road growth in Indonesia did not keep up with the growth of the vehicle; the road only expanded by 35% while the vehicle increased 200%. We can also note that Jakarta is the fourth highest province in case of accident number, only surpassed by West Java, Central Java and East Java – this is horrifying as Jakarta has only 3% area of other three provinces individually.

Santosa et al. (2017) did an anatomy of Indonesian traffic accident and categorized them based on vehicle type, collision type and age group and time. As motorcycles are the most owned vehicle in Indonesia, they also dominate the accident involvement and therefore at fault for 73% of accident fatalities and major injuries in Indonesia. Note that the classification of accident injury severity is based on *abbreviated injury scale* (AIS) with major injuries classified as AIS > 3 and minor injuries AIS < 3. Traffic accident in Indonesia mostly involved a crash between two vehicles (64,19%), with single vehicle accident takes 5,61% and accident involving 3 or more vehicles takes 2,7% involvement. Side impact collision (23,34% from 64,19%) is the most susceptible collision type as Bedard, Guyatt, Stones, and Hirdes (2002) found. Age group that is most involved in accident is 16-30 years old and by hour, accident mostly happened during 6 until 18, with 62%.

In the UK, Clarke, Ward, Bartle, and Truman (2010) analyzed the traffic accident data and found some traffic accident information. The assessed case is showing a *blameworthiness ratio* by age group. The age group 20 and under have a blameworthiness ratio of 12, and this means age group < 20 is 12 times more probable to cause fatal accident rather than to be not to blame for an accident. The ratio steadies around 1 from 31-65 goes up once again from age group 66-70 and older, with 81-85 have the ratio of 7,5. Another insight from Clarke et al. (2010) is that 34% of the fatal accident was not wearing a seatbelt. The front seat occupant (driver/front seat passenger) not wearing seatbelt resulting 85% fatalities and rear seat occupant not wearing seatbelts resulting 58% fatalities.

2.3.2 Speed and accident relationship

Speed is perceived to be most associated with the consequence severity of an accident. Speed also believed to be one factor of accident involvement. Aarts and van Schagen (2006) reviewed studies conducted toward the relation of speed and accident. The accident here is measured by crash rate. The relation between speed and crash rate can be defined into two categories: (1) Absolute speed and crash rate and (2) Speed dispersion and crash rate.

In the studies to find the relation between absolute speed and crash rate, individual speed and average speed at road section level are used. Maycock, Brocklebank, and Hall (1998) and Quimby, Maycock, Palmer, and Buttress (1999) used individual vehicle their studies and found that a 1% increase in speed affect 13.1% increase in *crash liability* while the latter studies found 7.8% increase. The difference in the founding said to be because of the difference of average speed and interestingly, study by Quimby et al. (1999) is having an average speed higher about 15 km/h with a lower increase in crash rate. The studies by Nilsson (1982, 2004) showed the relation between the speed and accident using average vehicle speed in Swedish rural roads. The idea is to alternate the speed limits on the road, and this way the average speed will change thus affecting the accident rate. Adjusting the kinetic energy formula, Nilsson established the relation between accident rate and speed in the following formulas:

$$A_2 = A_1 \left(\frac{v_2}{v_1}\right)^2$$

Furthermore, Nilsson also established the function for injury crashes and fatal crashes by increasing the function power:

$$I_2 = I_1 \left(\frac{v_2}{v_1}\right)^3 \text{ and } F_2 = F_1 \left(\frac{v_2}{v_1}\right)^4$$

Table 1 Power function relation between speed and accident, injury and fatality rate (Nilsson, 1982)

$A_2 = A_1 \left(\frac{v_2}{v_1}\right)^2$	Relation between speed and accident rate
$I_2 = I_1 \left(\frac{v_2}{v_1}\right)^3$	Relation between speed and injury rate
$F_2 = F_1 \left(\frac{v_2}{v_1}\right)^4$	Relation between speed and fatality rate

The researchers stated that these power functions are reliable to predict accident rate due to changes in average speed on the road. Baruya (1998) also used average speed to find the relation between speed and injury crash frequency and came up with a more complex power function. As Aarts and van Schagen (2006) summarize, 7 factors are accounted in the formula: (1) crash frequency is most affected by traffic flow; (2) higher speed limit means higher crash frequency; (3) the portion of speed limit offenders is affecting the increase in crash frequency; (4) larger junction density means higher crash frequency; (5) longer road section can affect the increase in crash frequency; (6) roads with narrower lanes are more susceptible to crash and (7) lower average speed means more crash frequency. The factor number (7) is in line with the result difference of Maycock et al. (1998) and Quimby et al. (1999).

2.3.3 Mechanical failures as a factor in accident

It is widely known that human factor is the primary cause of vehicle accident, but mechanical failure is also one of the factors causing a vehicle accident. van Schoor, van Niekerk, and

Grobbelaar (2001) established the role of mechanical failures in South Africa. In the study, van Schoor et al. (2001) defined the relationship between various factors in accident experience (Figure 2), it is shown that independently, accident experience can be caused from human characteristics (1), vehicle condition (2) and environment (3). Only vehicle condition can be affected further from periodic motor vehicle inspection (4), human characteristics (5) and environment (6).

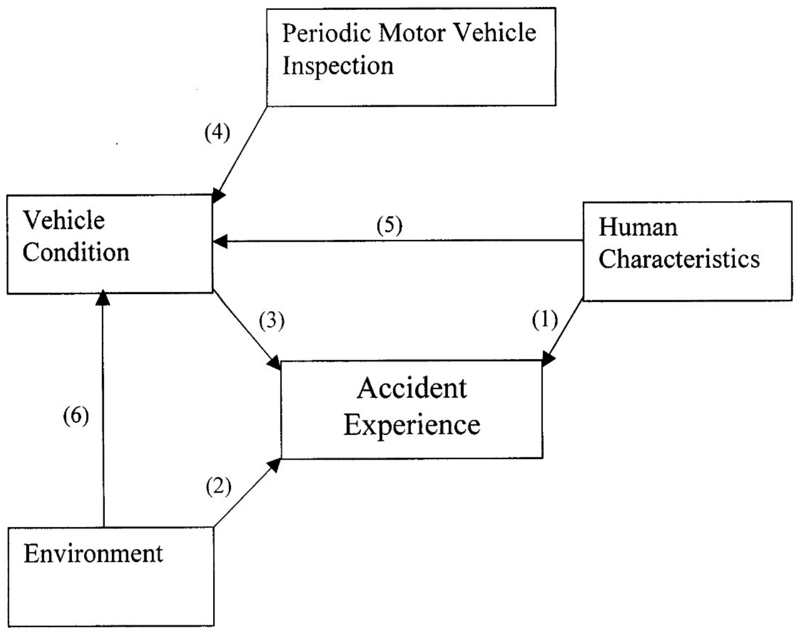


Figure 2 Relationship of various factors to the accident experience (van Schoor et al., 2001)

van Schoor et al. (2001) focused on the causal link number 3 using *potential mechanical defect tests* (PMDT) and minibus survey. The PMDT is conducted in highway and suburban roads, it was found that 40% of vehicle running in suburban roads have *potential mechanical defect* (PMD) while in highway, 29% of the vehicle showed PMD. The PMDT checked the various components like brakes, wheels, tires, suspension and steering systems.

Of all mechanical failures that caused an accident in Indonesia, Santosa et al. (2017) showed that the failed components are steering system (26,86), brakes (26,64%), tires (13,97%) and other notable problem in Indonesia is the failure to use visibility component (for example: front light/rear light/brake light) taking 28,76% with the rest is axle problems.

2.3.4 Driving behavior and accident involvement

Driving behavior comes from the human characteristic factor when driving a vehicle. Norris, Matthews, and Riad (2000) did a prospective study from 500 samples of road user over 4 years from 1991 to 1995 and study the effect of demographic, characterological, situational and behavioral towards accident involvement. In the behavioral section, the respondent admitted themselves of how they are following the rules and how they drive on the road. The results are, road users that never follow the rules and speed limit have an accident rate of 54,7%, road users that follow either one has 43,5% involvement and road users that obeys both have a rate of 29,2%. Driving defensively and avoiding bad conditions are also showing an effect on accident involvement. When the driver does not have a defensive driving behavior and avoiding bad conditions, they are involved in 48,7% of the accident. The driver that reported doing one of the behaviors involved in 46,4% and when both behaviors are exhibited on the road, they have 36.8% involvement. These data show that when the driver has the awareness towards rules, speed limits, driving defensively and avoiding bad conditions they will be less likely to be involved in an accident.

Santosa et al. (2017) shown that 88% of the accident in Indonesia were caused by human factors. Among the human factor cases, 45,66% disobey traffic rules (other than the speed limit), 32,2% distracted when driving, 14,53% disobey speed limit. The rest of the human-influenced accident are caused by fatigue (3,39%), drowsiness (2,34%), alcohol (1,31%), psychological problem (0,34%) and drug use (0,03%). The number shows that 92,39% of the accident caused by human factor in Indonesia caused by problematic driving behavior. And to note, in Indonesia alcohol is still a problem for human factor accident but is significantly lower than what Clarke et al. (2010) found with almost 20% of the fatal accidents, and this shows us how driving is influenced culturally as Clarke et al. (2010) study the accidents in the UK.

2.3.5 Quantitative risk assessment for vehicle accidents

QRA is a method to give insight about risk in a quantified form. For a vehicle accident, Meng, Weng, and Qu (2010) did a study to model vehicle crash in a work zone in the form of probabilistic quantitative risk assessment. In their study, as shown in figure 3 probabilistic QRA for vehicle crash is involving frequency estimation, building an event tree – with determining intermediate events and accident scenarios, frequency calculation for the scenarios, consequence estimation and casualty risk calculation.

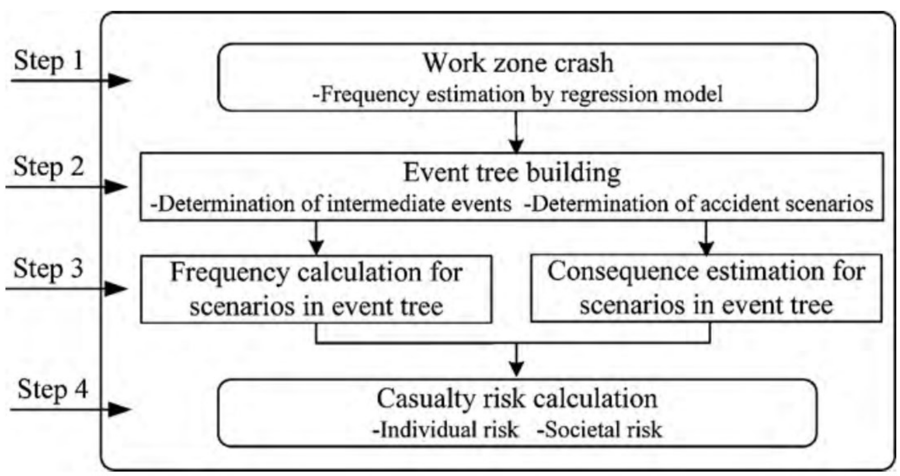


Figure 3 Flowchart for QRA model formulation (Meng et al., 2010)

Meng et al. (2010) used an event tree to model accident scenarios. They introduced "intermediate events" as the determining events to what kind of scenarios the accident may go. Event tree started with the "Vehicle crash" and ended with "Severity" node. 7 intermediate events are identified: age, crash unit, vehicle type, alcohol, light condition, crash type and crash severity. Among these intermediate events – age, alcohol and light condition is not reflecting an accident sequence. Vinnem (2013) explained that an event tree is a "visual model that describes possible event chains", therefore the intermediate events should reflect possible escalation of severity of a vehicle accident and the 3 events (age, alcohol and light condition) may be considered as a cause of a vehicle crash. While age may be a factor to a consequence severity of vehicle occupant (as older people is assumed to be more susceptible), but that is not the case in this event tree by Meng et al. (2010).

Meng et al. (2010) also suggested to estimate probabilities of intermediate events, we can use historical data and to reflect the uncertainty (in this case, variation), a distribution may be used; thus, the intermediate events are treated as random quantities. And the propagation of uncertainty among the intermediate events can use the Monte Carlo method to calculate the probabilities of various scenarios.

3 Jakarta transportation profile

The citizen of Jakarta commutes every day using various transportation modes. In this section, we present the data of Jakarta's transportation and focus is given to what considered to be the 4 main modes: motorcycles, private cars, bus rapid transit and commuter rail system. The data is provided by Badan Pusat Statistik Indonesia (Indonesian Statistics Bureau) in their Jakarta in Figures ("Jakarta dalam Angka," 2008-2018), Jakarta Transportation Statistics ("Statistik Transportasi DKI Jakarta," 2009-2018) and Polantas Indonesia (Indonesian Traffic Police), in Polantas in Figures document ("POLANTAS dalam Angka," 2012-2013) .In the Polantas document, the data is not only for Jakarta, but also covers Indonesia. Specifically, on the accident data of commuter rail system, we use various sources for the data as the data by the officials are not openly available.

3.1 Road transportation

3.1.1 Roads in Jakarta

The roads in Indonesia, including Jakarta, are regulated by the constitution (UU RI Nomor 38 Tahun 2004) and the ministry of public works (Peraturan Menteri Pekerjaan Umum Nomor: 03/PRT/M/2012) for their classification of function and status while the speed limits while the speed limits are regulated by the ministry of transport (Peraturan Menteri Perhubungan Nomor 111 Tahun 2015). We compiled the data and presented it in the following table

Table 2 Road classification by their function

Road type	Description	Speed limits (km/h)	Minimum width (meter)
Tol/Highway	Roads connecting some areas, and fees (toll) applies to the road user	60-100	-
Arteri primer/primary arterial	Roads connecting national central activity area, regional central activity area, main seaports and main airports	30-80	11
Kolektor primer/primary collector	Roads connecting regional capital cities and sub-region capital cities	30-80	9
Arteri sekunder/secondary arterial	Roads connecting city primary area and secondary area	30-50	11
Kolektor sekunder/secondary collector	Roads connecting city secondary areas	30-50	9
Lokal & lingkungan/local roads	Roads connecting city secondary areas and residential zone	25-60	6,5-7,5

And based on the data from the statistics bureau, we have the total length of Jakarta's road with 6.652,97 km and mainly consists of the local roads with 4.949,68 km.

Table 3 Road length in Jakarta by function

Road type by function	Length (km)
Tol/Highway	160,35
Arteri primer/primary arterial	57,70
Kolektor primer/primary collector	2,16
Arteri sekunder/secondary arterial	694,46
Kolektor sekunder/secondary collector	788,62
Lokal & lingkungan/local roads	4.949,68
Total	6.652,97

3.1.1 Registered vehicle in Jakarta

Looking at the data in Table 4, the number of vehicles alone that is registered under the Greater Metropolitan Jakarta Police Regional Police or usually known as Polda Metro Jaya is overwhelming. In 2016, the number of vehicles that can legally run on the road of Jakarta almost reached 18 million. More interestingly, 75% of the number of the road-legal vehicle consists of motorcycles.

Table 4 Number of registered vehicles in Jakarta

Year	Motorcycle	Private cars	Cargo cars	Buses	Total
2005	4 647 435	1 766 801	499 581	316 502	7 230 319
2006	5 310 068	1 835 653	504 727	317 050	7 967 498
2007	5 974 173	1 916 469	518 991	318 332	8 727 965
2008	6 765 723	2 034 943	538 731	308 528	9 647 925
2009	7 518 098	2 116 282	550 924	309 385	10 494 689
2010	8 764 130	2 334 883	565 727	332 779	11 997 519
2011	9 861 451	2 541 351	581 290	363 710	13 347 802
2012	10 825 973	2 742 414	561 918	358 895	14 489 200
2013	11 949 280	3 010 403	619 027	360 223	15 938 933
2014	13 084 372	3 266 009	673 661	362 066	17 386 108
2015	13 989 590	3 469 168	706 014	363 483	18 528 255
2016	13 310 672	3 525 925	689 561	338 730	17 864 888

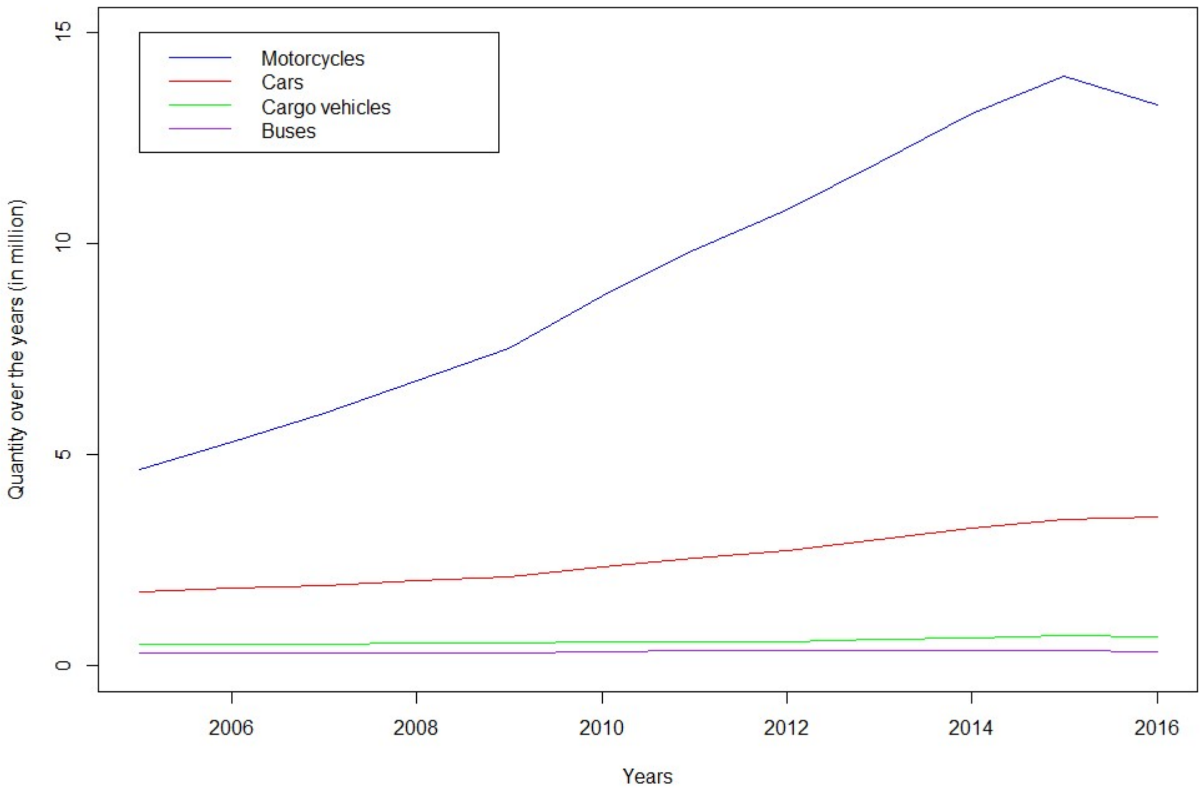


Figure 4 Growth of vehicle numbers in Jakarta

For motorcycles and private cars, the number grows significantly, in just 10 years from 2005 the numbers tripled from 4,5 million to almost 13,5 million for motorcycles, while the number of cars doubled from 1,75 million to 3,5 million.

3.2 Bus rapid transit

The Bus rapid transit (BRT) system in Jakarta is called *Transjakarta*. It started operating in 2004 and has been growing as part of the main public transport supporting the commuter within the city of Jakarta. As of 2018, Transjakarta has the world's longest BRT system with 251,2 km length. The system has 13 main lines with the expansion of 2 future main lines.

Transjakarta is certified with silver standard according to The BRT Standard (2016) by the Institute for Transportation & Development Policy (ITDP) but only for 1 line while other lines have a bronze standard or below. Meaning, the BRT system in Jakarta is still far from ideal in serving Jakarta commuters.

3.2.1 Transjakarta BRT yearly ridership

Passenger of Transjakarta is constantly growing in line with the increase of system size. By 2017, 13 years after Transjakarta began their service, 13 main lines are running and in 2017 it reached a yearly passenger of 144 million, an average of 400,000 passengers per day, still far from their target to serve 1 million passengers per day.

Table 5 Transjakarta BRT yearly ridership

Year	Passenger
2006	38 811 133
2007	61 446 336
2008	74 619 995
2009	82 377 690
2010	86 937 487
2011	114 769 432
2012	111 260 869
2013	112 522 638
2014	111 630 305
2015	102 950 384
2016	123 706 856
2017	144 868 949

3.2.2 Transjakarta BRT number of fleets

Transjakarta in 10 years is constantly growing their service, new lines meaning expanding their fleet to serve the growing number of passengers. Before Transjakarta, all the city buses are operating on their own and creating a bad competition in the city without looking at safety at all, the buses are old and unreliable.

Now, Transjakarta is established and operating under the government of Jakarta. Recently, around 2016 Transjakarta is aiming to modernize all the city bus in the city that is operating privately by having them to cooperate and operates under the flag of Transjakarta. As of 2016, as a result of cooperating with many private city bus operators, they have a fleet consisting of 910 buses.

Table 6 Transjakarta fleet size growth

Year	Fleet size
2005	91
2006	159
2007	339
2008	426
2009	456
2010	338
2011	545
2012	565
2013	579
2014	669
2015	502
2016	910

3.3 Jakarta commuter rail system

The train company of Indonesia operates a commuter rail system in Jakarta. The commuter rail system is commonly known as *commuter line* among the citizen of Jakarta. The current commuter line system we see was not established until 2008, before it was just another operating division of

Indonesian train company. And in 2011, they revolutionized how they operate from point-to-point service to become a 6 lines integrated service.

3.3.1 Yearly ridership

In 2017, the number of passengers almost tripled since they changed how they operate in 2011 and the addition of "new" rolling stock has been making an increase in the frequency of train trips. In 2017 they are serving 315 million of passenger and that is an average of 860,000 passengers per day.

Table 7 Growth of commuterline passengers

Year	Passenger
2006	104 579 720
2007	118 094 971
2008	126 699 747
2009	130 632 466
2010	124 331 056
2011	110 751 052
2012	134 087 064
2013	158 482 102
2014	208 494 094
2015	257 530 185
2016	280 588 767
2017	315 844 991

3.3.2 Rolling stock

Commuterline almost replaced all of their old rolling stocks into a "new" one. The operator imported Japanese train that was previously serving the Tokyo Metro and Japan Railway company, train operators in Japan. This is part of the plan to revolutionized how the system operates. When the current rolling stocks arrived from Japan, they were already 30 years old. With a designed service lifetime of 50 years, they are expected to serve as commuterline for 20 years.

Table 8 Number and types of commuterline rolling stocks

Year	Rolling stock addition	Type
2009	8	Tokyo Metro 8500 series
2010	110	Tokyo Metro 7000 series
2011	100	JR 203 series and Tokyo Metro 6000 series
2012	90	JR 203 series
2013	180	JR 205 series
2014	176	JR 205 series
2015	120	JR 205 series
2016	60	JR 205 series
Total	844	

3.3.3 Number of trips by route

The full service of 5 lines started in 2014. The number of trips is growing due to extension of lines and rolling stock addition, by 2018 we have 914 trips per day.

Table 9 Commuterline number of trips per day

Route	Number of trips per day			
	2014	2015	2017	2018
Bogor - Jakarta kota / Jatinegara	393	435	410	401
Bekasi - Jakarta kota	126	153	153	162
Rangkasbitung - Tanahabang	118	148	178	193
Duri - Tanahabang	74	90	76	93
Tanjung priok - Jakarta kota	46	50	64	65
Total	757	876	881	914

3.4 Accidents

From Badan Pusat Statistik Indonesia (Indonesian Statistics Bureau), we gather accident data that is openly available and happened in Jakarta and some are the accident data in Indonesia. The accident data contain the number of accidents, cause and consequences.

3.4.1 Road accidents and its consequences

We have the data of road accidents and their consequences from 2006 until 2016 and their consequences. The police classified the consequences to minor injuries, serious injuries and fatalities. In 2016, the accident number is 6.180 and the total victim of the road accident is 7.415, with 678 resulting in the loss of lives.

Table 10 Road accidents in Jakarta and the consequences

Year	Number of accidents	Accident consequences				Material loss (in million Rupiah)
		Minor injuries	Serious injuries	Fatalities	Total	
2006	4 395	2 075	2 158	1 028	5 261	7 641
2007	5 437	3 617	2 465	1 085	7 167	12 197
2008	6 393	4 317	2 597	1 169	8 083	12 249
2009	7 329	5 165	3 388	1 071	9 624	12 393
2010	8 235	5 820	3 473	1 048	10 341	17 744
2011	8 079	6 312	2 820	1 008	10 140	18 102
2012	8 020	6 153	2 938	912	10 003	21 885
2013	6 498	4 711	2 925	676	8 312	23 794
2014	5 966	3 582	2 643	636	6 861	23 149
2015	6 434	4 290	2 688	591	7 569	16 631
2016	6 180	4 487	2 250	678	7 415	20 295

3.4.2 Highway accidents with causes and consequences

Another accident data that has been recorded is accidents in highway road of Jakarta. This data gives us insight about the causes of accidents involving private cars, because in the highway of

Jakarta, only cars can run on the road and not motorcycles. We can see from the data in 2017, the major cause of the accident when driving a car is the faulty driver, 754 cases of 898 accidents.

Table 11 Highway accidents and the causes

Year	Number of accidents	Fatalities	Accident Causes		
			Driver error	Vehicle failure	Environmental condition
2011	1 267	95	1.003	250	14
2012	1 235	94	999	222	14
2013	1 192	76	996	188	3
2014	1 164	82	977	178	9
2015	1 030	72	846	181	3
2016	954	50	766	181	7
2017	898	52	754	128	16

3.4.3 Number of accidents by vehicle type

This data shows us the number of accidents classified by vehicle type. BRT here is the buses that are operated by Transjakarta, and the non-BRT public transport comprises of minibuses, non-Transjakarta city buses and some traditional form of transport, like *bajaj* (motorized tricycle). As of 2016, motorcycles dominated the type of vehicle involved in accidents, with a number of 3132 out of total 4675 accidents.

Table 12 Types of vehicle involved in accidents

Year	Public transportation			Private-owned vehicle		Total
	Non-BRT	Taxi	BRT	Cars	Motorcycles	
2008	521	239	369	1 873	5 898	8 900
2009	643	240	434	2 004	7 044	10 365
2010	642	234	477	2 102	7 787	11 242
2011	432	144	428	2 207	7 641	10 852
2012	439	246	383	2 256	7 241	10 565
2013	173	145	153	1 348	2 480	4 299
2015	178	151	234	1 233	3 231	5 027
2016	130	131	98	1 184	3 132	4 675

3.4.4 Number of drivers involved in accidents by license type or no license

The police in Jakarta recorded of every main suspect that causing the accident. To simply explain the types of license, A is for ordinary cars, B is for cargo cars and C is for motorcycles. This data shows the number of unlicensed drivers in Jakarta is massive. In 2016, the number of suspects that does not have any license taking 50% of the total numbers, this percentage was even higher the years before.

Table 13 Drive involved in accidents by license type

Year	Driver license type			
	A	B	C	No license
2008	926	1 017	1 585	1 860
2009	1 000	911	1 833	2 029
2010	1 223	1 115	1 815	2 141
2011	1 078	1 025	1 998	1 895
2012	880	819	1 565	2 802
2013	125	32	611	2 921
2015	113	31	976	2 864
2016	487	176	700	1 198

3.4.5 Number of accidents by road environment conditions

Road condition and its surrounding can be one of the factors that lead to an accident on the road. In Indonesia, 1 996 cases of accidents caused by no available road signs.

Table 14 Number of accidents by road condition in Indonesia

Road condition	Number of accidents
Damaged roads	857
Hole	1 288
Obstructed vision	870
Slippery	482
No lightings	1 185
No road signs	1 996
Sharp turns	1 366
Total	8 044

3.4.6 Number of accidents by faulty driver conditions

As stated from table 10, driver error is the most common cause leading to accident in Jakarta highway. By the data of the Indonesian traffic police, the most common error caused by the driver in Indonesia are they disobeying traffic rules in 41 717 cases, followed by distracted by 29 421 cases.

Table 15 Number of accidents by driver conditions in Indonesia

Driver condition	Number of accidents
Distracted	29 421
Exhausted	3 096
Drowsy	2 140
Ill	185
Disobeying the rule	41 717
Mentally unstable	314
Medication influence	27
Alcohol influence	1 198

Disobeying speed limits	13 273
Total	91 371

3.4.7 Number of accidents by faulty vehicle conditions

Vehicle conditions are important factors to notice. Critical vehicle controlling components, brakes and steering are the most common cause of the accident when it does not function properly. In Indonesia, brake malfunction caused 879 cases and steering malfunction caused 886 cases. While lights also a critical factor, especially when driving in a dark environment, causing 866 case of accidents with defective light on vehicle.

Table 16 Number of accidents by vehicle condition in Indonesia

Vehicle condition	Number of accidents
Brake malfunction	879
Steering malfunction	886
Tyre malfunction	461
Broken front axle	55
Broken rear axle	36
Defective front light	613
Defective rear light	253
Misused front light	63
Total	3 246

3.4.8 Number of accidents by environmental conditions

Driving in different conditions than a normal good-weather condition is also a source of accidents. Most common environmental factors that lead to an accident in Indonesia is rain with 874 cases.

Table 17 Number of accidents by environment conditions in Indonesia

Environmental condition	Number of accidents
Flood	34
Landslide	13
Fog	94
Rain	874
Earthquake	6
Tsunami	2
Hurricane	28
Fallen tree	19
Total	1 070

3.4.9 Commuter train accident

For the last 5 years of commuter rail system operating in Jakarta, there are 2 notable accidents in which one of them causes 5 fatalities. The only accident that causes fatalities is when the train hits a tanker truck on a level crossing, and the portal to prevent cars crossing the railway is late to close. The other accident is between two trains collision at one station, no fatalities come from this accident, but several have a serious injury and minor injury.

Table 18 Commuter line accident statistics

Year	Number of accidents	Accident Causes			Accident consequences			
		Derailment	Level-crossing failure	Train collision	Minor injuries	Serious injuries	Fatalities	Total
2013	3	1	2	0	81	9	5	95
2014	1	1	0	0	0	0	0	0
2015	6	3	2	1	28	14	0	42
2016	2	1	1	0	0	0	0	0
2017	7	5	2	0	0	0	0	0
2018	3	0	3	0	0	0	0	0

4 Quantitative risk assessment framework for transportation accident

We develop the framework as the basis to perform quantitative risk assessment (QRA) specific in transportation accident. The framework is focused to identify the causes and consequences of a vehicle accident. The framework is established based on the principle of risk analysis quantitatively and some studies about vehicle accident, we covered both in section 2. Figure 5 shows our established framework for transportation accident QRA.

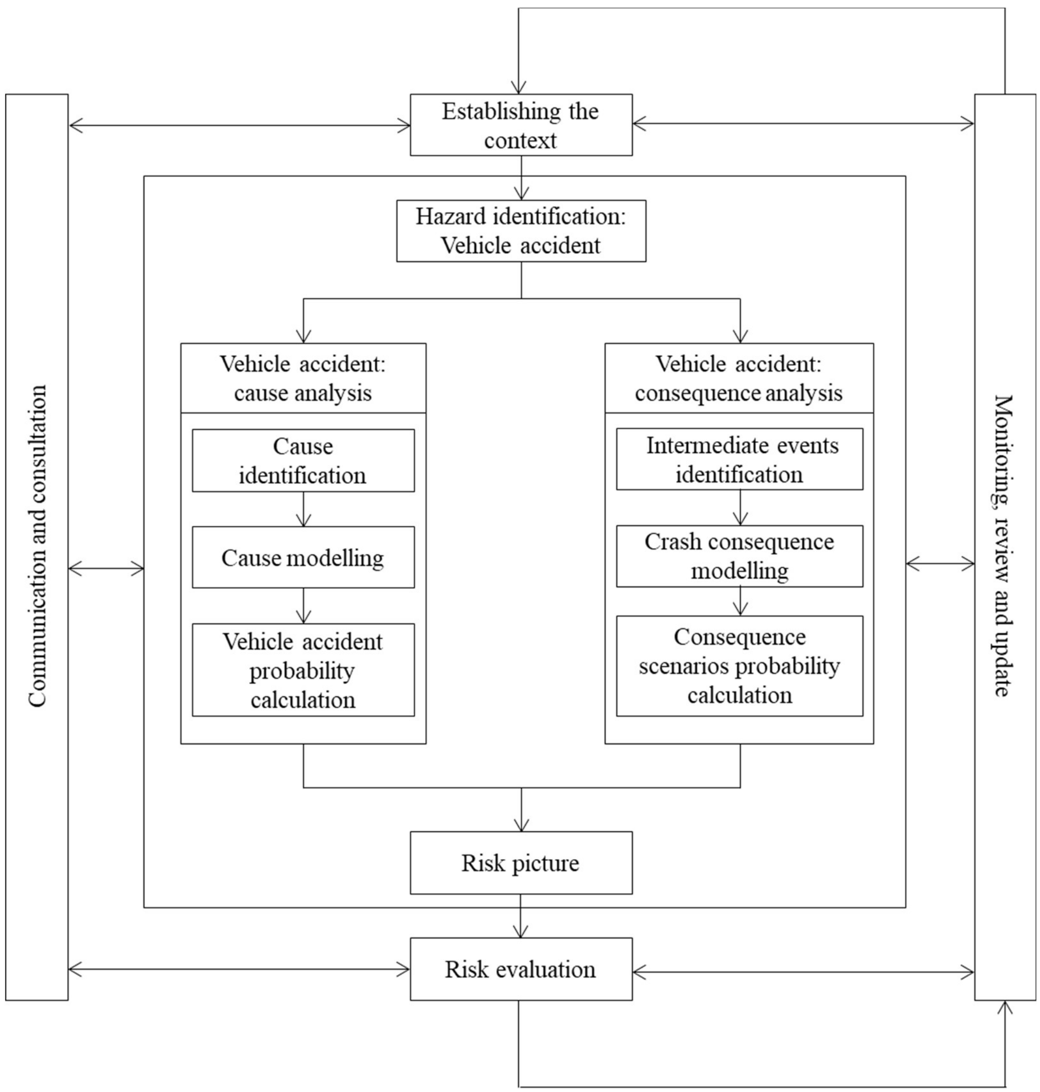


Figure 5 Framework for transportation accident QRA

4.1 Establishing the context

Establishing the context means defining the basis of the assessment. Scope, limitations and methods should be defined. Scope should define to what extent the assessment will cover, it can be for all people affected by the crash, or only for the passenger/driver in the vehicle assessed. Limitations should address the availabilities of the data, tools and resource used. Methods used should be defined and consider the suitability for the assessment.

4.2 Hazard identification

Hazard identification is a critical step in risk assessment. All possible hazards must be identified, because this is the starting point for risk assessment. Unidentified hazard will not be considered further in the assessment, and further, will affect the overall risk picture.

For risk assessment specific to transportation accident, various hazards are present in the situations assessed. In line with the principles of risk analysis, the hazard should be an observable quantity, a quantity of our interest for the analysis and it will have a true value in the future. We classified the hazard we may identify into two categories:

1. Hazards affecting human
2. Hazards affecting goods being transported

The starting point to identify hazards can be based on the two categories. We distinguished the hazard because when we focus on human, the hazards will be different than when it is affecting the goods. It also means that our interest is different when we focus on people or goods. The main idea is that we must focus on our quantity of interest, with goods we may be interested in how intact the goods is during transportation, meanwhile with human we may be interested in fatality.

In our study, the focus is given to vehicle accident with respect to the condition of human (vehicle passenger) as the top event. From the top event, we may establish analysis for the cause leading to the vehicle accident and the consequences resulting from the accident.

4.3 Accident cause analysis

Accident cause analysis is performed to get an understanding of the sources of the vehicle accident and how likely it is to happen. Significant sources of accidents and their respective basic events should be included in analysis. The objectives in the cause analysis are

1. To identify possible causes and understand the characteristic of the phenomenon
2. Establish the probability of the initiating event

We have identified the following three categories as the common main sources of accidents, but we are not limiting the analysis to these three categories. The three categories are vehicle driver failure, vehicle component failure and environment condition at the site of accident.

In the vehicle driver failure category, the analyst should identify the conditions which the driver can potentially lose or fail to control the vehicle that leads to accident. The condition may be unique from one specific to another and it is the analyst's task to define the characteristics of the driver in the area of interest. The conditions may come from breaking the rule, behavior, or just simply distracted. Some conditions that need focus on analysis are:

1. Distraction
2. Exhaustion
3. Drowsiness
4. Illness
5. Rule adherence
6. Speed limit adherence
7. Psychological condition
8. Alcohol influence

9. Drugs influence

Vehicle component failure should consider which of the component that may significantly cause an accident. As we covered in section 2, mechanical failure of a vehicle may also be influenced by the human (vehicle owner) characteristic and vehicle inspection, which resulted in the typical maintenance system of the vehicle, and the environmental factor. In this condition, the driver is considered to be in perfect condition that they are fully able to control the vehicle, obeying the rule and free of any psychological condition, but the component in the vehicle fails to function properly and therefore causing accident. The component failure that is common as vehicle accident cause are:

1. Braking components
2. Steering components
3. Tires
4. Front and rear axle
5. Lightings

In the environmental factor, any external condition other than the driver and the vehicle happening as the source of the accident should be considered. It should be clear that different areas must have different distinctive characteristics in the environment and these characteristics must be specified. The environmental factor that may cause vehicle accidents are

1. Road condition
2. Weather condition
3. Landslide
4. Natural disaster

Every analysis of the factors identified must be performed with regards on the area characteristic and their frequency of occurrence using historical data, if available. After the factors are analyzed, we develop a model representing the cause of our main interests, the vehicle accident. And this vehicle accident is considered as the initiating event in our study.

4.4 Accident consequence analysis

Accident consequence analysis is the analysis of event sequence after the vehicle accident happened. The event sequence must have a result of scenarios that may happen and their final consequences. Every scenario identified must have a calculation of probability (or any other uncertainty measures used) to reflect how likely the scenario will happen. The objectives of consequence analysis are

1. Identifying the outcome of initiating events
2. Identifying possible escalation scenarios
3. Establish the uncertainty distribution for every scenario identified

In the consequence analysis, any event and condition between start of the accident and the final condition of the accident must be identified. We may call the events as the “intermediate event” as Meng et al. (2010) used the term. Some of the intermediate event and condition that may be considered as potential escalation are

1. Vehicle speed at accident
2. Functionality of a vehicle’s safety feature

3. Road type
4. Traffic situation
5. Passenger situation

We may develop a model to construct the scenarios when a vehicle crashed until the final condition. The intermediate is considered as the basis to calculate the uncertainty distribution for every scenario in the model.

Speed is the condition that is most associated with the consequence of an accident. An analysis should be done to account the link between the speed of a vehicle and the consequence of an accident when a vehicle is involved in a crash.

Vehicle safety feature must be accounted to the analysis as this is a consequence reducing measure when a vehicle accident happened. Different type of vehicle will have a different kind of safety feature. An analysis of how the safety measure can affect the consequences of the accident should be considered.

The situation on the road, how busy is the traffic will affect the consequences as it will affect the speed when an accident happened and how many vehicles will be involved in the accident. Speed is closely related to the outcome of accident, as the higher the speed at accident, it is more likely to have a fatal consequence. The same goes with the traffic situation, the busier the traffic means it is more likely that the accident will involve another vehicle.

Passenger vehicle situation should be considered in the analysis. Vehicle occupancy are different for every kind of vehicle. If we have accidents with similar magnitude, vehicle with lower occupancy may have a lower severity than vehicle with higher occupancy as the number of passengers exposed to the hazard is lower.

4.5 Risk picture

The result from accident cause and consequence analysis should be documented and presented in a risk picture. The risk picture should be clear and present the scope and limitation of the analysis performed. Every result should show the risk level we are facing and what factor contributes the most to that level of risk. Risk acceptance criteria may be introduced to compare with the present risk level. And if the risk level considered too high, we may identify and introduce a risk-reducing measure.

4.6 Risk evaluation

Risk evaluation assesses the risk presented in the risk picture and gives the decision whether a risk reducing measure is needed or the risk is acceptable. When the risk level is not acceptable, then a risk reducing measure should be implemented and this process should be monitored and reviewed.

4.7 Monitoring and review

Monitoring, review and update is an important part as this will keep the validity of the risk assessment. Any risk reducing measure implemented should be monitored and reviewed for their effectiveness. Any changes in the process should be monitored and if necessary, should be reviewed to update the context in the risk assessment.

4.8 Communication and consultation

Communication and consultation should be an inclusive and a learning process for stakeholders and all personnel involved in the risk assessment. Any concern from the stakeholders should be considered and must be integrated into the risk assessment process. This process should also be a learning process, as all the stakeholder involved in the transportation activity should be informed of the risk identified in the activity.

5 Quantitative risk assessment

5.1 Scope and limitations

In the quantitative risk assessment, we are focusing on the occurrence of vehicle accident. There are four types of vehicle that we assess: car, motorcycles, bus rapid transit and commuter rail system. For each type of vehicle, we perform cause and consequence analysis to obtain the risk picture.

In the cause analysis, we model the cause of vehicle accident using the fault tree model. Using the model, we establish the uncertainty distribution for the occurrence of a vehicle crash, we use probability as the measure of uncertainty. We assess every cause identified and we assign a probability distribution to the basic event. From every basic event, we establish the probability distribution of the top event, vehicle crash, using Monte Carlo simulation.

The same method (with cause analysis) applies to the consequence analysis. From the top event vehicle crash, we identify possible scenarios of the consequences. We model the consequence using the event tree method. In the event tree model, we identify the intermediate events to produce the escalation scenarios. For every intermediate event, we assign a probability distribution. Using the model, the intermediate events and the assigned probability distributions we can establish uncertainty distribution for the consequences.

The data we are using is mainly from the statistical bureau of Indonesia, some historical data regarding accidents is available. Some data represents the occurrence of accidents in the road of Jakarta by type of vehicle and some represents the accident occurrence in Indonesia. Other relevant studies for vehicle accident are considered to improve the analyst's knowledge regarding how vehicle or driver behave at time of accident.

5.2 Hazard identification

In this risk assessment, we focus on the occurrence of vehicle crash. This means that other hazard will not be considered further in the assessment and our main quantity of interest is the occurrence of vehicle crash. We define the vehicle crash as *an event of vehicle accident involving one or more vehicle*. Vehicle crash is a clear quantity of interest, as we may easily distinguish between a "crashed" vehicle and when they are not. In our analysis, this means the top event is *vehicle crash*.

5.3 Car accident

Using the framework for transportation accident we developed in section 4, we perform cause and consequence analysis for car crash. In Jakarta, car is the first choice for family in the middle-class and upper-class income. Based on the data of registered vehicle in Jakarta, 3.5 million car is road-legal and according to Susilo, Tjoewono, Santosa, and Parikesit (2007), the average occupancy of private car in Jakarta in 2000 is 1.75. Based on these numbers, car is responsible for the commuting activity of around 6.1 million people daily. In this study, we identify car crash cause and consequences to provide the risk insight to the car user.

5.3.1 Cause analysis

5.3.1.1 *Cause identification and modelling*

We identify the main causes of car crash, and in line with Santosa et al. (2017) and van Schoor et al. (2001) we recognized the three main factors: driver error, mechanical failure and environmental

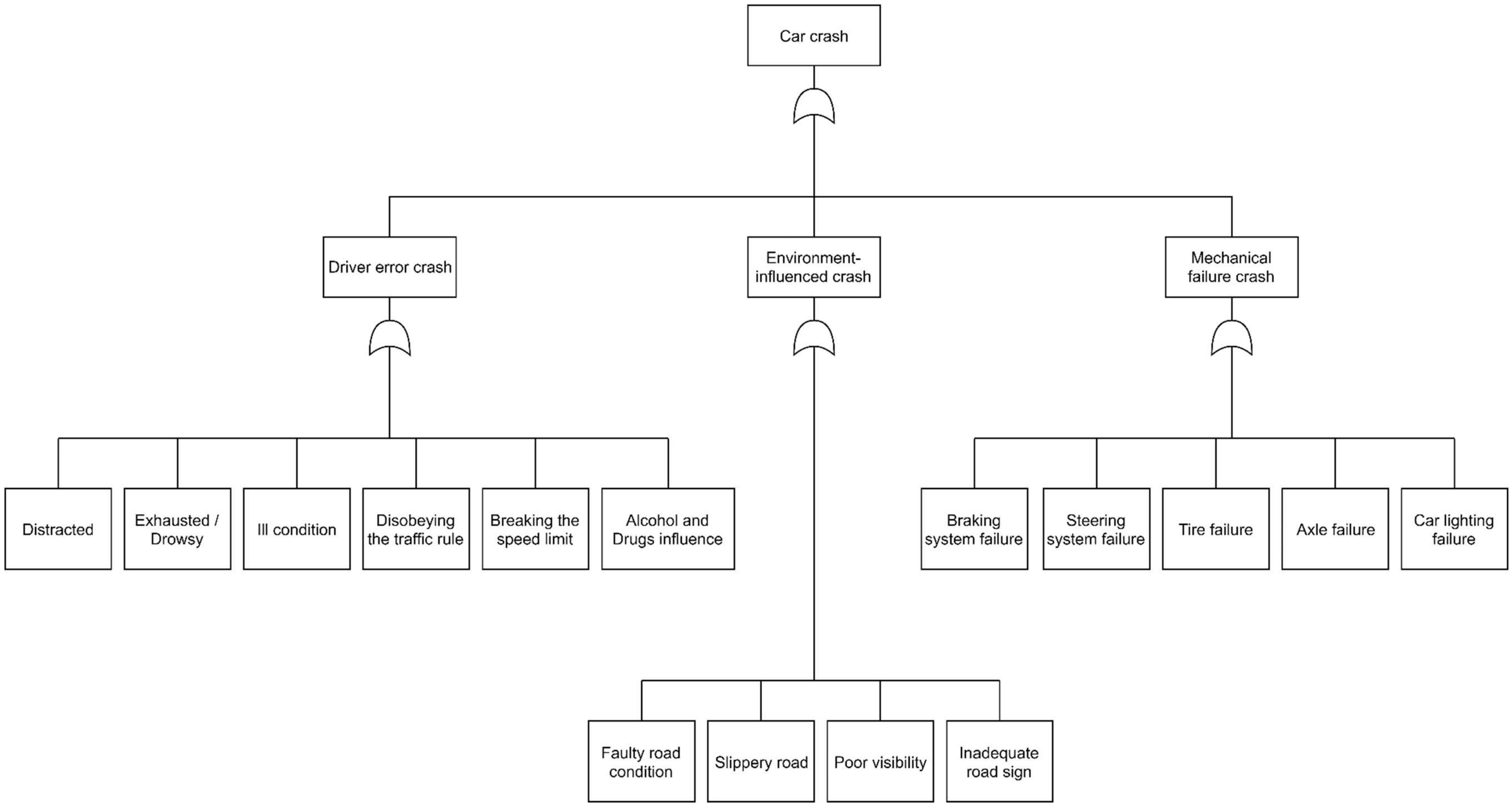


Figure 6 Fault tree model for Car crash

factor (surroundings of the car when running, external component). From these factors, we established the model of car crash analysis using the fault tree model. Fault tree model of car crash provided in figure 6.

5.3.1.2 *Car crash cause analysis*

Based on the data from Indonesian traffic police (KORLANTAS POLRI), we processed the data for vehicle accident in Indonesia and adopted the data as the share of accident cause for car in Jakarta. In line with the vehicle accident studies we covered in section 2, the most dominant cause for accident is driver/human error. Large gap is present between the driver error and environmental factor and mechanical failure. The rationale behind environmental factor being the number two is that, in Jakarta roads are constantly abused by heavy density of vehicles running above it, heavy rain and floods that come right after. With these conditions, Jakarta roads are frequently damaged, and sometimes the measure to fix it failed to be done. Using these conditions, we assume the car crash share and present the assumed share for car crash cause in Jakarta in figure 7.

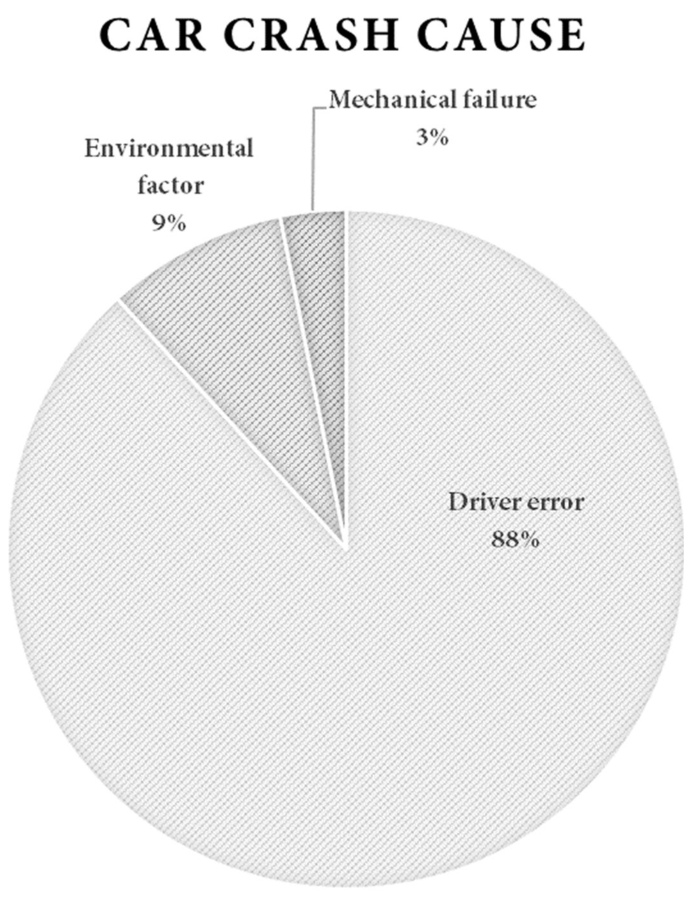


Figure 7 Car crash cause in Jakarta

Using the statistics bureau's historical data of car crash and the assumptions, we predict the expected occurrence of car crash. We found that the frequency of car crash in Jakarta is having the average of 1776 cases. Based on the studies, the growth of vehicle highly correlates to accident rate in Indonesia (Jusuf et al., 2017) and we add correction factor to include this. The correction factor is 1,02, as this number is our predicted growth for car in Jakarta.

Table 19 Car crash frequency historical data

Year	2008	2009	2010	2011	2012	2013	2015	2016
Accident frequency	1 873	2 004	2 102	2 207	2 256	1 348	1 233	1 184
Average frequency	1 776							

With the basis of historical data and the assumptions we use, we establish the expected frequency of car crash in table 20, With this expected frequency, we are assessing the frequency for every car crash cause identified and we assign probability distribution for every crash cause.

Table 20 Expected car crash frequency

Car crash cases	Frequency
Driver error case	1 594
Environment influenced case	163
Mechanical failure case	54
Car crash frequency	1 811

a. *Driver's error*

The Indonesian traffic police provided us with some data regarding car crash with driver error as the cause. We study about each individual cause that is in category of driver error. We identified the cases that falls in category of driver error and characterized which case are the most dominant. Based on the data of KORLANTAS, we assume the share of driver error car crash is divided into 6 cases, with cases that relates to breaking the traffic rule is the most dominant factor in crash caused by driver error. We present the share in figure 8.

From the expected frequency car crash, we use the assumed share of driver's error crash and established the expected frequency of the individual case. The expected frequencies in the individual crash case are going to be used as the basis to assign the probability distribution of crash occurrence in every single case we identified and used in the fault tree model in the section before. We present the probability density function in figure 9 and the knowledge behind it in the following pages. This probability density function is reflecting our judgement towards the occurrence of car crash with driver's error cause in 1-year period.

Table 21 Expected frequency for driver's error car crash

Error type	Frequency
Disobeying traffic rule	733
Distracted	510
Breaking speed limit	223
Exhausted/drowsy	96
Alcohol and drug influence	19
Health condition	13
Driver error car crash	1 594

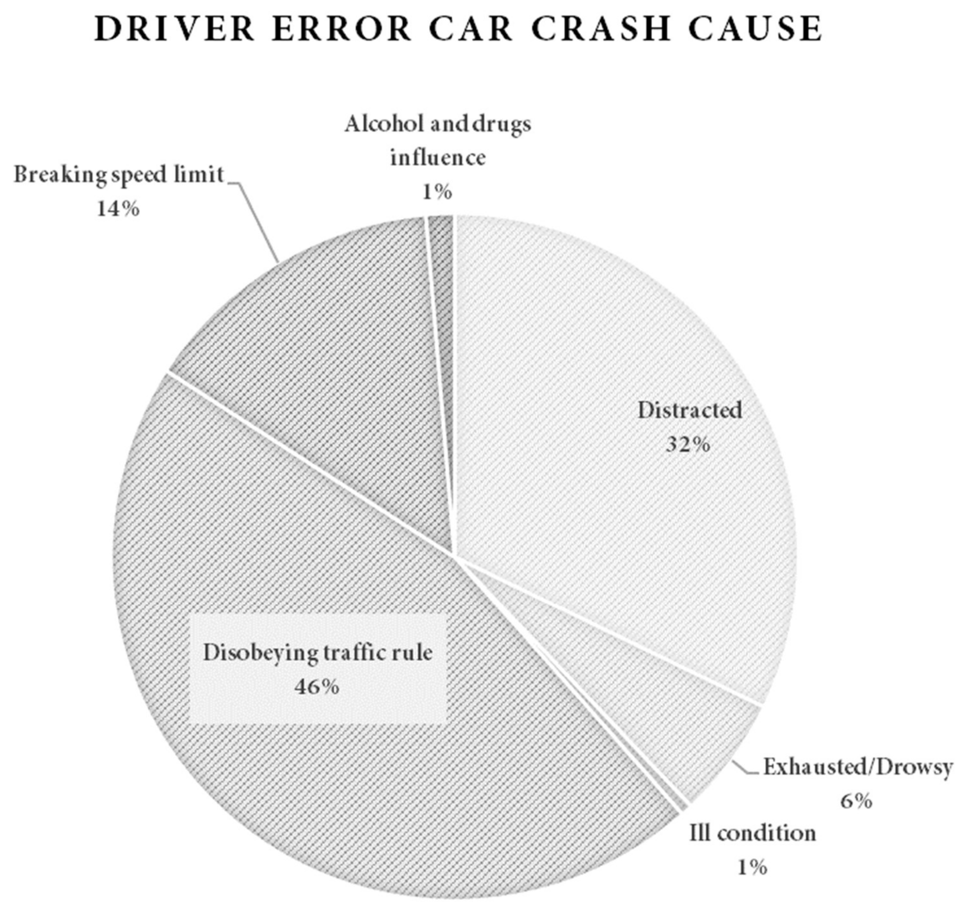


Figure 8 Driver's error car-crash cause

Disobeying the traffic rule & breaking the speed limit

When we use 46% as the share for driver error in violating the traffic rules, we based our judgement on the data of Indonesian traffic police. If we account the number of speed limit violation, we reached the number of 60%, more than half of the share. We judge that the most dominant cause for driver's error is violating the traffic rules. And this number reflects the attitude of drivers in Jakarta towards the rules itself.

Joewono, Vandebona, and Susilo (2015) in their study included the factor of attitude in Indonesian drivers. The result is from a score of 1 (very often violate) to 5 (never violate), they have a score of 3.5 and for us this means that Indonesian drivers are not very good at abiding the traffic rule. As Rahman (2018) said, the drivers can go as bad as driving in the wrong lane just to have a shortcut and even the speed limit violator will not be punished. These conditions are influencing our judgement towards the occurrence of car crash due to violating the traffic rule, making the uncertainty higher. And we reflect our judgment towards the frequency of crash due to rule and speed limit violation in probability distributions.

Distracted driving

We define distracted driving as a condition when the driver is doing his/her primary task in a vehicle, that is driving/controlling the vehicle, intentionally adds a secondary task. In their study, Klauer et al. (2014) identified what is usually drivers do as their secondary task. Cell phone related activities are dominating driver distraction – reaching, dialing, texting and reaching are all considered as distraction – while looking at roadside objects, eating and drinking (non-alcoholic beverage) also considered a major distraction. Among novice drivers, dialing a phone is the most significant risk-increasing secondary activities when driving with odds ratio 8.32 (interpreted as 8.32 crash or near-crash event compared to 1 normal performance driving), followed by reaching for objects other than phone (odds ratio 8.00), reaching for phone (odds ratio 7.05) and looking at roadside object (odds ratio 3.90). For the experienced drivers, dialing a call (odds ratio 2.49) and reaching for objects still have a significant effect of increasing crash risk.

Indonesia have a law to ensure the driver in "full concentration" when driving. It does not specify on how a full concentration is, but some cases involving a phone are considered guilty, even when a driver lowers their focus by looking at a navigation screen. The traffic police are doing the control function for this specific rule, doing some inspectional operations on the street. But we doubt it is the effective way and there is a chance it will not decrease the risky attitude for the coming years unless another measure is established.

Exhausted/drowsy

The drowsiness during driving can cause a massive crash and related heavily to long hours of driving. Reyner and Horne (1998) stated that driver with KSS (Karolinska Sleepiness Scale) of 8 and 9 have significant increase in crash risk. The scale of 8 and 9 means that the drivers are aware that they are sleepy, and they are fighting the sleepiness with some and great effort to stay awake respectively. It is also stated that drivers are aware when they are sleepy but chose to keep fighting the sleepiness for a long time.

In Jakarta, if we are commuting, the average distance is 10 km (Susilo et al., 2007) and it should be a relatively shorter distance hence there should not be any sleepiness-fighting case unless we are forcing our self to drive when we are in KSS scale above 5 (KSS scale 1-5 is the acceptable condition for us). Therefore, we understand that the accident may come from a job that requires a long time in the driving activities itself – vehicle driver as an occupation.

Alcohol and drugs influence

In Indonesia, as reported, the crashes from alcohol influence are very low, contrast from Clarke et al. (2010) said in their study, alcohol is one of the "unholy trinity" of crash cause in the UK. This may be the result of very low alcohol consumption, as drinking alcoholic beverage is viewed as socially unacceptable and the availability of it are very limited. We believe that alcohol will be stayed as minor issue in Indonesia – even less likely to happen compared to drowsiness-induced crash.

Health condition

Some crash reported health condition as the cause. We believe this is the rarest case to happen as a cause to car crash situation. In our study, we do not find many cases where this happen and study regarding the matter are connected to older age and mental problems. We believe this will happen but as a minor cause, as likely to less likely than the alcohol-influenced driving.

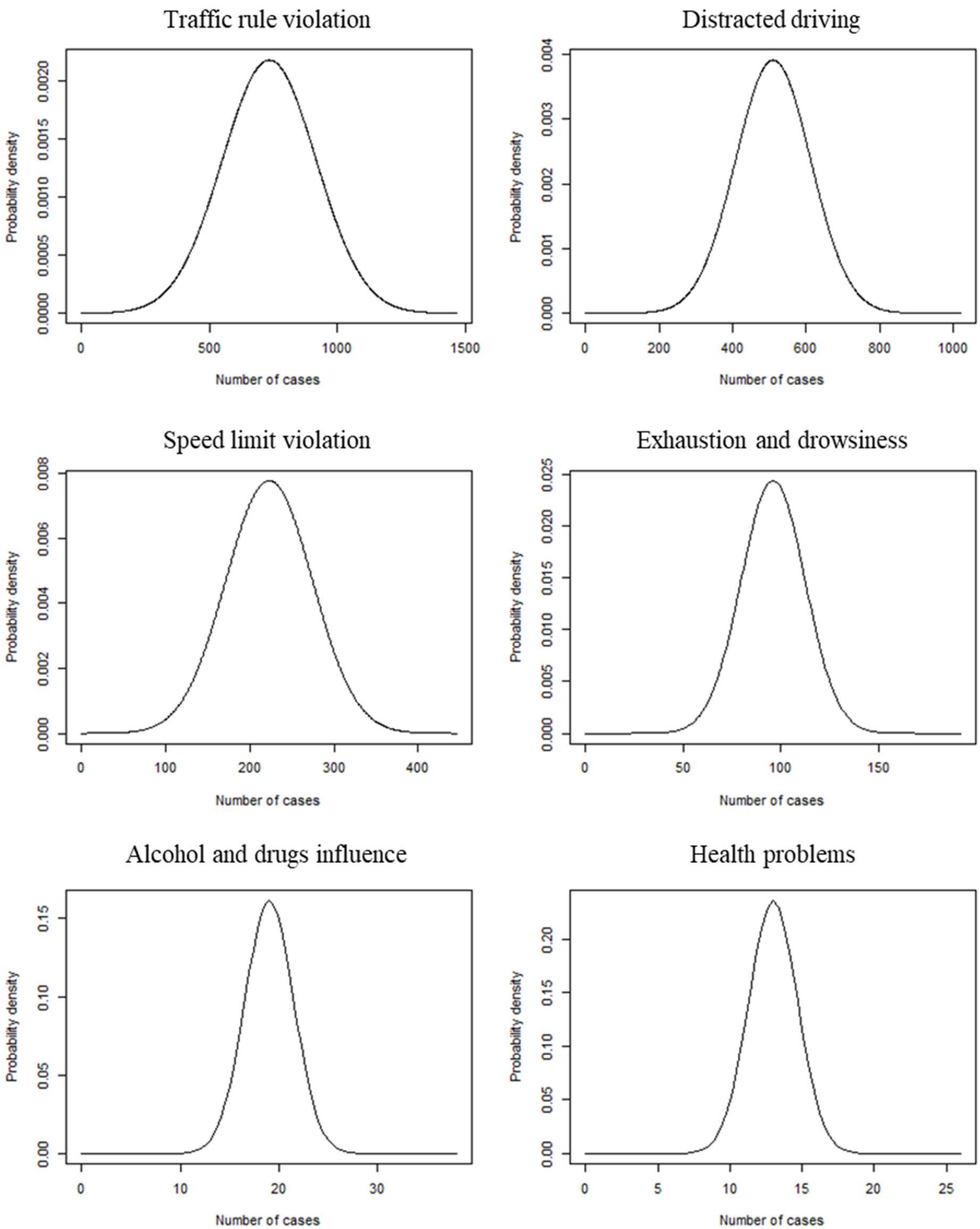


Figure 9 Probability density function for driver's error car crash occurrence in 1-year period

b. Environmental factor

Based on the reported number on the cause of environment-influenced crash we established a share for a car crash with the main crash influence of environment. We put 4 main causes that is likely to happen in the road of Jakarta: defected road condition, inadequate road sign, slippery road and poor visibility. Some cases like landslide and hurricane are not accounted in this analysis, knowing Jakarta is a flat area and located below the equator, wind is unlikely to be a disaster. Flood and rain, including heavy rain are accounted in slippery road and poor visibility.

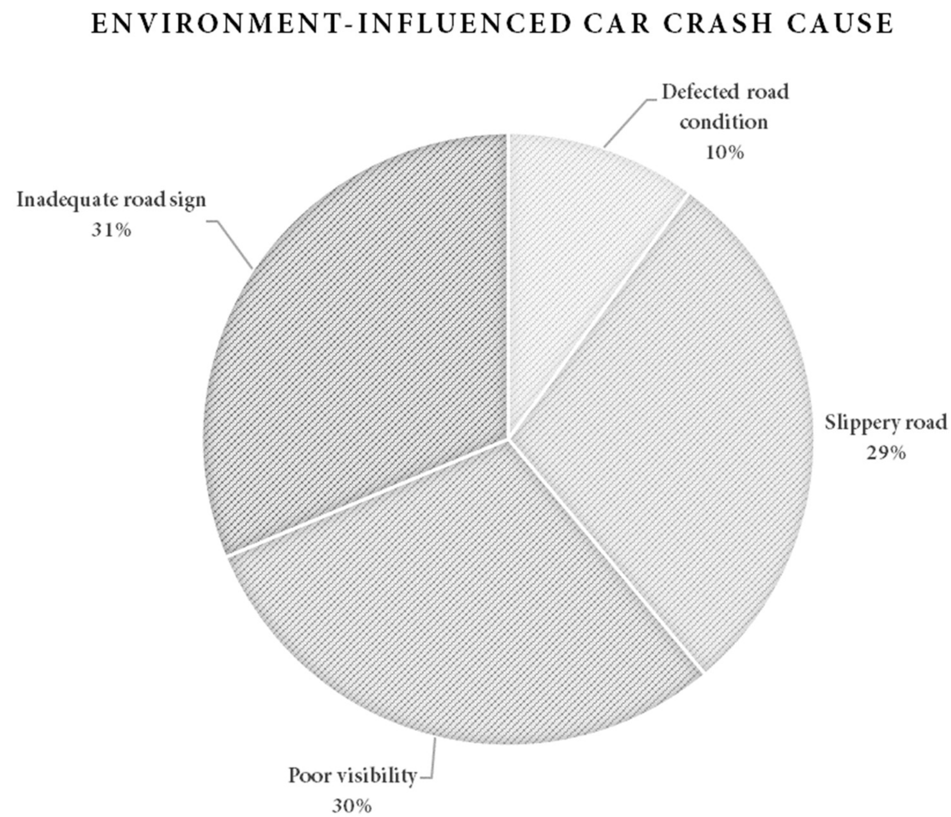


Figure 10 Environment-influenced car crash cause

Using the expected frequency of environment-influenced car crash in table 20, we divide the number in to 4 identified car crash causes with the share we established above. For every environmental cause of crash, we study the characteristic of it for the city of Jakarta and make use the knowledge of it to assign probability distributions. Our knowledge regarding the subjects are presented in the next pages. The expected frequencies and the assigned probability distributions for every case are presented in table 22 and figure 11 respectively.

Table 22 Expected frequencies for environment-influenced car crash in 1-year period

Environment condition	Crash frequency
Inadequate road sign	51
Slippery road	49
Poor visibility	47
Defected road condition	16
Environmental-influenced crash	163

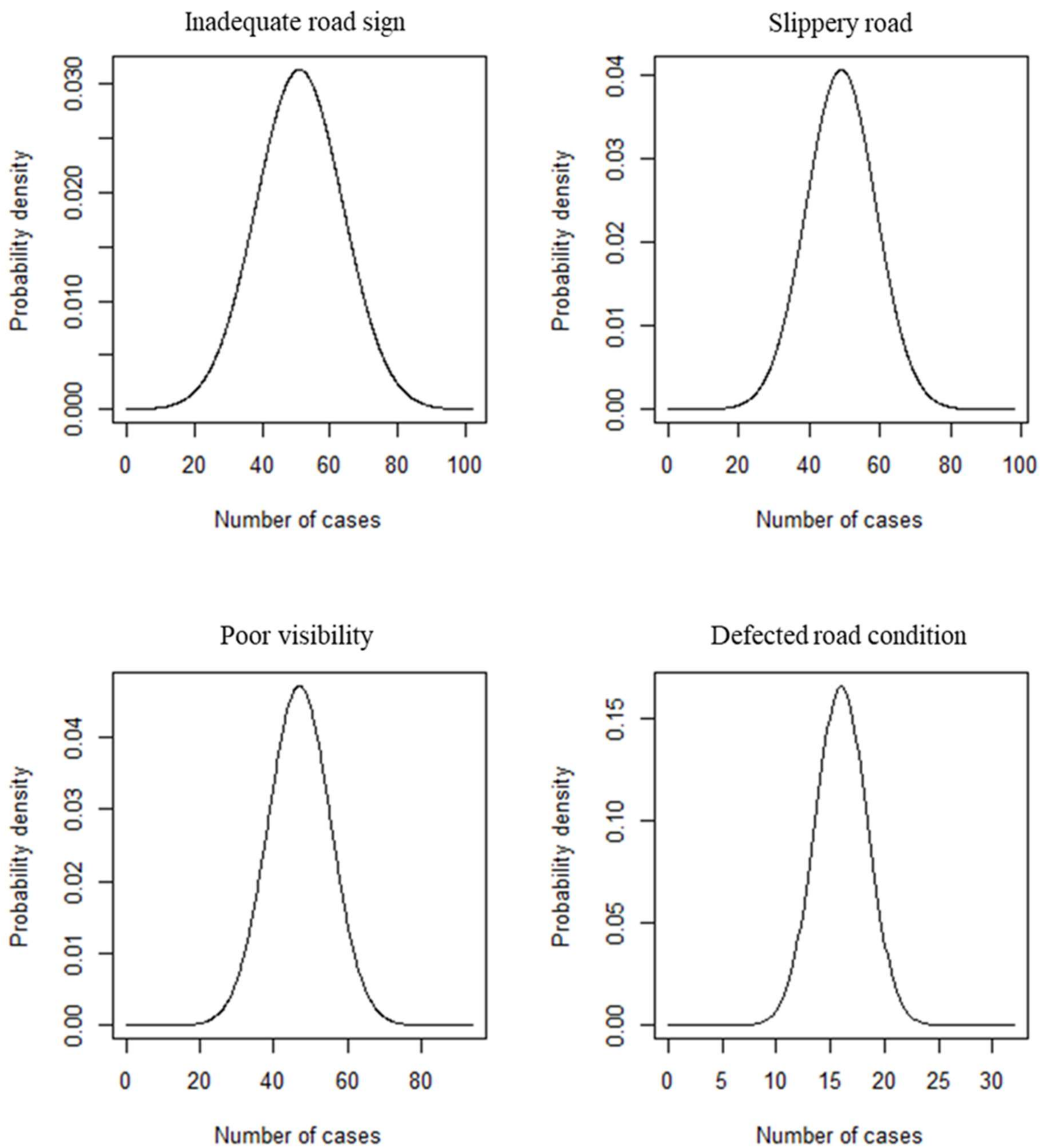


Figure 11 Probability density function for environment influenced car crash occurrence in 1-year period

Inadequate road sign

Road signs are a measure to address road user how to drive properly on a certain road section. It is a way to set a standard on how to behave on the road. With the road signs, driver will know how fast they can go, what is up ahead, whether there is a construction or intersection, if there is hazard present.

Based on the data of traffic police, the absence of a proper road sign is the cause of some cases of car crash. We give focus into some intersections that are not placed in the main roads, but in the local roads, where a traffic light or stop sign may be considered as unimportant. In that condition, a crash with the main cause of inadequate road sign is likely to happen than in the main roads. Considering there are a lot of intersection in the local roads with heavy traffic, we consider inadequate road sign to be the most likely cause for a car crash with environment-influenced case.

Slippery road and poor visibility

For a car crash with cause of slippery road and poor visibility, we relate both causes to a condition of heavy rain. Jakarta has an annual average rain day of 130 and a precipitation of 1 700 mm yearly. When there is water present on the road surface, the grip of the tire surface will not be as good as in dry conditions. The same with vision, heavy rain condition will make visibility not as clear as a clear day. This condition will be possible if rain is present, making this less likely to happen than the case of inadequate road sign.

Defected road surface

It is a common sight to see damaged roads around Jakarta. The frequently reported cause – see Ramdhani (2019) – is the residual water of rain that are left on the road and damaging the road structure, this is due to bad road elevation that makes the water fails to flow to the drain. This condition makes the government of Jakarta struggle to fix every single damaged road, because it happened so frequently as reported by Nailufar (2019) and we know that the hole in damaged road have a gap of 5-10 cm to normal road elevation, making it a possible cause of accident.

In our knowledge, quite a lot of spot in the road Jakarta are potentially causing an accident. Car is a vehicle that has 4-point contact to a road surface, making it stable to stand on their own. The condition of the road must be extremely bad for the car driver to lose control or the car are travelling in a certain speed that makes it possible to hit a bump and lose control. By this knowledge we know that this case is the most unlikely case of all environment-influenced car crash.

c. *Mechanical failure*

The reported occurrence of crash with the cause of mechanical failure are the fewest of other causes. Based on the police report, there are 5 components that are critical and causing crashes: braking system, steering system, tires, axle and lighting. We present the share and expected frequency of mechanical failure in figure 12 and table 23.

Table 23 Expected frequencies for mechanical failure car crash in 1-year period

Mechanical failure	Frequency
Steering system	20
Braking system	20
Tire failure	10
Axle system	2
Lighting failure	2
Driver error car crash	54

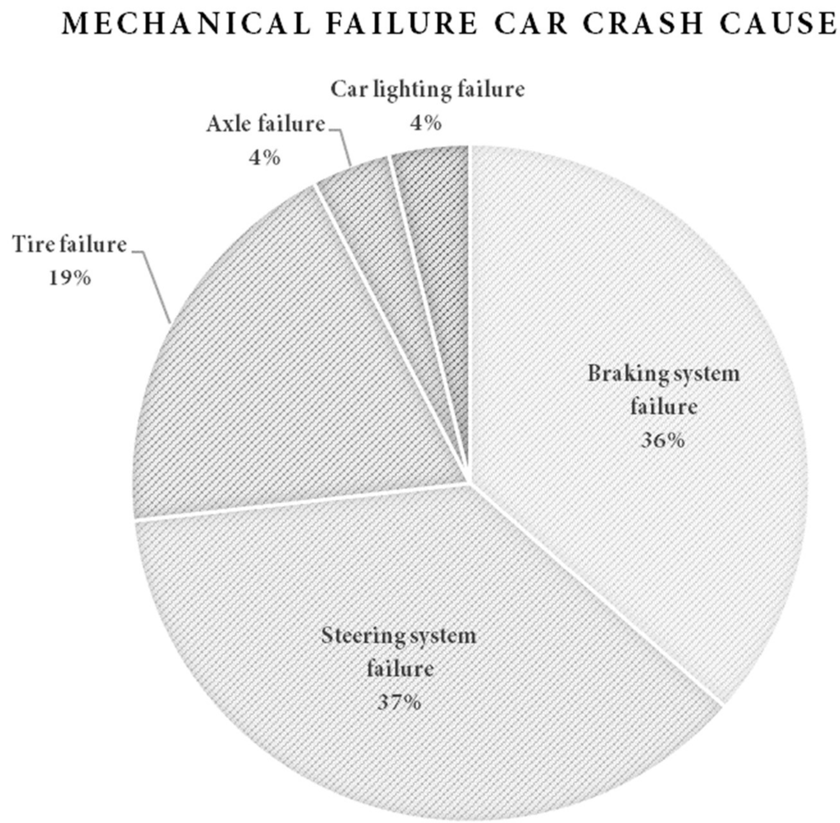


Figure 12 Mechanical failure car crash cause

From the overall data, mechanical failure is the least likely cause of car crash in Indonesia. But we give attention to the highway accident data (section 3.4.2), where mechanical failure ranked second in causing a car crash, this may be due to better road environment in the highway itself.

The most dominant causes are steering system and braking system failure. Steering failure here means that car is not responding properly to the driver, due to failure in power steering system which may be caused by a fluid leak, pump failure or loss of power to the power steering. Braking failure may also due to fluid leak, worn brake pads, and overheating (which may relate to long time usage or harsh environment). Meanwhile tire failure, is due to the wrong air pressure used, as van Schoor et al. (2001) studied. Axle failure and lighting failure is as likely to happen, with axle may be broken due to wear or unsuitable environment, lighting failure is when the car does not have a working light, making them not properly visible to other.

The study of mechanical failures, van Schoor et al. (2001) stated that the difference between areas when identifying mechanical defects are due to methods used in investigating the accident and environmental difference and vehicle condition in various areas. We relate this to how the owner of a car does the maintenance of their car regularly. It is also stated that the correct maintenance is the most important factor when dealing with mechanical failure. In Jakarta, it is a normal procedure to have time based or distance based included maintenance service for newly bought car. So, the focus is given to car when it no longer has maintenance service and when a car is used frequently as a service car or for other needs, making it has a bigger exposure to crash risk.

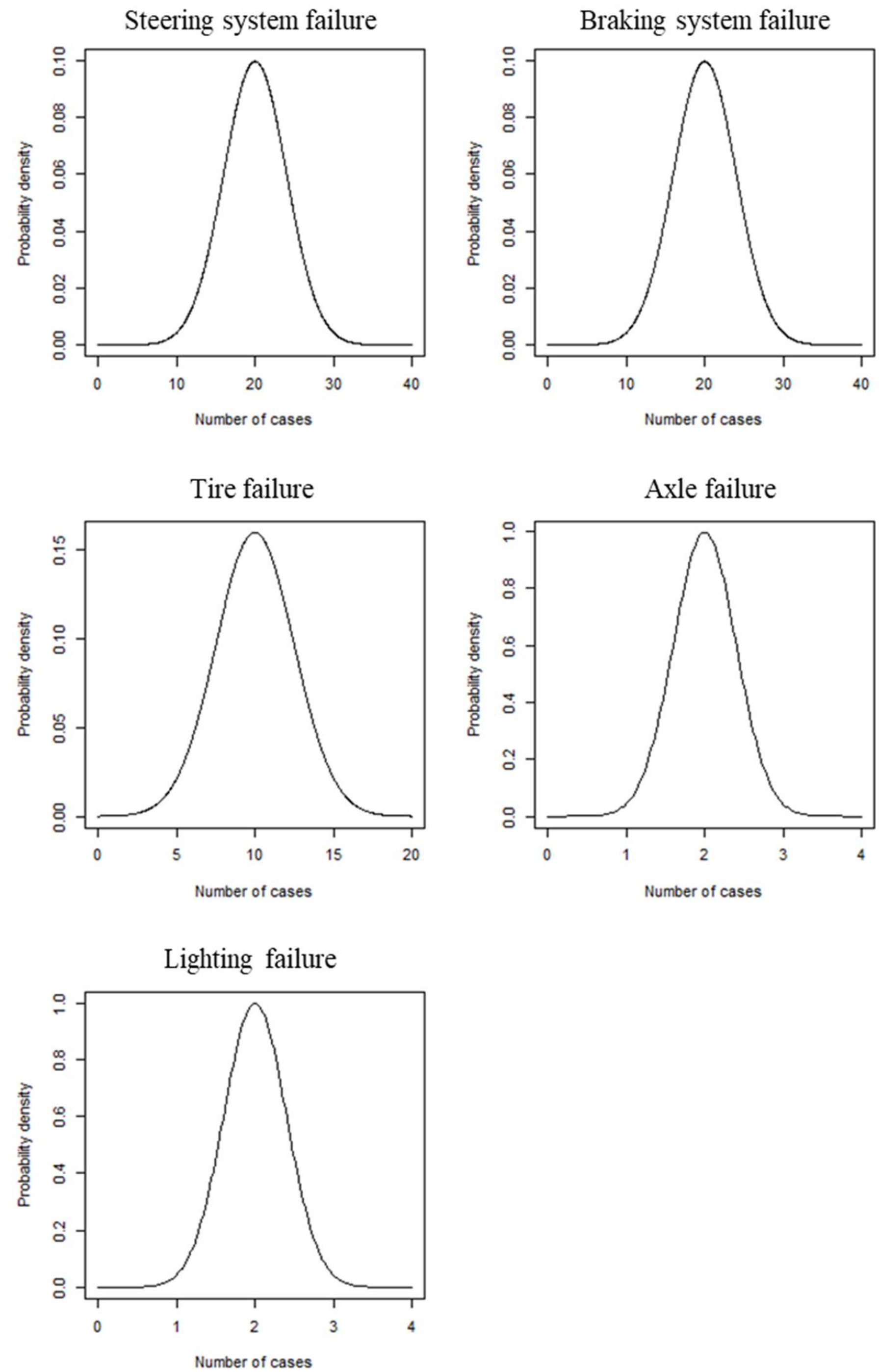


Figure 13 Probability density function for mechanical failure car crash occurrence in 1-year period

5.3.1.3 ***Probability calculation***

For every crash case we identified, we now have the frequency of occurrence with their probability density function (pdf). To assign a probability, we are dividing the frequency of every car crash cause with the total hour car being used.

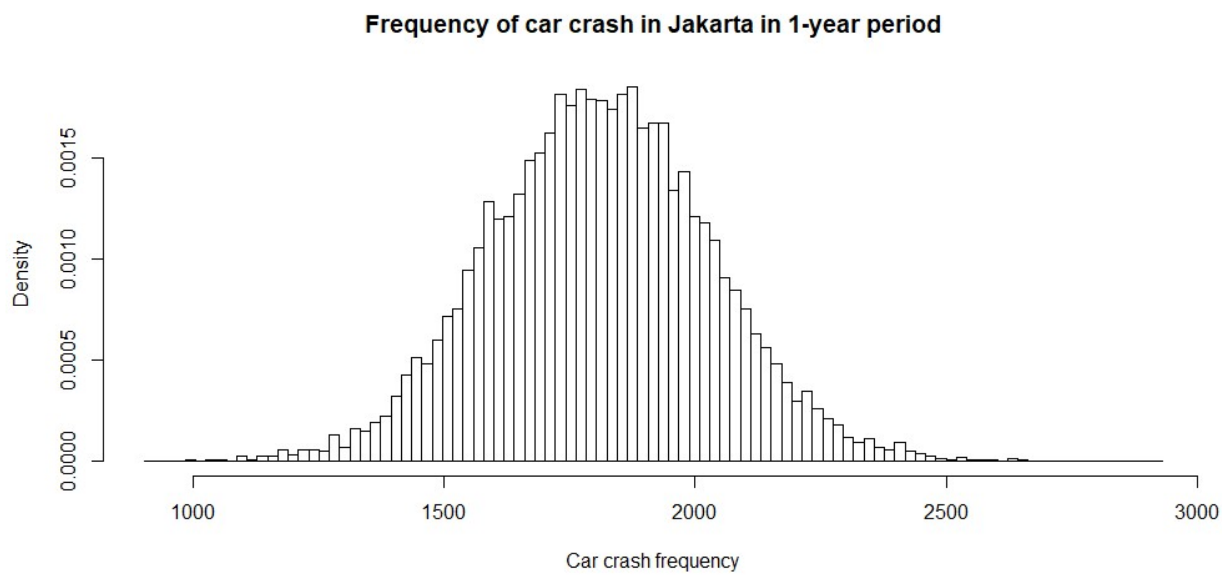


Figure 14 Simulated frequency and probability of Car crash in Jakarta

The total passenger in here is the expected total passenger using car in 1-year. We formulate our knowledge-based probability for car crash case i with

$$P_i(\ Car\ crash\ case\ i\ |\ K) = \frac{Number\ of\ crash\ case\ i}{Total\ hours\ car\ used\ in\ 1\ year}$$

And using the probability of the individual crash, we use it to calculate the probability of car crash in Jakarta. Because the fault tree is using only OR-gate, we can calculate the probability using the sum of all probabilities of car crash cases occurrence, a total of 15 car crash cases are identified.

$$P(Car\ crash \mid K) = \sum_{i=1}^{15} P_i(Car\ crash\ case\ i \mid K)$$

We have *pdf* of every single car crash case and using the model we established we can calculate the probability distribution of car crash occurrence in Jakarta. Monte Carlo simulation is a well-known method to do this step. We use an average of 4 hours for one car per day and we do 10 000 simulations to calculate the probabilities. The simulation result can be seen in figure 14. The probability distribution established from the simulation is our (the analyst) assessment towards how likely one person involved in a car crash in Jakarta. In the distribution, we have a mean of 3,4 $\times 10^{-7}$, and based on the uncertainty standard by Lindley (2014), this probability means that the occurrence of a car crash is comparable to drawing 34 specific ball in an urn containing 10 million ball.

5.3.2 Consequence analysis

5.3.2.1 ***Intermediate events identification and consequence modelling***

The objective in consequence modelling is to understand the possible escalation of a car crash. The escalation is due to what happen between the initial crash and the final condition of the event and we must identify the *intermediate events* to determine how many scenarios are possible in event tree.

There are 5 intermediate events that we identified, and we use these in the event tree as we believe these intermediate events will affect the outcome of a car crash. The intermediate events are high speed at crash, car hit other vehicle, side impact crash, functionality of car safety feature, secondary crash and the occupancy of a car. We apply these events to an event tree model and as a result we have 24 different scenarios. We assess and assign probability to every intermediate event and the occurrence these events are determining the severity of the scenarios. The event tree model is shown at figure 15 and the consequence of every scenario is presented at table 24.

Table 24 Consequence scenarios outcome of car crash

Scenario	Outcome		Scenario	Outcome	
1	1 injury	0 fatalities	13	1 injury	1 fatality
2	2 injuries	0 fatalities	14	2 injuries	1 fatality
3	0 injuries	0 fatalities	15	2 injuries	0 fatalities
4	0 injuries	0 fatalities	16	3 injuries	0 fatalities
5	2 injuries	0 fatalities	17	2 injuries	2 fatalities
6	3 injuries	0 fatalities	18	3 injuries	3 fatalities
7	0 injuries	0 fatalities	19	3 injuries	1 fatality
8	0 injuries	0 fatalities	20	4 injuries	2 fatalities
9	1 injury	1 fatality	21	0 injuries	4 fatalities
10	2 injuries	2 fatalities	22	0 injuries	6 fatalities
11	2 injuries	0 fatality	23	1 injury	3 fatalities
12	4 injuries	0 fatality	24	1 injury	5 fatalities

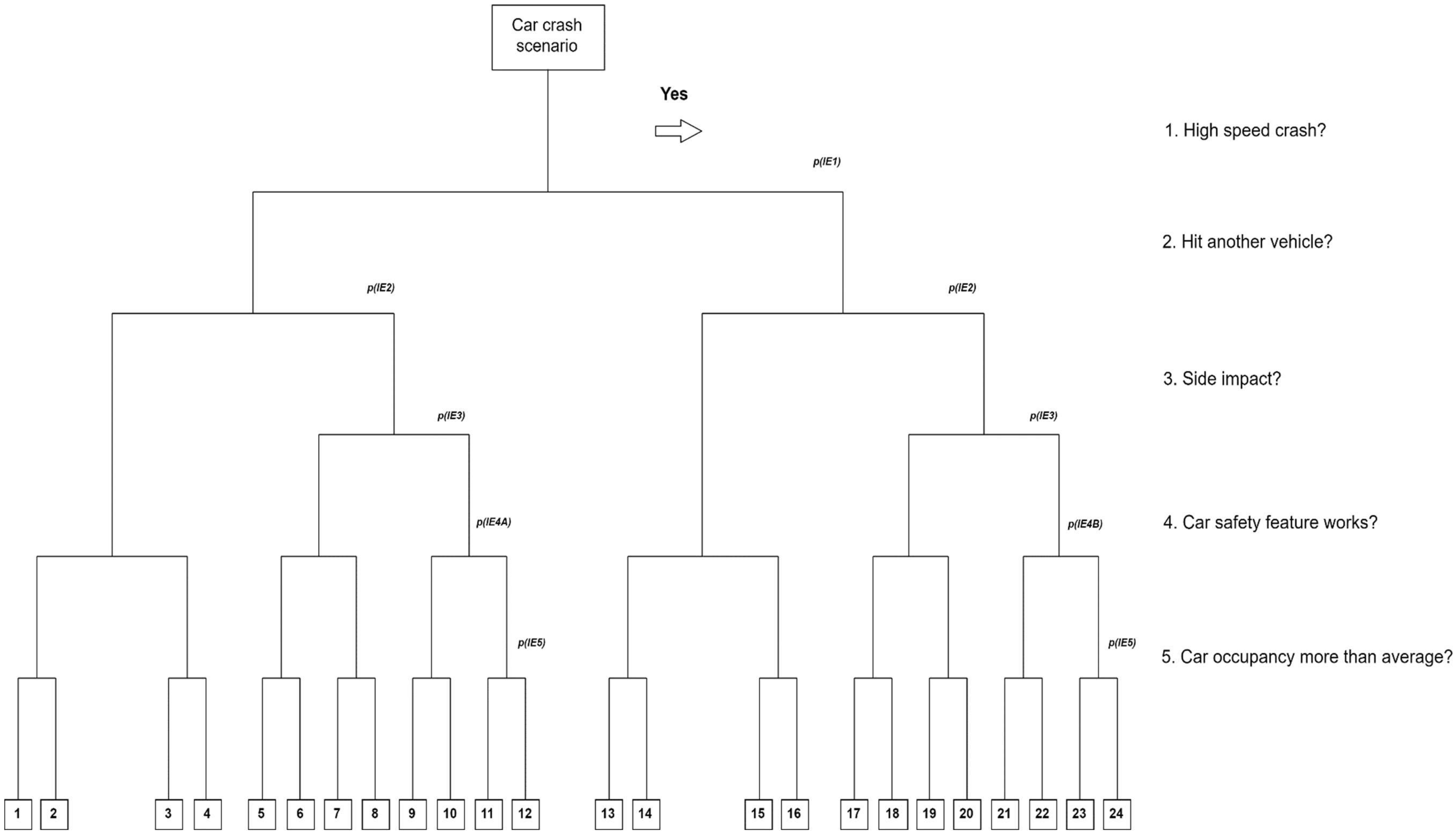


Figure 15 Event tree for car crash

5.3.2.2 ***Intermediate events analysis***

The identified intermediate events are determining the outcome of the car crash. We analyze the occurrence of the intermediate events and we assign probabilities for every event. The analysis we do will be the basis of the probability assigned, it is the knowledge behind the probabilities. Our analysis will be based on the best available knowledge regarding the event analyzed and the data from Indonesian traffic police. The next paragraphs in this section is our knowledge regarding the intermediate events and the distributions used in our analysis are presented in figure 16.

High speed crash (IE1)

Aside from causing a crash, the speed of a vehicle can determine the consequences. As Nilsson (2004) studied, the speed limit on a road is linked directly to how fast the car will travel (because it is the guide for the driver on the road itself), when the traveling car lower their speed, the accident rate, including the injuries and fatalities rate also reduced. This study is summarized in the power functions, we cover this in section 2. From the power functions we know that, the higher the speed a car travels, when it crashed, it will have a more severe outcome.

In Indonesia in 2013, 13 273 out of 100 106 cases of vehicle accident are due to violating the speed limit. The speed limit of a car traveling in a non-highway road is 80 km/h and in highway it is 100 km/h, meaning the speed limit violation cases are when the cars are traveling above said speed limits. In other studies, Nusholtz et al. (2003) and Evans (1996) about the effectiveness of airbags and safety belts respectively in relation to crash speed, stated that both safety measures effectiveness are decreasing when the speed increase. Both studies said that the effectiveness of the safety components are reaching 0% in speed above 65 km/h, in around 65km/h the effectiveness is around 10-20%. This makes that speed above 65 km/h is categorized as "high speed" and we understand that high speed makes the outcome is more severe.

Using the data from Indonesian traffic police, we use relative frequency of the speed limit violation as our probability in the number of 0,1325. To cover the uncertainties, we use the triangle distribution, we use the minimum probability of 0,13 and maximum of 0,15. The right side of the most probable number is bigger to cover the speed between 65-80 km/h as it may not be recorded in the data.

Hitting another vehicle (IE2)

It should be clear that hitting another vehicle affects the outcome of vehicle crash, the possible victims of a crash will increase when two vehicles involved. The data shows that 79715 cases are single vehicle accidents, and this brings us to a probability of 0,7963. We express our uncertainties in uniform distribution on the interval of 0,7763 to 0,8163.

Side impact occurrence (IE3)

We identified side-impact crash to be a factor of severity in car crash outcome. Based on the study of Bedard et al. (2002), the side-impact crash scenario is having twice as much fatality than other crash scenario. This may be due the impact from the side have larger force magnitude to the car occupant.

In Indonesia, 31 345 cases are involving a side impact. Based on this number, we assign a probability of 0,314 and to cover the uncertainties we use the interval in uniform distribution of 0,264 to 0,364.

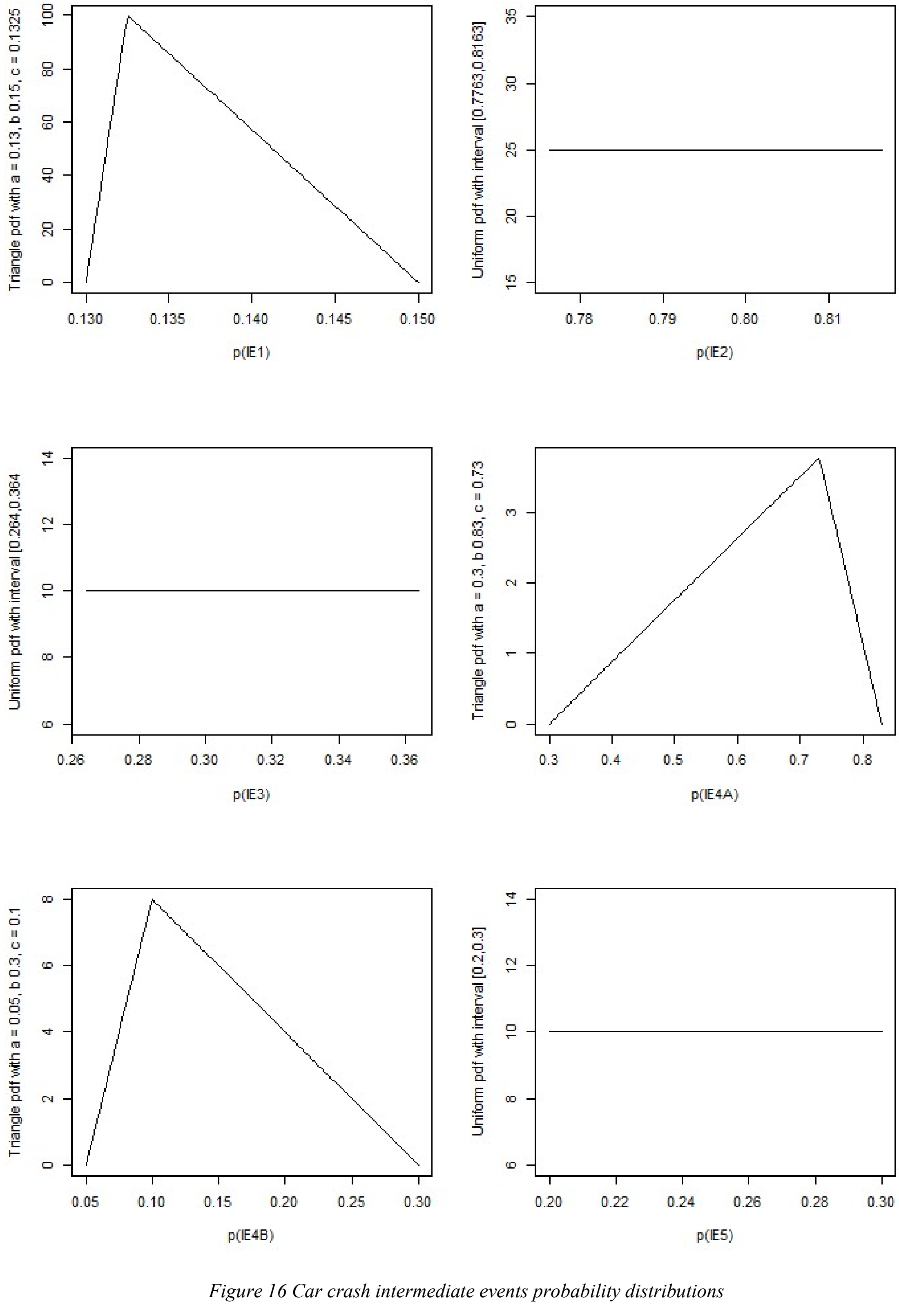


Figure 16 Car crash intermediate events probability distributions

Car safety feature functionality (IE4A and IE4B)

In a car, there are two main safety features that is critical to its occupant, safety belt and airbags. Safety belt functions to keep the passenger in the seat when there is an impact and the airbags protect the car occupant from colliding with the vehicle itself. We refer to the figure in Nusholtz et al. (2003) about the effectiveness of safety belt paired with airbags.

We divide the probabilities of safety features functionality when the car travels at high speed or not. We use triangle distributions to express our uncertainties for both cases. For the not high-speed scenario, we use the probability (min = 0,3, max = 0,83, most probable = 0,73) and the high-speed case we use (min = 0,05, max = 0,3, most probable = 0,1)

Occupancy of a car (IE5)

We take occupancy of car into the severity of car crash outcome. In Jakarta, we use an average occupancy of a car in the number of 2. Probabilities here are expressing our judgement towards the occupancy of a car in Jakarta that has more than 2 persons inside. In our probabilities, we use the uniform distribution in the interval of 0,2 to 0,3.

5.3.2.3 ***Consequence scenarios probability calculation***

In our assessment, we identified 24 scenarios in the event tree model of car crash. This means there are 24 uncertainty distribution that must be calculated. Every intermediate event in the event tree are assigned a probability distribution, and we calculate the propagation of our uncertainty using those probability distributions. For example, scenario number 10 is the worst scenario in our low-speed crash, and we calculate the probability using

$$P(Scenario\ 10) = [1 - p(IE1)] \times p(IE2) \times p(IE3) \times [1 - p(IE4A)] \times p(IE5).$$

Because we are using probability distributions in our event, the propagation of probabilities will not be straightforward. Simulations are needed to establish the uncertainty distributions of the scenarios identified. Addressing this issue, we are using the Monte Carlo simulations in calculating the uncertainty distributions of every scenario. We present our calculation result in table 25 and figure 45, 46, 47 in appendix B.

Table 25 Summary statistics for the probability distributions of car crash scenarios

Scenario	**Uncertainty distributions quantiles**					**Mean**
	0,05	**0,25**	**0,50**	**0,75**	**0,95**	
1	0,029	0,038	0,048	0,061	0,078	0,050
2	0,009	0,012	0,016	0,020	0,027	0,016
3	0,054	0,070	0,083	0,094	0,106	0,082
4	0,017	0,023	0,027	0,031	0,037	0,027
5	0,077	0,101	0,128	0,163	0,209	0,134
6	0,025	0,033	0,042	0,054	0,072	0,045
7	0,144	0,189	0,223	0,251	0,282	0,219
8	0,046	0,061	0,072	0,083	0,099	0,072
9	0,034	0,046	0,058	0,075	0,097	0,061
10	0,011	0,015	0,019	0,025	0,033	0,020
11	0,064	0,085	0,101	0,115	0,134	0,100

12	0,020	0,027	0,033	0,038	0,046	0,033
13	0,0149	0,0165	0,0178	0,0191	0,0209	0,0178
14	0,004	0,005	0,0058	0,0065	0,0074	0,0059
15	0,0015	0,0022	0,0029	0,0039	0,0053	0,0031
16	0,0005	0,0007	0,00098	0,00132	0,00183	0,00105
17	0,040	0,045	0,048	0,051	0,055	0,048
18	0,012	0,014	0,016	0,017	0,020	0,016
19	0,0042	0,0060	0,0080	0,0107	0,0142	0,0085
20	0,0013	0,0019	0,0026	0,0035	0,0048	0,0028
21	0,0176	0,0199	0,0217	0,0238	0,0265	0,0219
22	0,0054	0,0064	0,0071	0,0081	0,0093	0,0072
23	0,0018	0,0027	0,0036	0,0048	0,0060	0,0038
24	0,00060	0,00089	0,00121	0,00162	0,00227	0,00129

5.4 Motorcycle accident

5.4.1 Cause analysis

5.4.1.1 *Cause identification and modelling*

Motorcycles are one of the types of vehicle that runs on a normal road in Jakarta. There are no special lanes for motorcycle to run in Jakarta. This condition makes motorcycles to have almost the same crash cause with cars (the type of vehicle they are sharing the road with), other than their smaller dimension and balance – motorcycles cannot stand straight without support or by the momentum when moving. We removed steering system failure as a cause of crash (compared to the car crash cause), because motorcycles used a simpler system (no power steering) and we believe the case steering system failure is extremely rare. We present our fault tree model in figure 18.

5.4.1.2 *Motorcycle crash cause analysis*

Motorcycle is still the type of vehicle where it depends heavily on the driver to control it. Once the driver loses the proper driving attitude, it may cause a crash. We are still using the same rationale on the driver's error being the most dominant case here, with 86%. The share on crash caused by environmental factor is increased, we use 11%, because motorcycles are more prone to external crash cause, say damaged roads and slippery roads. And the rest is mechanical failure, where it depends heavily on the maintenance of the vehicle itself. We present the share in figure 17.

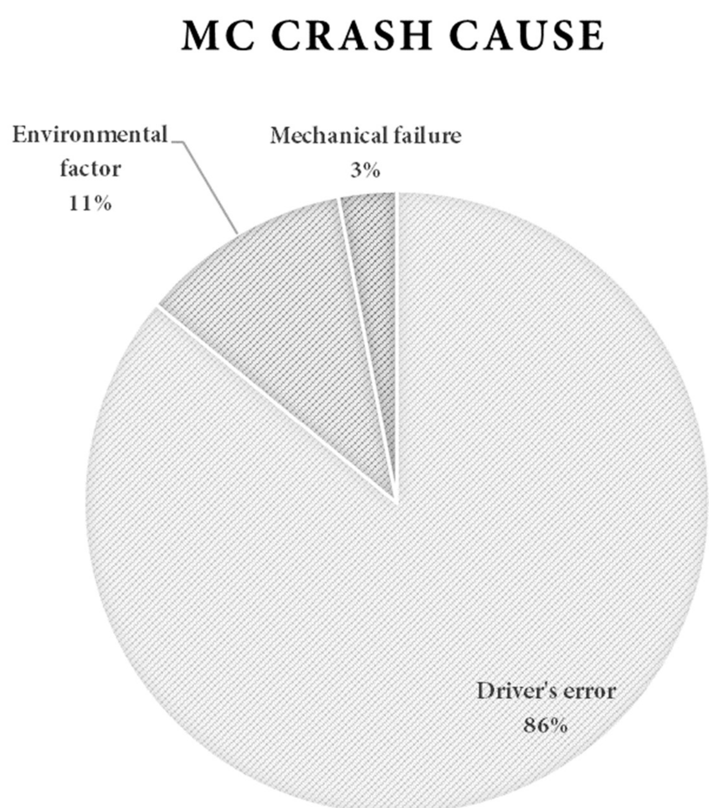


Figure 17 Motorcycles crash cause in Jakarta

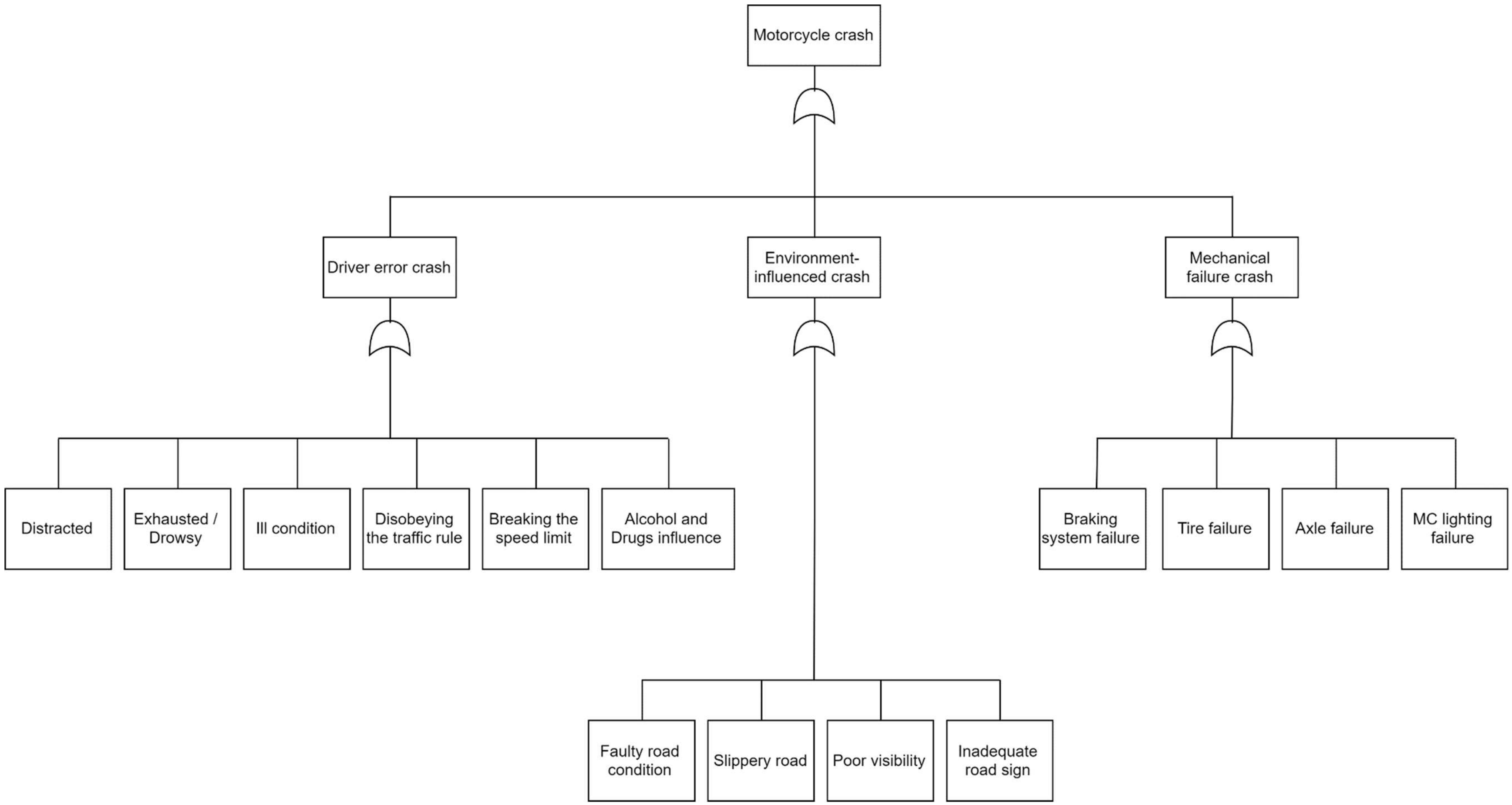


Figure 18 Motorcycle crash fault tree

Using the crash data from Indonesian traffic police, we have the highest number in 2010 with 7787 cases and some major decrease in 2013, with 2 480, This sudden drop maybe caused by the change in recording system or simply variation in the data. We are still going to treat this number as variation, as the true number lies in the distribution we established later in this section. The average of the historical data is 5 557 crash cases in 1-year and using this number we established the expected frequency of motorcycle crash, multiplied by 1.02 to factor the growth of motorcycle number resulting 5 668. The historical data for motorcycle car crash is presented in table 26.

Table 26 Motorcycle crash frequency historical data

Year	2008	2009	2010	2011	2012	2013	2015	2016
Accident frequency	5 898	7 044	7 787	7 641	7 241	2 480	32 31	3 132
Average	5 557							

Using the share in figure 17, we divide the frequency into 3 main causes of motorcycle crash, driver's error, environmental factor and mechanical failure. The frequency for every category is shown in table 27, we see that in the table the expected frequency is 5 668 motorcycle crash cases in 1-year.

Table 27 Expected motorcycle crash frequency

Motorcycle crash cases	Frequency
Driver error case	4 874
Environment influenced case	623
Mechanical failure case	170
Motorcycle crash frequency	5 668

a. Driver's error

In figure 19 we present our judgement towards the proportion of motorcycle crash causes. Our procedure to establish the expected frequency of motorcycle crash is the same with car accident in previous section. Table 28 presents our expected frequency for every crash cause. This expected frequency is used as the basis when we assign a probability distribution to every crash cause. The knowledge behind the cause of motorcycle crash is similar to what we study for car accident, with some difference addressed in the next page. We address the difference in disobeying traffic rule, violating speed limit and distracted, for other causes the phenomena is considered the same in our analysis.

Table 28 Expected frequency for driver's error motorcycle crash

Error type	Frequency
Disobeying traffic rule	2 437
Breaking speed limit	1 267
Distracted	731
Exhausted/drowsy	292
Alcohol and drug influence	97
Ill condition	49
Driver's error motorcycle crash	4 874

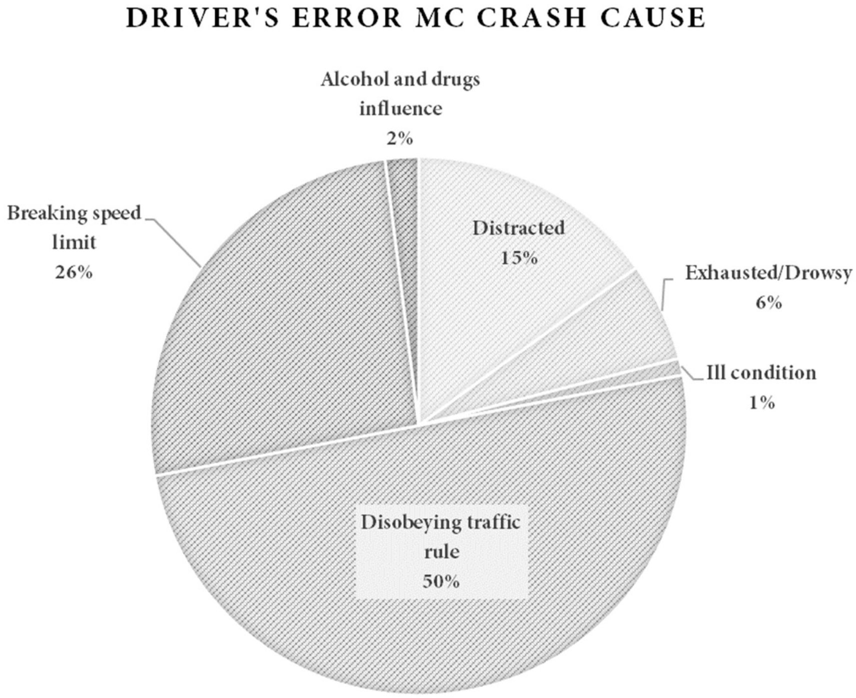


Figure 19 Driver's error motorcycle-crash cause

Disobeying traffic rule & speed limit

Clarke, Ward, Bartle, and Truman (2007) mentioned in their study there are two main condition in motorcycle accidents, right of way violations and losing control on bends/curves. We categorized the first one as traffic rule violation and the latter as speed limit violation in our study. Right of way violations are common in the urban are, especially in the rush hour period and losing control on bends are common on the rural area, when the driver is out for "recreational riding". It is also stated that losing control on bends are more likely to result as a more severe outcome, this is in line with high speed is highly related to severe outcome. We would like to note that driver's error here is not only caused by the driver of the assessed vehicle, but also any type of vehicle running on the road, and here we assess the effect to the motorcyclist – this being said, most of right of way violation case is caused by "looked but did not see" or "inattentional blindness" by other vehicle drivers, this may be due to the visibility of the motorcyclist or the condition of the driver itself (conspicuity, expectation, mental workload and capacity, we refer to Clarke et al. (2007)).

In Indonesian media, it is widely reported that motorcycle is the type of vehicle that is easy to disobey the traffic rule. Driving in the opposite direction lane and driving in bus-only lane are the case of the common and dangerous violation in Jakarta. These phenomena are affecting our assessment towards the occurrence of motorcycle crash, it is easy to violate the traffic rule and some motorcyclists are willing to take the risk. It is reflected in our probability distribution that it is more likely that we have a number of motorcycle crash caused by violating traffic rule and speed limit far exceeding our expected frequency.

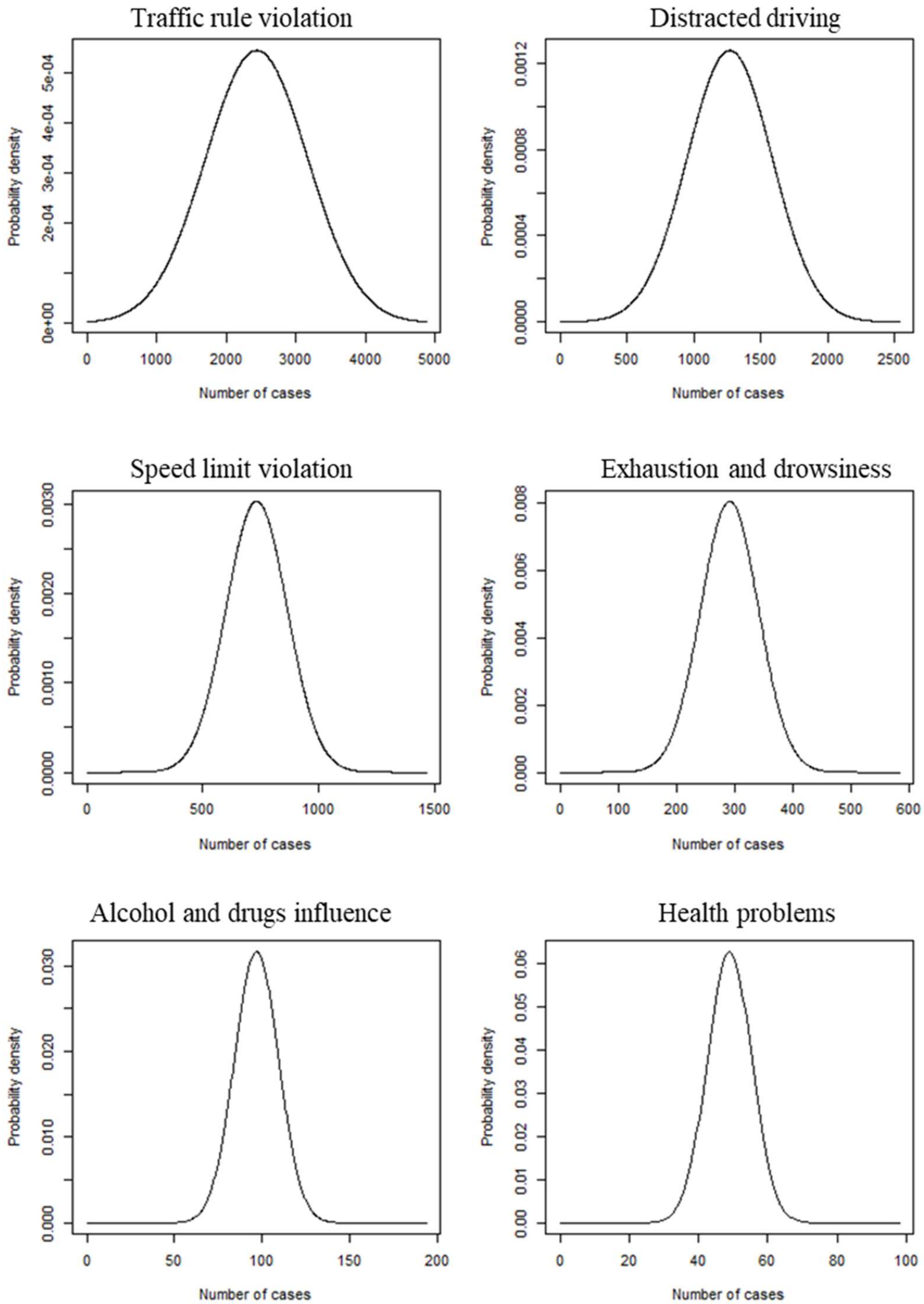


Figure 20 Probability density function for driver's error motorcycle crash occurrence in 1-year period

Distracted driving

In our assessment, we decided that motorcycle requires more focus than car, therefore it is not easy to lose focus when driving motorcycles. Driver must maintain balance during the travel and the secondary task when on motorcycles are limited, eating, drinking, texting and dialing phone number are unlikely to be done when driving motorcycles. What may count as distraction is when the driver is talking on the phone/with the passenger behind and looking at roadside objects. This knowledge is the background of having the distracted driving as the third most dominant cause instead of second.

b. Environmental factor

Environmental factor is still considered as the second dominant cause for a crash. We believe that, in environmental side (external factor), motorcycle crash is most affected by the condition of the road. A road that has hole or uneven will affect the safety of motorcyclist traveling on it. Inadequate road sign is still more influential than poor visibility and slippery road as the latter is conditional on weather and light situation. The share of cause from environment conditions are presented in figure 21.

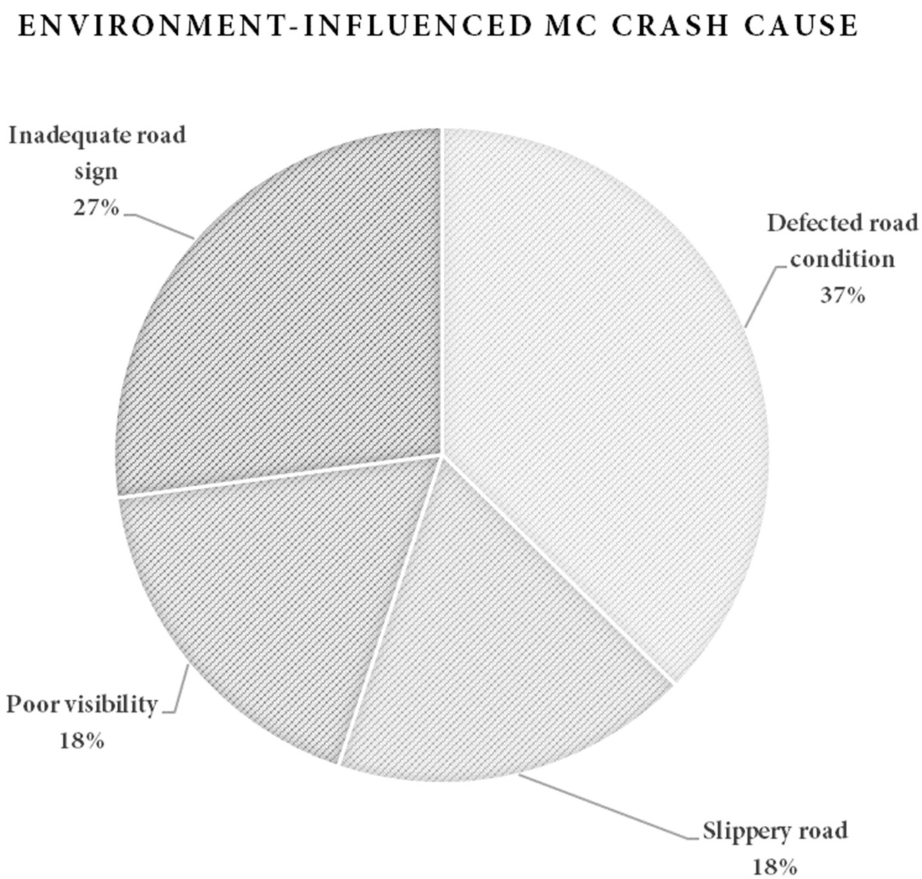


Figure 21 Environment-influenced motorcycle crash

With the expected frequency of motorcycle crash, we divide the number according to the proportion we established. The result is the expected frequency for every crash cause. The numbers are shown in table 29.

Table 29 Expected frequency for environment-influenced motorcycle crash

Environment condition	Frequency
Defected road condition	231

Inadequate road sign	168
Poor visibility	112
Slippery road	112
Total	623

Using our judgement and knowledge regarding the phenomena of every cause identified, we assign probability distribution to the frequency of every cause. Our knowledge regarding the environment-influenced car crash is relevant to the motorcycle crash as well because both are situated running on the road of Jakarta. The distributions are shown in figure 22.

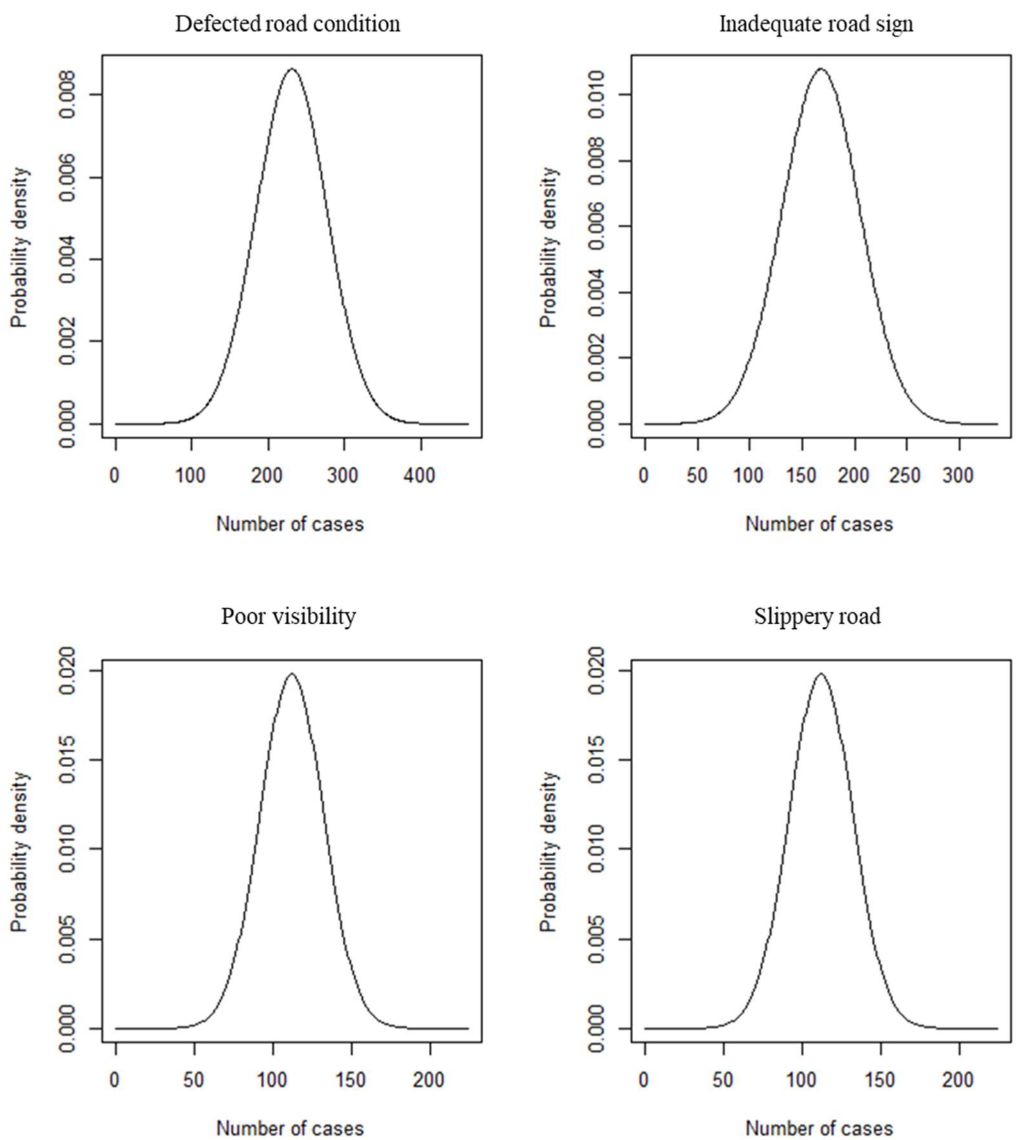


Figure 22 Probability density function for environment-influenced motorcycle crash occurrence in 1-year period

c. Mechanical failure

Mechanical failure category is the least likely to happen as cause to motorcycles in our assessment. We removed the steering system failure in analyzing the motorcycle crash cause, as we believe motorcycles' steering is more straightforward and no assisting system as in car's power steering. By this knowledge we assign braking failure as the dominant mechanical failure cause, followed by tire failure. Axle and lighting failure are minor failure causes as with the historical data of vehicle accident in Indonesia, it is insignificant, but we are still considering it in the analysis. We assign the share of mechanical failure causes in figure 23.

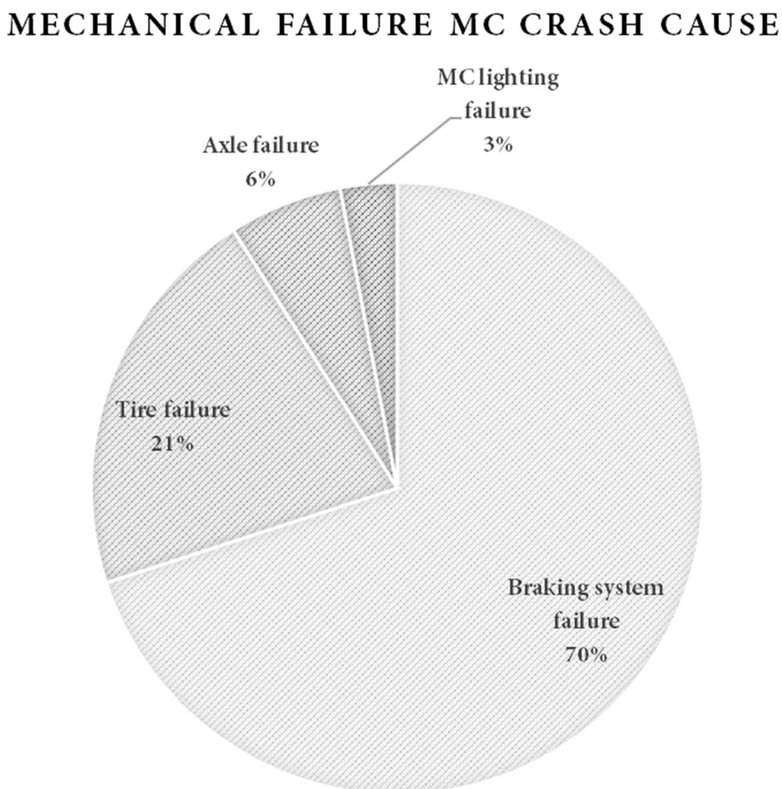


Figure 23 Mechanical failure influenced motorcycle crash

Using the proportion, we assigned and the established expected frequency of mechanical failure causes, we calculate the frequency of every individual cause and it is shown in table 30,

Table 30 Expected frequency for mechanical failure motorcycle crash

Mechanical failure	Frequency
Braking system	119
Tire failure	36
Axle system	10
Lighting failure	5
Total	170

We believe the knowledge regarding the phenomena of motorcycle mechanical failures are the same with car, excluding the steering system. With the same knowledge, we assign our probability distributions to every single mechanical crash cause. The probability distributions are presented in figure 24.

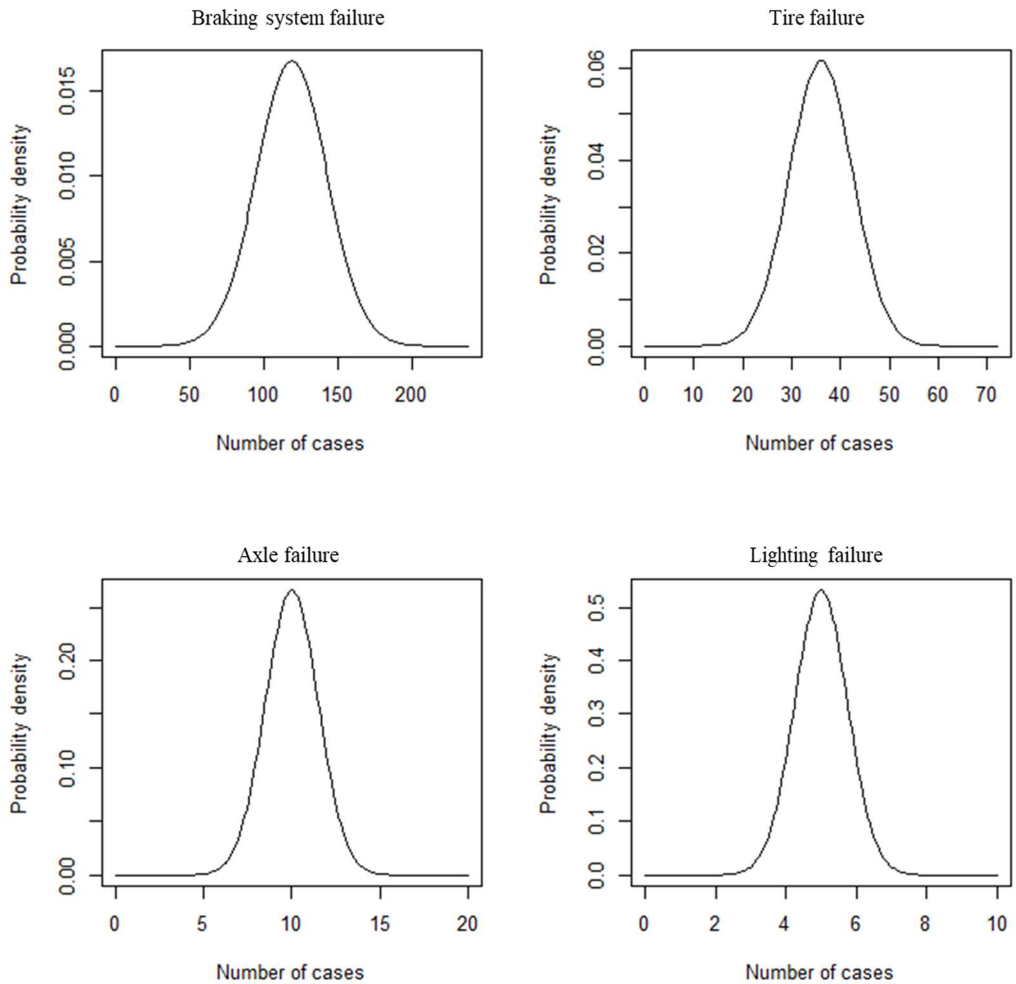


Figure 24 Probability density function for mechanical failure motorcycle crash occurrence in 1-year period

5.4.1.3 ***Probability calculation***

The same procedure applies for the calculation of probability of involvement in motorcycle crash. We simulate the frequency using the individual probability density function assigned for every crash case. After we got the distribution of frequency in motorcycle crash, we calculate the probability by comparing the occurrence frequency with the total time all motorcycles operate in a year in Jakarta. We calculate the probabilities with the following formula

$$P_i(MC\ crash\ case\ i \mid K) = \frac{frequency\ of\ crash\ case\ i}{Total\ hours\ car\ used\ in\ 1\ year}$$

And to calculate the occurrence of a motorcycle crash in Jakarta during 1-year period, we use the following formula

$$P(MC\ crash \mid K) = \sum_{i=1}^{14} P_i(MC\ crash\ case\ i \mid K)$$

Using the formula and Monte carlo simulation to establish the uncertainty distribution of a car crash in Jakarta, we have a mean of $3{,}8 \times 10^{-7}$ and this means it is comparable to drawing 38 specific ball out of an urn containing 10 million balls. The mean here is our expected probability of occurrence, but we must see the uncertainty distribution (figure 25) to obtain the information regarding our uncertainty towards the occurrence of a motorcycle crash.

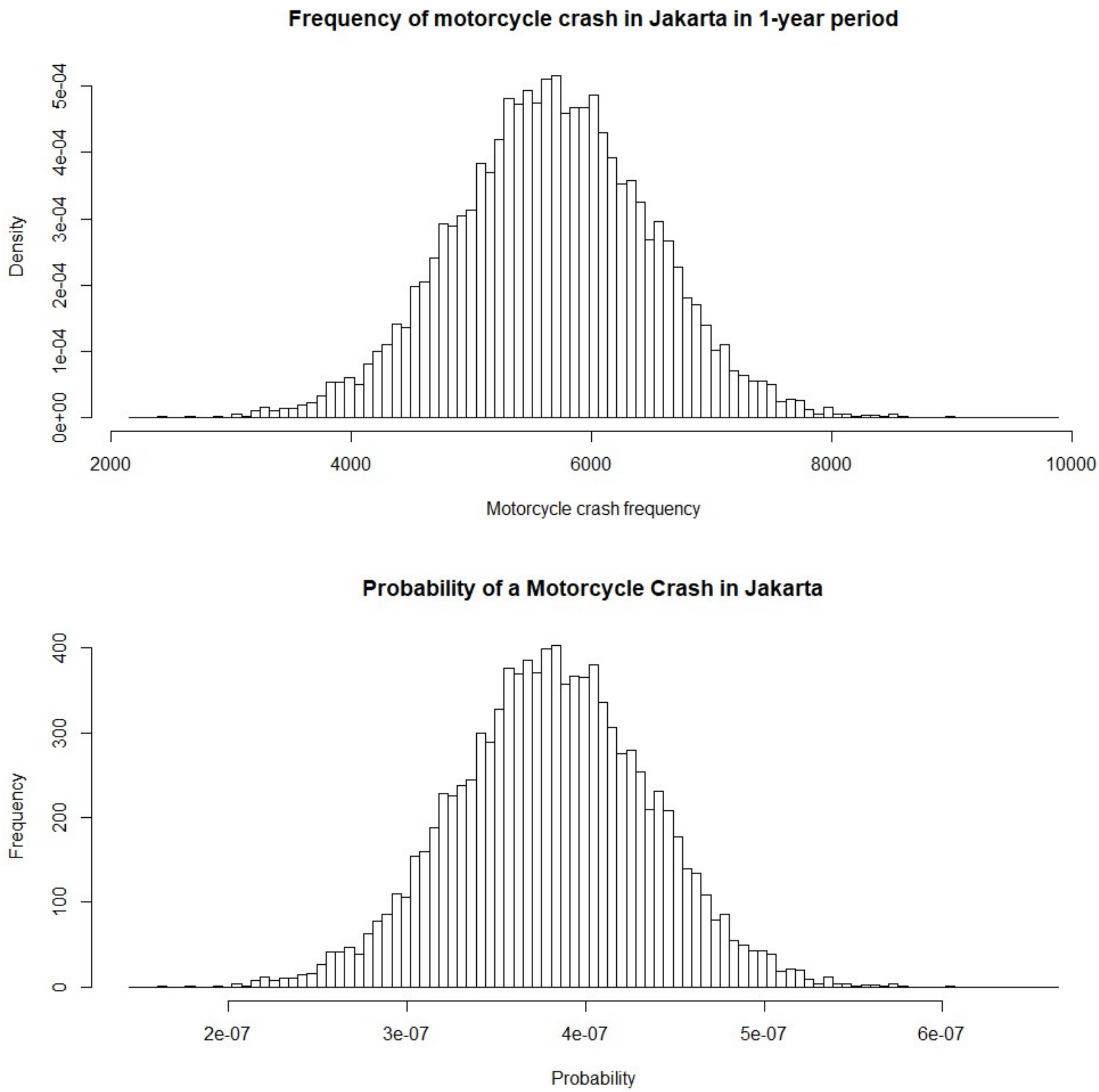


Figure 25 Simulated frequency and probability of Motorcycle crash in Jakarta

5.4.2 Consequence analysis

5.4.2.1 ***Intermediate events identification and consequence modelling***

In motorcycle accident, we identified 4 intermediate events in building the consequence model to identify the possible scenarios. This means we consider there are 4 event that may affect the outcome of the crash. We consider the motorcycle speed at crash, hit/got hit by heavier vehicle, the effectiveness of helmet (head protector) and the occupancy of motorcycles itself. We incorporate the 4 intermediate events to a model using the event tree model. We assign probabilities in the form of probability distribution to every intermediate event for the purpose of establishing the uncertainty distribution for every outcome scenario. We build the event tree and we present it in figure 26.

Table 31 Consequence scenarios outcome of motorcycle crash

Scenario	Outcome		Scenario	Outcome	
1	1 injury	0 fatalities	9	0 injuries	1 fatality
2	2 injuries	0 fatalities	10	0 injuries	2 fatalities
3	0 injuries	0 fatalities	11	1 injury	0 fatalities
4	0 injuries	0 fatalities	12	1 injury	1 fatality
5	0 injuries	1 fatality	13	0 injuries	1 fatality
6	0 injuries	2 fatalities	14	0 injuries	2 fatalities
7	1 injury	0 fatalities	15	0 injuries	1 fatality
8	1 injury	1 fatality	16	0 injuries	2 fatalities

5.4.2.2 ***Intermediate events analysis***

The intermediate events analysis is our knowledge regarding the occurrence of the events. We assign probabilities for every event and this analysis is the knowledge behind the probabilities. The following paragraphs are our understanding about the intermediate events considered. The probabilities assigned are shown in figure 27.

High speed crash (IE1)

When dealing with motorcycle accident in Jakarta, due to the information we have, we must understand that it is easier to violate the traffic rule with motorcycles than cars, including speeding. The knowledge behind high speed driving with motorcycle is covered in our cause analysis, and we use the probability of 0,26 as it is the share of motorcycle accident with high speed. In expressing our uncertainty regarding the probability of occurrence in motorcycle accident with high speed crash, we are using triangle distribution with minimum value of 0,16 and maximum 0,36.

Hit/got hit by heavier vehicle (IE2)

In our consequence analysis, motorcycle hit or got hit by another heavier vehicle will be clearly having a more severe outcome. This means that if this event occurs, then the scenario will be a motorcycle crashed with a heavier vehicle, such as car, truck or bus. Otherwise it is a single accident or motorcycle hit another motorcycle.

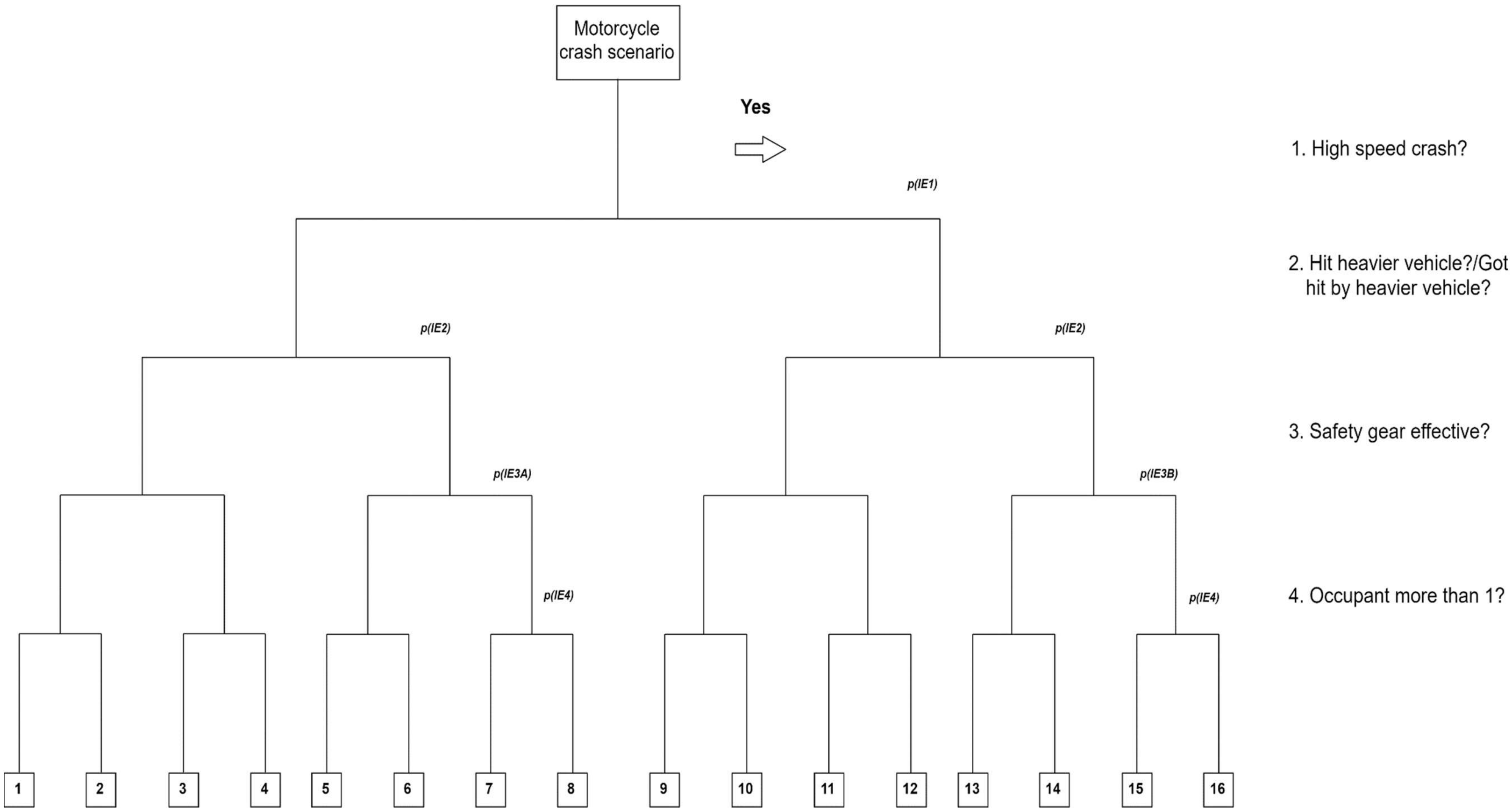


Figure 26 Event tree for motorcycle crash

In Indonesia, almost 80% of crash cases are involving another vehicle, and in Jakarta, the proportion of vehicle heavier than motorcycles are only 25% of total registered vehicle, with the rest being motorcycle category. With this understanding, the probability will be lower than 0,80 (accident cases probability involving other vehicle), and we use the probability of 0,55 in this intermediate event, and to cover our uncertainty in the probabilities, we are using uniform distribution with interval of 0,45 to 0,65.

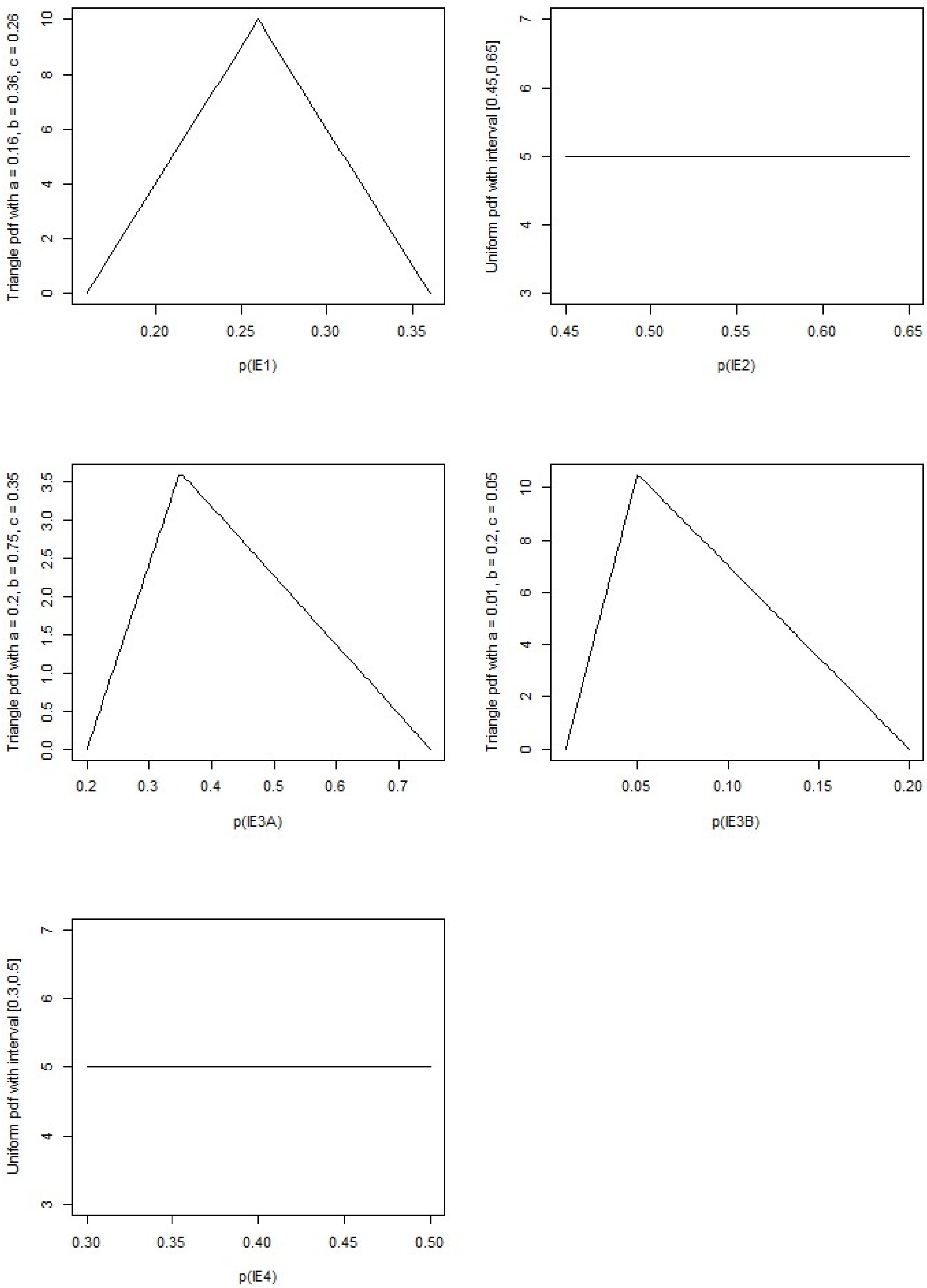


Figure 27 Motorcycle crash intermediate events probability distributions

Motorcycle safety gears (IE3)

There are several gears that considered as important when riding motorcycles, helmets are the mostly mentioned gears when talking about the safety when riding motorcycles, but there are others that is as important, gloves, jackets with pads, pants with pads, leg-covering boots are also critical. As for the motorcycles itself, we do not really see the vehicles have anything to protect the riders from impact. Specific for helmet use, Ouellet and Kasantikul (2006) stated in their study about the effectiveness of motorcycle helmet, that 75% of crash involving head impact is saved by the helmet, but this is conditional on a "less-than-extreme" condition, and we interpret this as the crash with low speed and only involving head and not below the neck impact.

With that knowledge we believe that motorcycles are far less safe in terms of protective feature. And we assign the probability of safety gear works in motorcycle crash with two probability distributions, the low-speed case and the high-speed case. We use the triangle distribution to reflect our uncertainties. For the low speed case, we use the maximum probability of 0,75 (adopted from the helmet effectiveness study), minimum of 0,2 and the most probable probability of 0,35. For the high-speed crash case, we use maximum probability of 0,2, minimum of 0,01 and most probable probability of 0,05.

Occupancy of motorcycle (IE4)

The number of occupants in motorcycle will affect the severity of the outcome – how many people will be affected by the crash. In Jakarta, we believe the proportion of single rider is greater than the rider bringing one passenger. We use the probability of 0,2 here, and we assign a uniform distribution to reflect our uncertainties in the interval of 0,1 to 0,3.

5.4.2.3 ***Consequence scenarios probability calculation***

Using the same method as before (covered in 5.3.2.3) we calculate the uncertainty distribution for every scenario in the event tree. The summary statistics is presented in table 32 and the graph is covered in figure 48 and 49 in appendix B.

Table 32 Summary statistics for the probability distributions of motorcycle crash scenarios

Scenario	Uncertainty distributions quantiles					Mean
	0,05	**0,25**	**0,50**	**0,75**	**0,95**	
1	0,0872	0,1222	0,1489	0,1768	0,2176	0,1501
2	0,0171	0,0262	0,0355	0,0472	0,0645	0,0376
3	0,0645	0,0877	0,1102	0,1386	0,1820	0,1152
4	0,0126	0,0195	0,0267	0,0359	0,0529	0,0288
5	0,1092	0,1517	0,1838	0,2166	0,2624	0,1846
6	0,0213	0,0325	0,0437	0,0581	0,0787	0,0462
7	0,0806	0,1091	0,1355	0,1692	0,2208	0,1416
8	0,0154	0,0242	0,0329	0,0443	0,0640	0,0354
9	0,0567	0,0711	0,0832	0,0973	0,1191	0,0851
10	0,0103	0,0153	0,0204	0,0264	0,0351	0,0213
11	0,0025	0,0048	0,0074	0,1080	0,0162	0,0081
12	0,0005	0,0011	0,0017	0,0026	0,0044	0,0020
13	0,0715	0,0883	0,1029	0,1192	0,1430	0,1045

14	0,0130	0,0189	0,0253	0,0323	0,0426	0,0261
15	0,0031	0,0060	0,0091	0,0133	0,0198	0,0100
16	0,00068	0,00138	0,00217	0,00332	0,00547	0,0025

5.5 Bus rapid transit accident

5.5.1 Cause analysis

5.5.1.1 *Cause identification and modelling*

In analyzing the cause of the bus rapid transit crash cause, we still use the trinity of driver's error, environment and mechanical failure as the main causes. We identify what may happen under the main causes and we present our fault tree model for bus rapid transit crash in figure 29.

5.5.1.2 *Bus rapid transit crash cause analysis*

Bus rapid transit (often abbreviated as BRT and called with the term Transjakarta – their brand name) in Jakarta is a bus transportation system running on exclusive lane on the road. The lane is separated with a physical separator to prevent other vehicles entering the bus-only lane, shown in figure 28. When the buses are traveling in this exclusive lane, they must adhere the 50 km/h speed limit.

Figure 28 Jakarta's Bus rapid transit system in one of the transit shelters with physically separated lane (Picture taken from The Jakarta Post, 2018)

We have the data of crash frequency of the bus rapid transit from 2008-2016 recorded from the operator company. We use this data to predict the frequency of crash in the future and we assign a probability distribution for every crash cause. The data is shown in table 33.

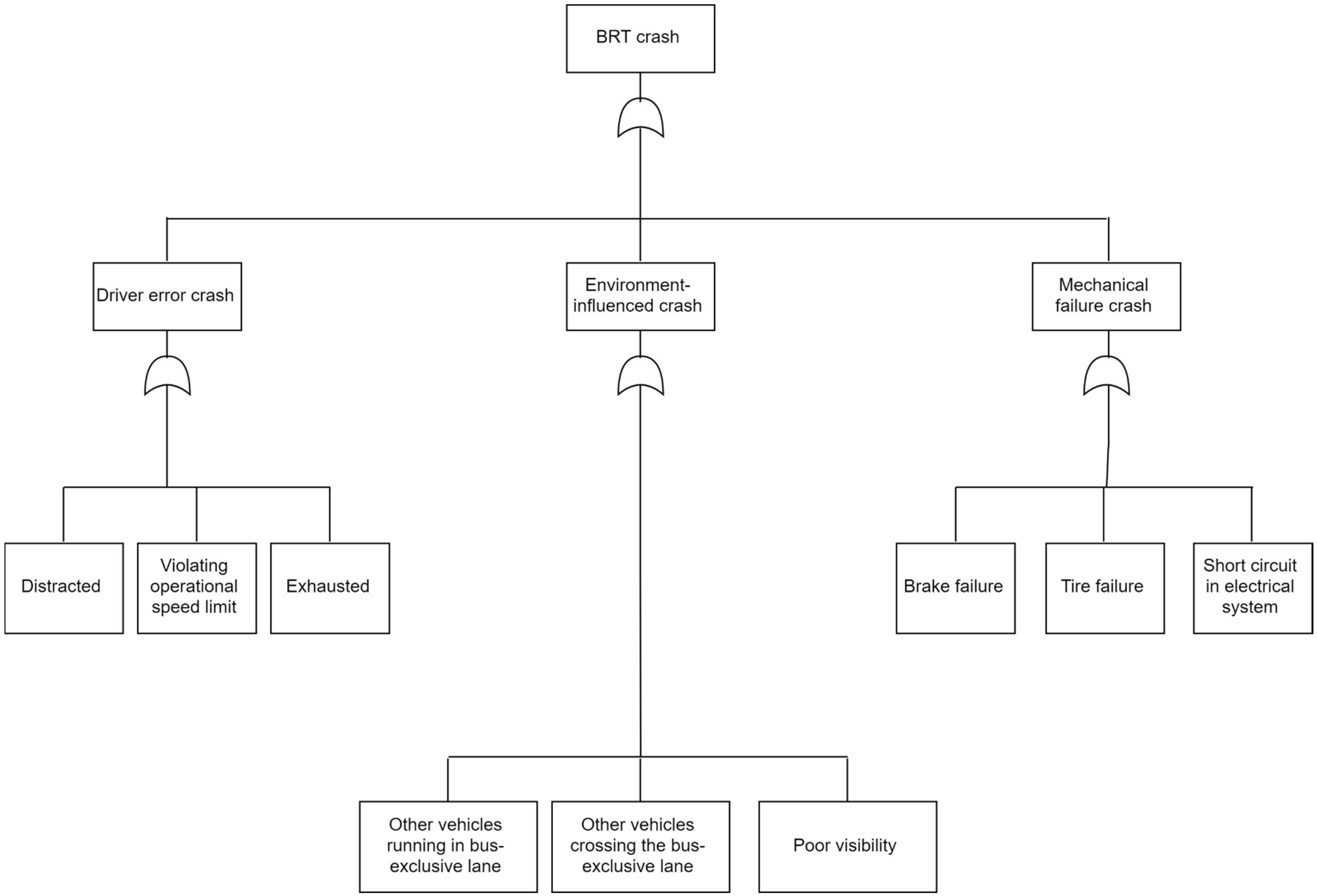


Figure 29 Fault tree model for Bus Rapid Transi (BRT) crash

Table 33 BRT crash frequency historical data

Year	2008	2009	2010	2011	2012	2013	2015	2016
Accident frequency	369	434	477	428	383	153	234	98
Average	322							

The head of the company said in Komara (2018) that the cause of Transjakarta crashes are mostly because of other vehicles disturbing the exclusive lane of Transjakarta or the driver is distracted.

Based on this statement, we divide the portion of the crash cause with environment-influenced the most dominant (52%), followed by driver's error (46%) and we do not leave the possibility of mechanical failures (2%). Using these numbers, we divide the crash frequency into the three categories in table 34.

Table 34 BRT crash frequency

BRT crash cases	Frequency
Driver's error case	148
Environment influenced case	167
Mechanical failure case	6
Car crash frequency	322

a. Driver's error

We assess the causes of driver's error in causing an accident, and we believe that there are 3 types of error that may happen, distracted as the dominant cause (75%), speed limit violation (15%) and exhausted or drowsy (10%). With this proportion, the accident frequencies are divided and shown in table 35.

Table 35 Expected frequency for driver's error BRT crash

Error type	Frequency
Distracted	111
Violating speed limit	22
Exhausted/drowsy	15

There are a total of 295 occurrence of distracted behavior from BRT driver noted by Astuti, Azmi, Safitri, and Aryani (2017) shown by 100 drivers in their 8 hours shift. And for our assessment, this number is very large, and we predict the distracted behavior of BRT driver will be one of the main factors when a crash occurs.

From the same study, Astuti et al. (2017) also found that there 84 cases where drivers fail to adhere the limit of 50 km/h speed. We would like to note that only 19 of the 84 are intentional, where the other 65 are because they fail to notice the speed exceeding the limit. These data are informative for us, because in speed is also the main influence to cause a crash, and when they are traveling, the average speed must be much lower, if it is in the range of 20km/h then speed will definitely not be the main factor of a crash.

As for exhausted and drowsy, as we emphasize in section 5.4.1, driving as occupation means longer time in driving and longer time in driving means the driver must experience some exhaustion that may lead to drowsiness. And we take this exhaustion as one of the factors of BRT crash. The distributions related to the cause frequency is shown in figure 30.

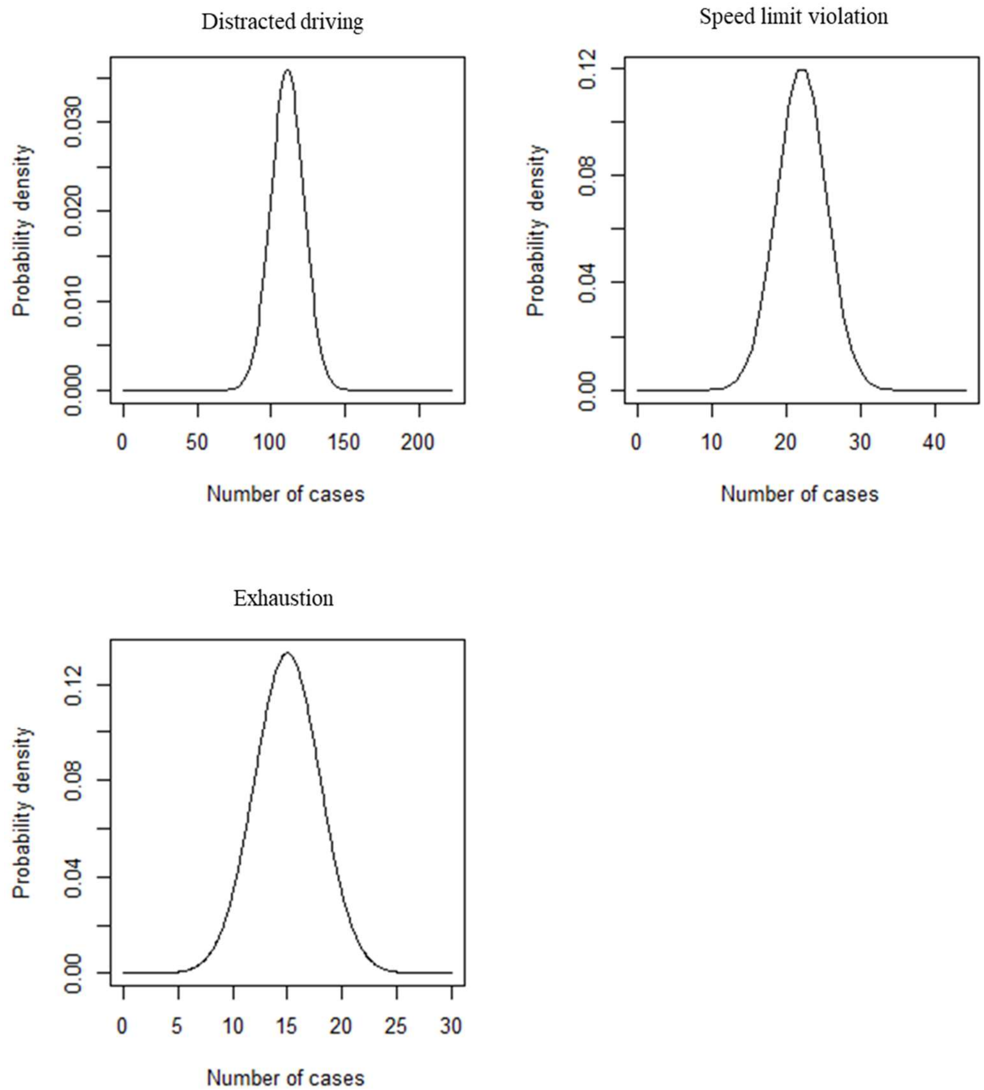


Figure 30 Probability density function for driver's error BRT crash occurrence in 1-year period

b. Environment factor

We did some research in the news, and we found that the crash of Transjakarta often involved vehicles running illegally in the bus lane and when the vehicles are suddenly crossing the bus lane to make a U-turn or simply changing direction in an intersection where the bus-exclusive lane is present. This is due the bus-exclusive lane "unsterilized" from another vehicle. The ease of other vehicles violating the bus exclusive lane makes us judge that these are the two most uncertain condition, and we reflect it in our probability distribution. And we also include the possibility of the driver experiencing poor visibility on the road due to the weather or simply because other vehicles are in the blind spot of a bus. By this knowledge we divide the proportion of the environment-caused crash as vehicles crossing the bus-exclusive lane (50%), vehicles running in bus-exclusive lane (45%) and poor visibility (5%), the frequency are shown in table 36 and the distributions are shown in figure 31.

Table 36 Expected frequency for environment-influenced BRT crash

Environment condition	Frequency
Other vehicles crossing the bus-exclusive lane	84
Other vehicles running in bus-exclusive lane	75
Poor visibility	8
Total	167

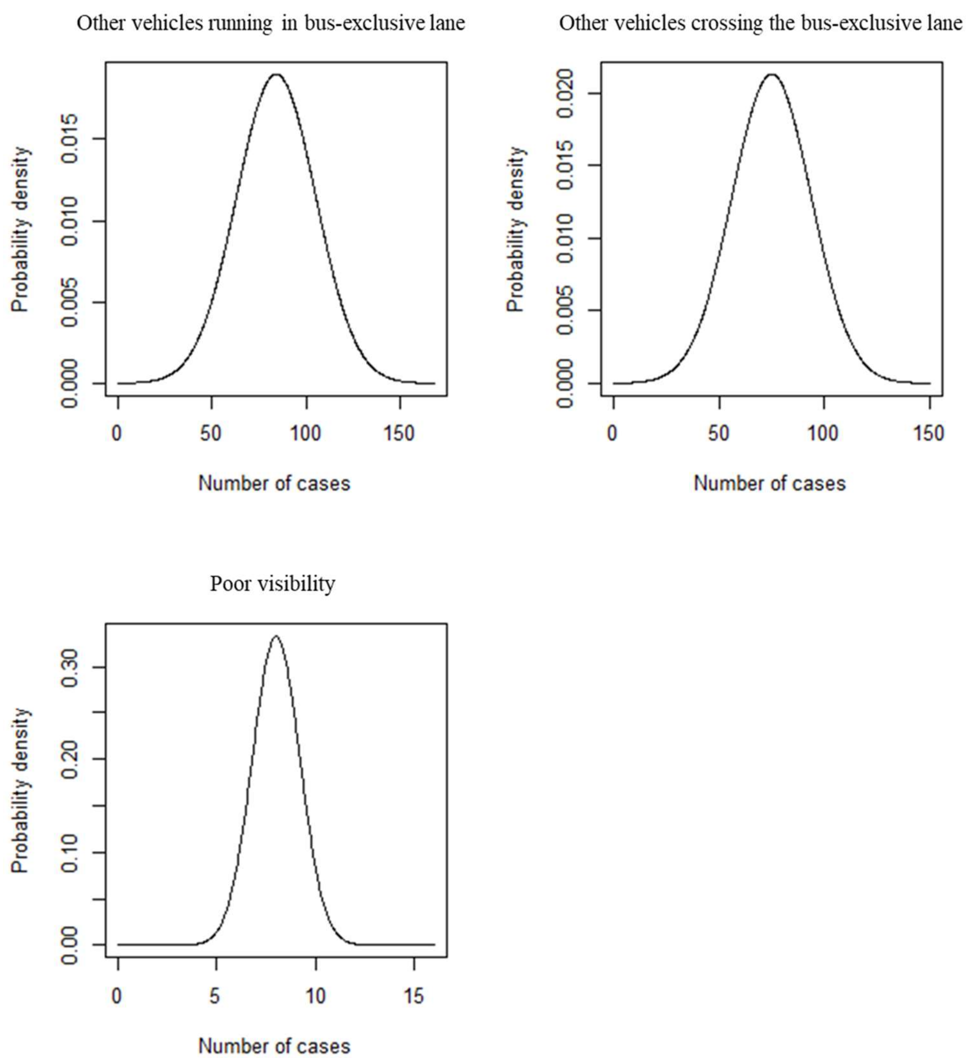


Figure 31 Probability density function for environment-influenced BRT crash occurrence in 1-year period

c. *Mechanical failure*

The cause of mechanical failure that is seen in the news are that the buses are having a short circuit that causes it to catch a fire. But we believe that the most critical component failure in a vehicle travelling on road is the brake and tire pressure as it is the two main controlling components, while steering should not be the problem here, as the buses are travelling in a track. We present the frequency for every mechanical failure case in table 37 and the related distributions in figure 32.

Table 37 Expected frequency for mechanical failure BRT crash

Mechanical failure	Frequency
Braking system	3
Tire failure	2
Short circuit in electrical system	1
Driver error car crash	6

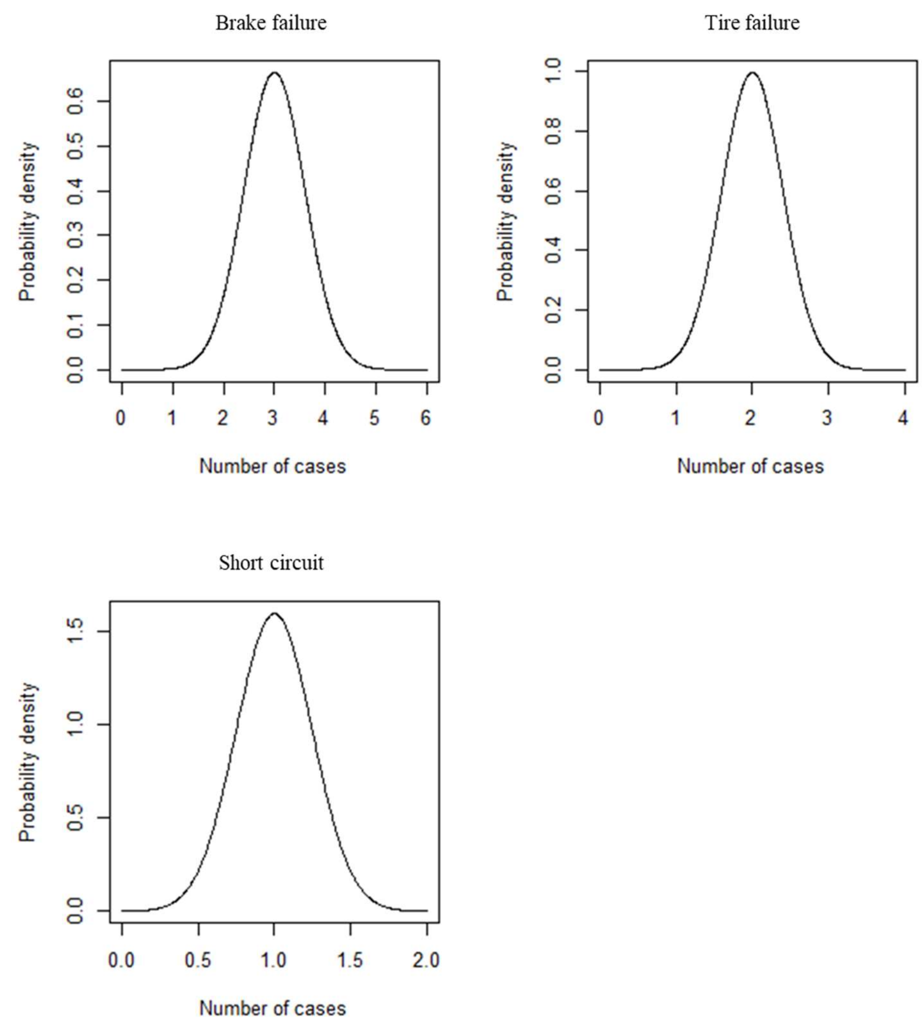


Figure 32 Probability density function for mechanical failure BRT crash occurrence in 1-year period

5.5.1.3 ***Probability calculation***

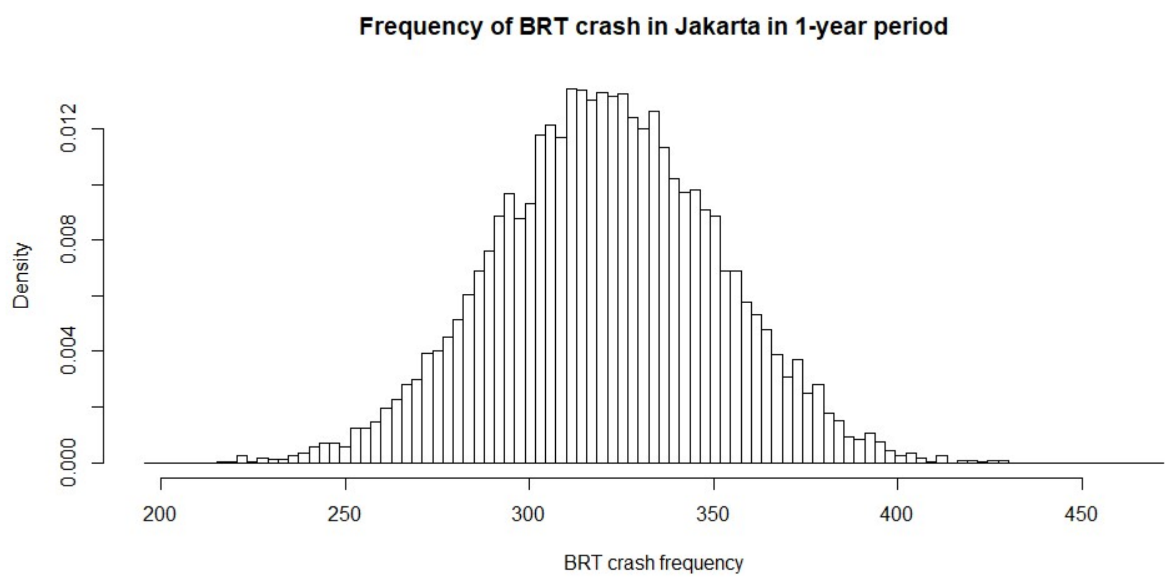
The same procedure is used to calculate the probability of a BRT crash in Jakarta. We formulated our knowledge-based probability as

$$P_i(BRT\ crash\ case\ i \mid K) = \frac{frequency\ of\ crash\ case\ i}{Total\ BRT\ operating\ hours\ in\ 1\ year}$$

And to calculate the total probability from every crash case we use the formula

$$P(BRT\ crash \mid K) = \sum_{i=1}^{9} P_i(BRT\ crash\ case\ i \mid K)$$

Using Monte Carlo simulation, we establish the distribution of probability in figure 33. The interpretation of the probability is the same as before, following Lindley's uncertainty standard.



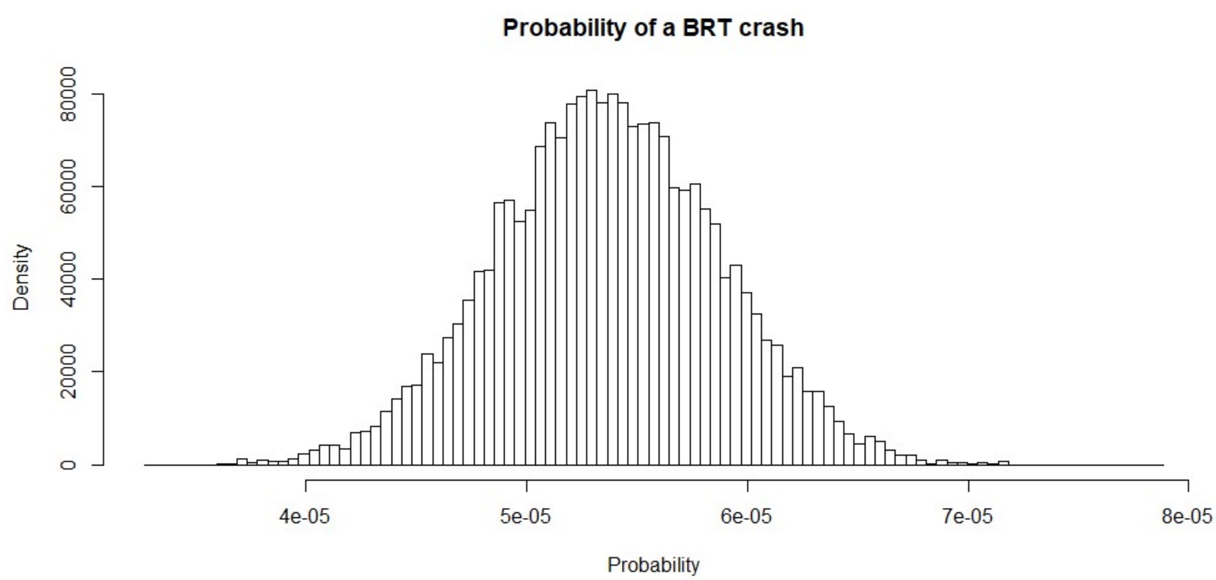


Figure 33 Simulated frequency and probability of BRT crash

5.5.2 Consequence analysis

5.5.2.1 *Intermediate events identification and consequence modelling*

Even though it runs on the road alongside cars and motorcycles, ideally, bus rapid transit (BRT) should have an exclusive, isolated lane. We are doing the intermediate events identification and consequence modelling based on this thinking – what can be wrong in the exclusive lane therefore escalating the crash consequence and we consider this, based on our framework as the traffic situation and road type category. The other factors – speed, safety feature and bus occupancy – are still considered in the intermediate events identification.

We identified 4 intermediate events that may escalate the crash consequence in a BRT environment in Jakarta. Speed, hitting lighter vehicle, hitting lane separator and bus occupancy are considered as the factor that may define the result of crash. We do not consider the vehicle safety feature because we did not find any information regarding the availability of a safety feature designed for a mass transport like the BRT, as all the passengers are standing hanging to the pole or grabbing the hand grip, and the seat do not have safety belt. We analyze the 4 events and present the event tree in figure 34.

Table 38 Consequence scenarios outcome of Bus rapid transit crash

Scenario	Outcome		Scenario	Outcome	
1	0 injuries	0 fatalities	9	5 injuries	0 fatalities
2	0 injuries	0 fatalities	10	10 injuries	0 fatalities
3	2 injuries	0 fatalities	11	5 injuries	1 fatality
4	4 injuries	0 fatalities	12	10 injuries	2 fatalities
5	2 injuries	0 fatalities	13	5 injuries	1 fatality
6	4 injuries	0 fatalities	14	10 injuries	2 fatalities
7	4 injuries	0 fatalities	15	10 injuries	2 fatalities
8	8 injuries	0 fatalities	16	20 injuries	4 fatalities

5.5.2.2 *Intermediate events analysis*

This section is our knowledge regarding the occurrence of intermediate events when a BRT crash happened. We assign probability distribution to every intermediate event to reflect our uncertainties. The probability distributions for intermediate events are shown in figure 35.

High speed crash

In the study from Astuti et al. (2017) regarding the Jakarta's BRT driver, as we mentioned in cause analysis, there are 84 cases where the drivers fail to follow the 50 km/h operating speed of Transjakarta. It is definitely a factor to increase the severity of a crash, as studied by Nilsson (2004), higher speed means more crash rate, more likely to result in injuries and fatalities. We do not consider the drivers at fault are going for speeding with more than 60 km/h, if they do disobey the rule, most of it will only be because an unintentional action. With this knowledge, we use a direct assignment of probability, that we judged it is very rare to see a BRT crashing with high speed, and we quantify our uncertainties with a probability of 0,05, and triangle distribution to cover our uncertainties regarding the value of probability itself with minimum probability of 0,025 and maximum probability of 0,075.

Hit car or heavier vehicle and hit lane separator

Both events of the bus hitting another vehicle (cars and heavier) and hitting the exclusive lane separator are considered as an escalation in BRT crash. Both may happen in one crash, or as an individual. As we mentioned in the cause analysis, the crash of a BRT is highly influenced by unsterilized exclusive lane, and we believe this influenced a confusion for the driver's focus level, they do not know when to be alert for another vehicle running or crossing in their lane, with the

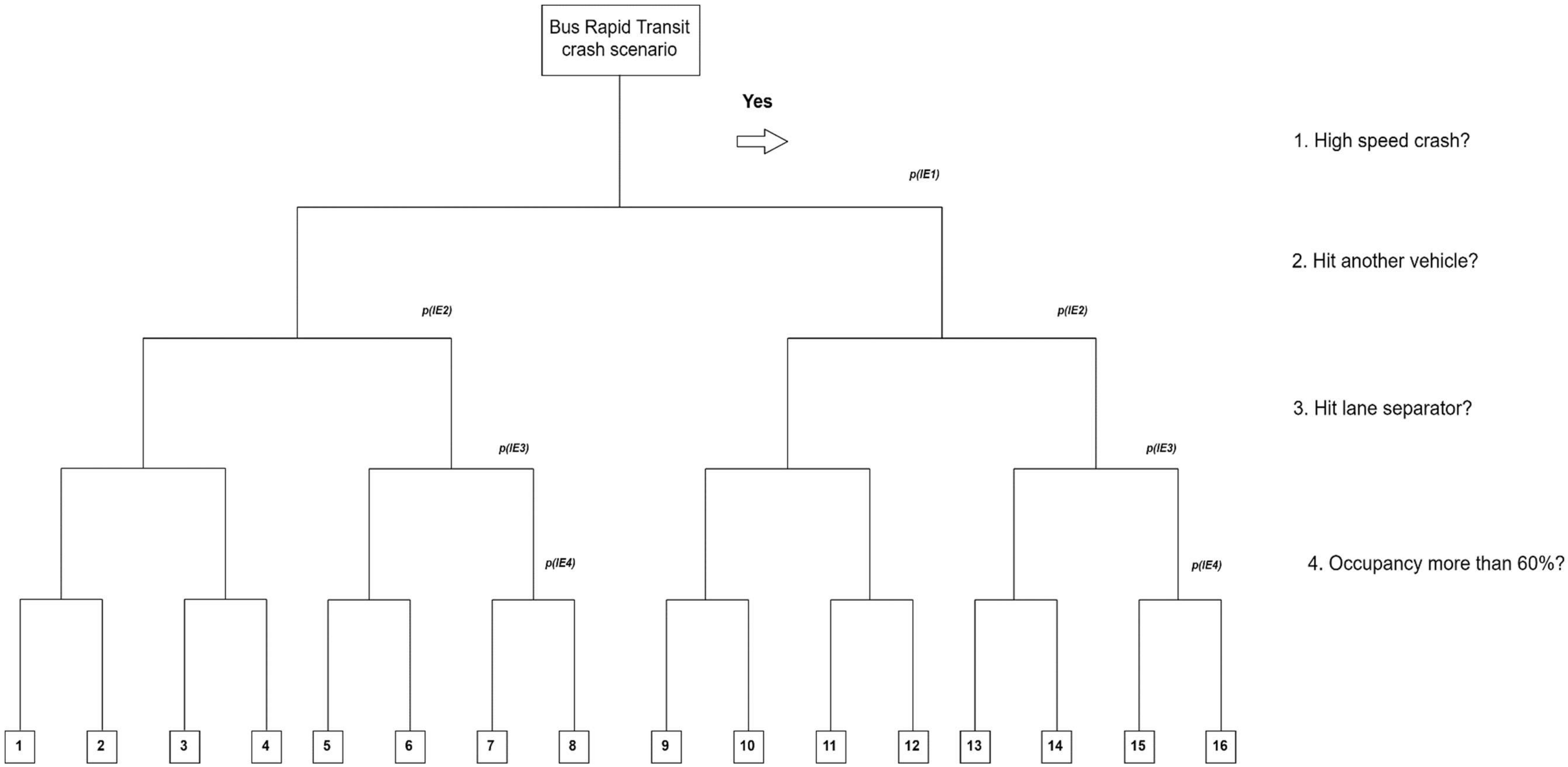


Figure 34 Event tree for Bus Rapid Transit crash

condition of some of the lane are clear of other vehicle and some others are not. With this knowledge, we understand that hitting another vehicle is very likely if the BRT lane are not free from another vehicle, and the current condition is that only (as we understand) 40% of the lanes are real BRT-exclusive. This leaves us with 0,6 probability of hitting another vehicle, and we cover the uncertainties with uniform distribution of 0,55 to 0,65.

A purely distracted driver may fail to control the bus and hitting the lane separator as a result, but even the highly focused driver can hit separator because they are avoiding the crash with lighter vehicles and resulting the same output. This makes us sure that hitting the separator is highly unavoidable, and it is very often even the bus do not hit another vehicle. We assign the probability of 0,8 and we use the interval of 0,7 to 0,9 to express our uncertainty.

Bus occupancy

The capacity of Transjakarta bus varies from 80-120 passengers, and in our assessment, we consider 60% capacity, or more is a factor to increase the severity of crash consequence as it increases the number of passengers in exposure to risk. Considering the buses are the citizen of Jakarta's one of main mode of public transport, it is almost always 50% full, so we use the probability of 0,75 for this intermediate event.

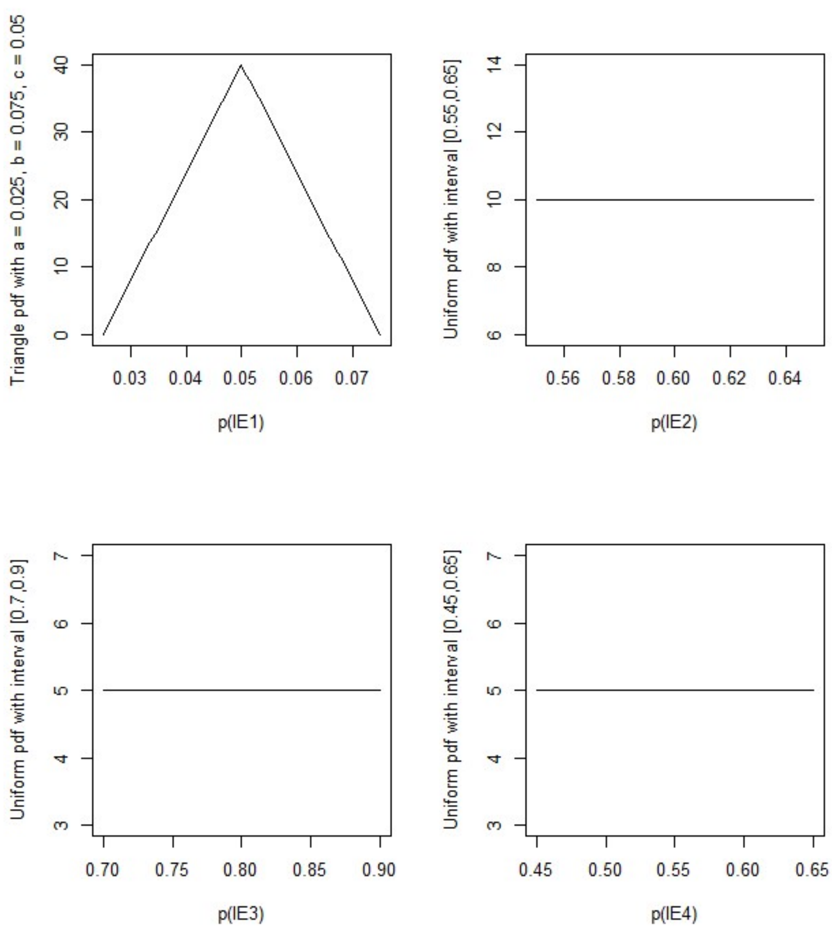


Figure 35 Bus rapid transit crash intermediate events probability distributions

5.5.2.3 *Consequence scenarios probability calculation*

Using the same method as before (covered in 5.3.2.3) we calculate the uncertainty distribution for every scenario in the event tree. The summary statistics is presented in table 39 and the graph is covered in figure 50 and 51 in appendix B.

Table 39 Summary statistics for the probability distributions of BRT crash scenarios

Scenario	Uncertainty distributions quantiles					Mean
	0,05	0,25	0,50	0,75	0,95	
1	0,0100	0,0141	0,0187	0,0234	0,0295	0,0190
2	0,0310	0,0427	0,0568	0,0706	0,0851	0,0571
3	0,0577	0,0672	0,0752	0,0840	0,0964	0,0759
4	0,1880	0,2094	0,2260	0,2446	0,2704	0,2273
5	0,0152	0,0212	0,0282	0,0353	0,0439	0,0286
6	0,0468	0,0643	0,0855	0,1064	0,1261	0,0858
7	0,0882	0,1016	0,1135	0,1258	0,1428	0,1142
8	0,2908	0,3180	0,3410	0,3645	0,3971	0,3418
9	0,00046	0,00070	0,00095	0,00125	0,0017	0,0010
10	0,0014	0,0021	0,0028	0,0037	0,0050	0,0030
11	0,0024	0,0032	0,0039	0,0046	0,0058	0,0039
12	0,0075	0,0099	0,0118	0,0138	0,0167	0,0119
13	0,00071	0,0010	0,0014	0,0018	0,0025	0,0015
14	0,0022	0,0032	0,0043	0,0056	0,0074	0,0045
15	0,0036	0,0048	0,0059	0,0070	0,0087	0,0060
16	0,0114	0,0150	0,0178	0,0207	0,0252	0,0179

5.6 Commuter rail system accident

5.6.1 Cause analysis

5.6.1.1 *Cause identification and modelling*

Based on our framework, we still identify the causes of a crash, including train, are from 3 main factors, human error, environment (the surroundings, the system) and mechanical failure. Distracted and exhaustion are always present when a crash involves human error, where environment influenced crash are due to the imperfect system where the trains are running.

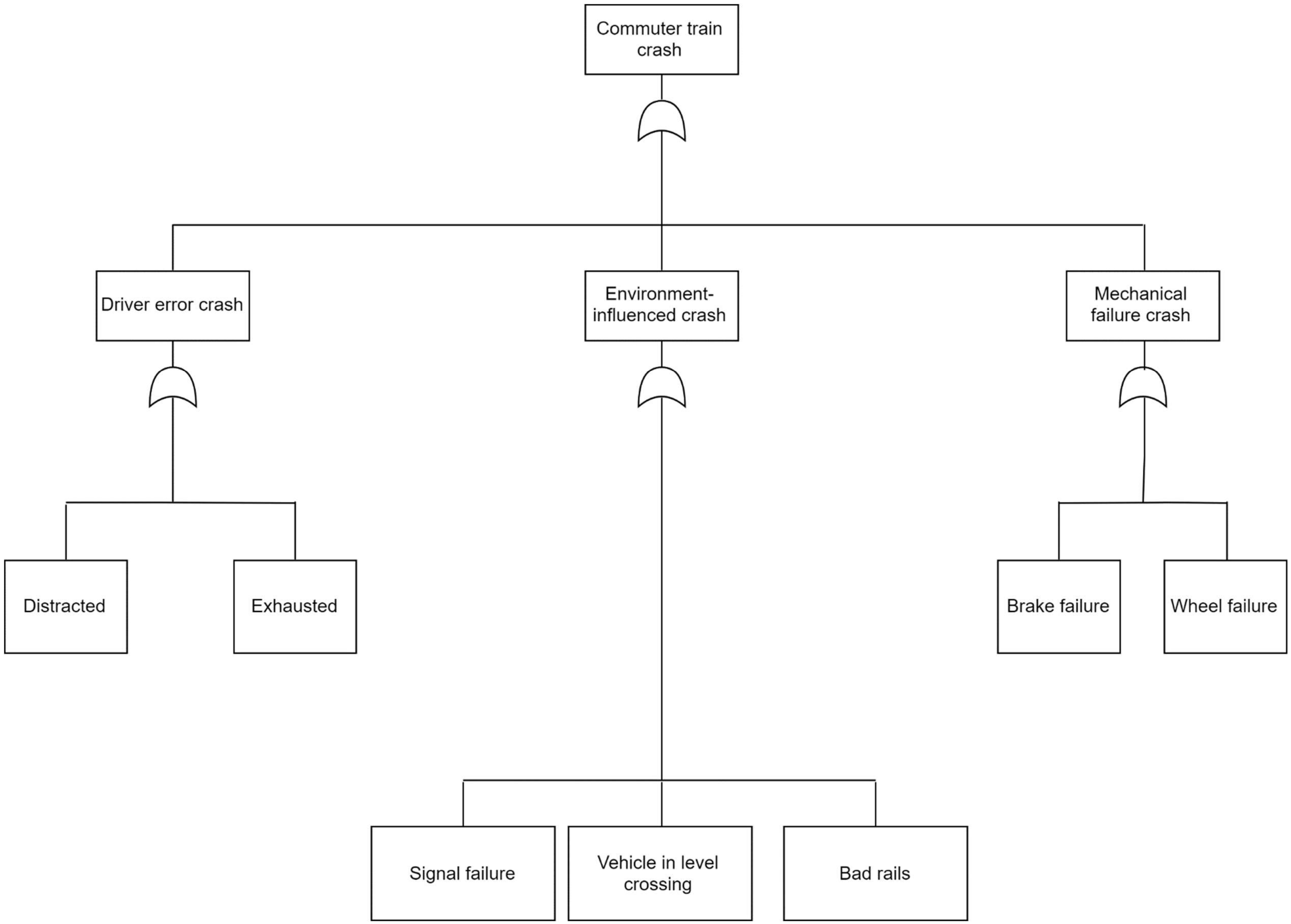


Figure 36 Fault tree model for train crash

We identified signaling failure, vehicle inappropriately placed in level crossing when trains are present and bad rails, where broken rail joints or dents are present. In mechanical failure, we identified brake and wheel are a source of crash when it fails to do the proper function. We model the causes of train crash and present it in a fault tree in figure 36.

5.6.1.2 *Commuter rail cause analysis*

The commuter rail, in this assessment is the mode of transport when we are looking at the historical accident frequency has the lowest number of all. We would like to note that, when the accident does happen, according to the data in section 3, the severity is very high. In predicting the number of accident frequency, we use the historical data and we get the average of 4 accidents per year. Table 40 presents the historical data of accident frequency.

Table 40 Historical data of accident frequency for the commuter rail

Year	2013	2014	2015	2016	2017	2018
Accident frequency	3	1	6	2	7	3
Average	3,67					

Based on our judgement and the previous scenarios of commuter train crash, we believe that 70% of the frequency will come from the environment (in this case, uncleared level crossing or bad rails), 20% come from train driver's error and the rest of 10% come from mechanical failure. Using this proportion, we divide the crash frequency to an individual main crash cause. In the frequency in table 41, we see we have 0,73 in driver's error frequency, this can be interpreted that, in a year, the crash with the source of driver's error may not happen, but in two years, it may happen once. This interpretation applies to all cases.

Table 41 Commuter train main crash causes frequency

Commuter train crash cases	Frequency
Driver error case	0,73
Environment influenced case	2,57
Mechanical failure case	0,37
Commuter train crash frequency	3,67

When assessing accident, human error must always be considered. We identified distracted and exhausted as the two causes in causing an accident. One of the tasks that must be performed when working as a train driver is to comply the signs along the line, it keeps the train from hitting each other, as it informs the train the driver is on is clear to move to the next block or not. Here, we consider distracted is the only way to miss or misinterpret the signs, and we do not believe that there is a train driver that may intentionally disregard the sign. As for exhaustion, we understand that this is a job that requires focus for a long time, and we cannot take exhaustion out of the equation. We believe that the trainings of train driver in Jakarta is adequate to have them very careful when driving the train, and we have very low uncertainty regarding human error in commuter line case. The frequency for driver's error crash cause is on table 42.

Table 42 Commuter train driver's error crash frequency

Error type	Frequency
Distracted	0,55

Exhausted/drowsy	0,18
Driver's error frequency	0,73

We believe the source of train accidents are mainly lays in the environment of the rail system. The commuter rail system is an extensive rail system that covers the greater area of Jakarta, and that makes it involves a great number of level crossing (level crossing is a specific area where the road-based vehicles may cross the rail). When we gather the information regarding the environment influenced crash cause, we identified 3 possible sources of crash, signal-related failure, vehicle blocking the train in level crossing and bad rails.

Of all the 3 causes, we consider the second as the most influential yet dangerous to the train. Level-crossing-related crash is related to how the drivers in Jakarta adhere to the rules (cars and motorcycles accident cause), some may still try to disobey the portal that is blocking the way when the train is coming, while other scenario may involves the failure of the portal (lateness) to block the level crossing, like the 2013 train accident where it involves a total of 95 victims, with 5 fatalities occurred.

Bad rails are also significant in causing a train crash, where it can cause a derailment, hence a crash. Bad rails may happen in the form of broken joint, dented rail or inadequate ballast (bottom cushion of the rail). Bad rails are quite often cited as the source of train accident in Indonesian media, that is why we use the frequency of 1 per year. The signal failure was the source of the biggest Indonesian train crash in 1987, where the stationmaster gave the go signal when they were not supposed to do that, resulting two trains collided, consequently a large number of fatalities. Since then, there are no signal failure related crash, but we still include that in our assessment as it is an identified cause, but with a small frequency.

Table 43 Commuter train environment-influenced crash frequency

Environment condition	Frequency
Signal failure	0,13
Vehicle in level crossing	1,28
Bad rails	1,16
Environment influenced crash	2,57

Brake failure is the source of 2015 train collision. Where the driver brakes and the train did not stop within the appropriate distance and resulting to crash with the train in front, there are many injuries as the consequence but luckily no fatalities as it is a slow speed crash. That was the only recorded brake-related failure in commuter trains in Jakarta. The wheel failure was never going on the record, but it is a source of accident, so we include it in our assessment, with a small frequency.

Table 44 Commuter train mechanical failure crash frequency

Mechanical failure	Frequency
Brake failure	0,26
Wheel failure	0,11
Driver error car crash	0,37

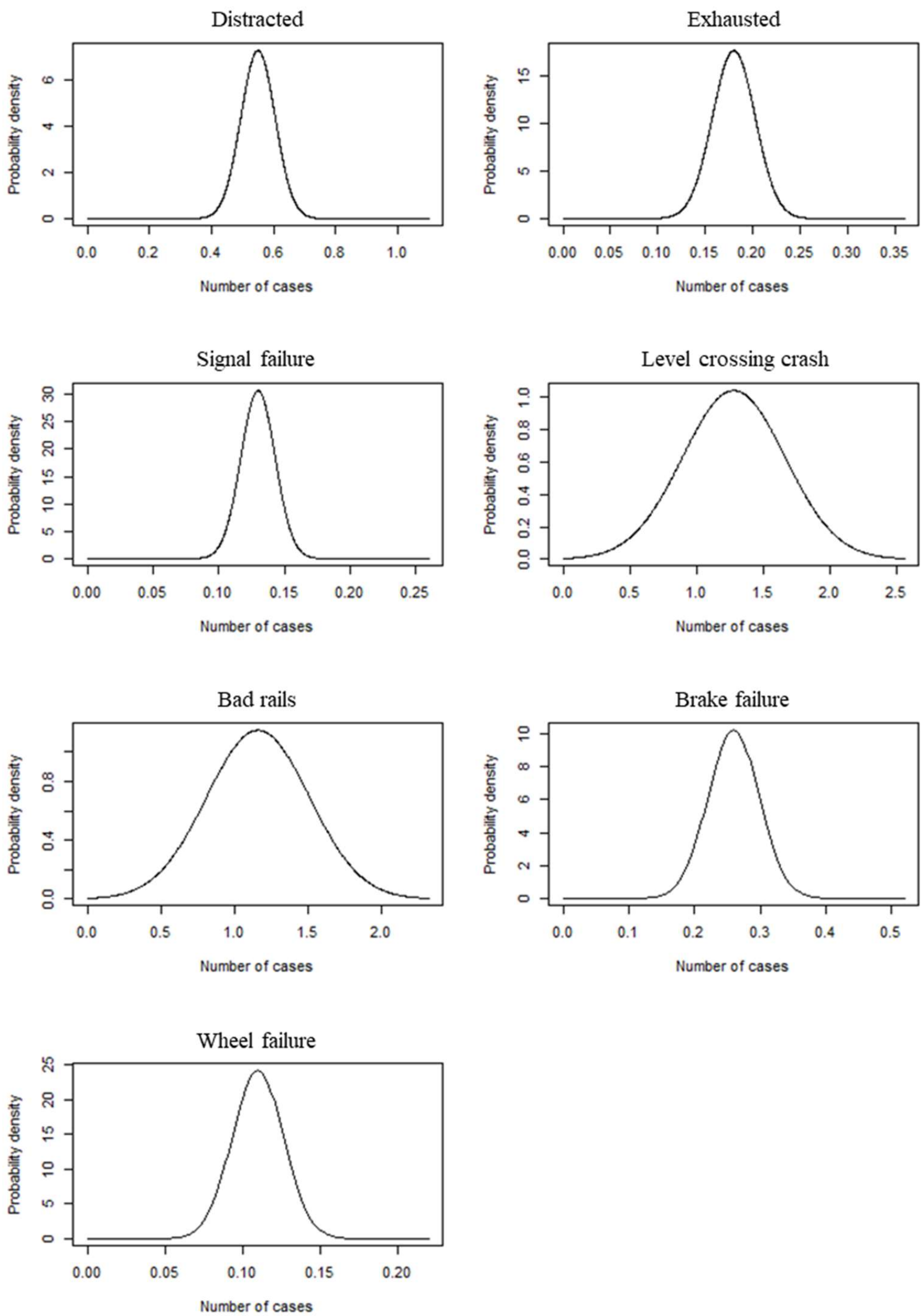


Figure 37 Probability density function for every case of commuter train crash occurrence in 1-year period

5.6.1.3 ***Probability calculation***

The same procedure is used to calculate the probability of one person involved in a commuter train crash in Jakarta. We formulated our knowledge-based probability as

$$P_i(\textit{Commuter train crash case } i \mid K) = \frac{\textit{frequency of crash case } i}{\textit{Total train operating hours in } 1 \textit{ year}}$$

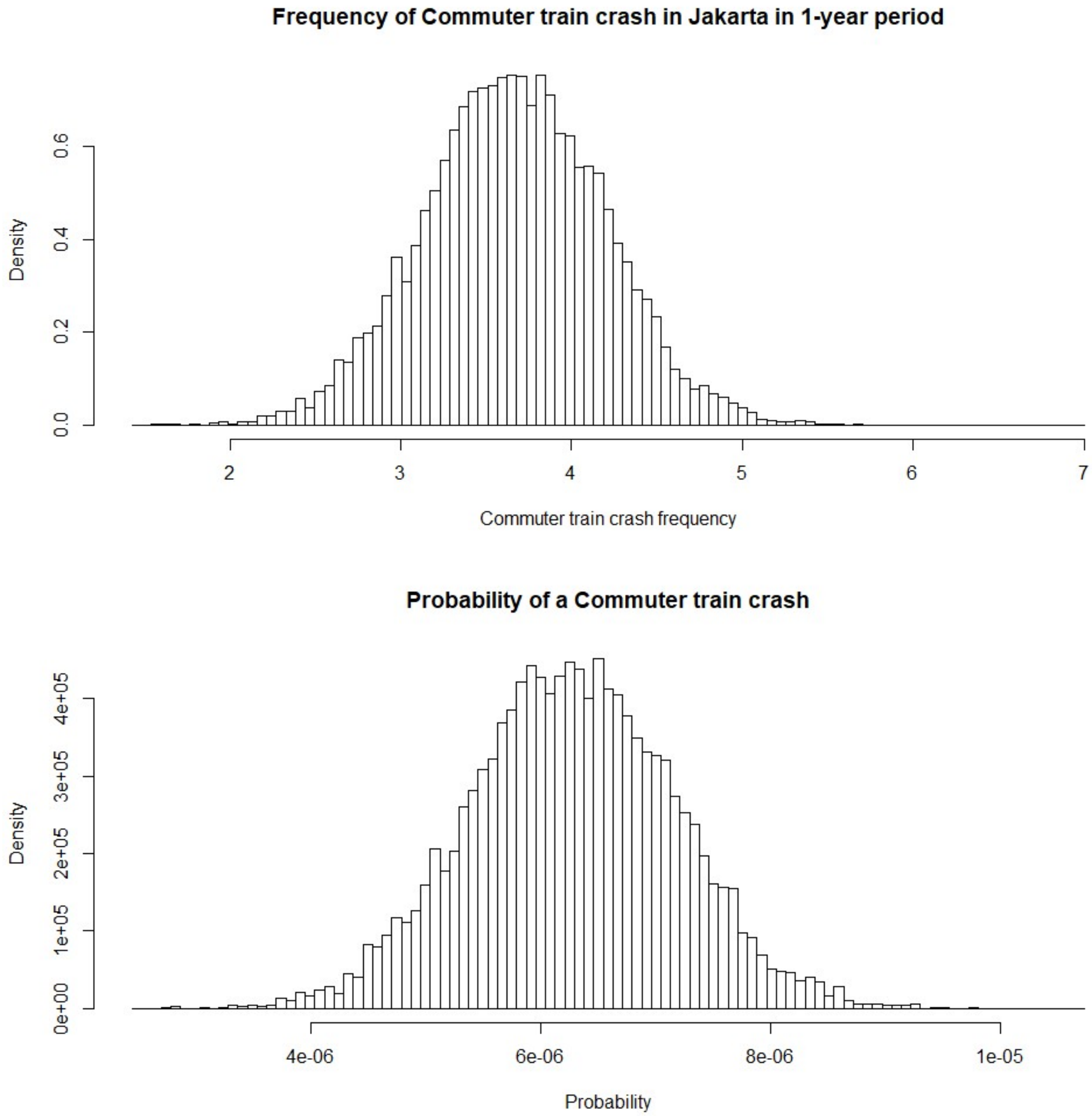


Figure 38 Simulated frequency and probability of Commuter train crash

And to calculate the total probability from every crash case we use the formula

$$P(\textit{Commuter train crash} \mid K) = \sum_{i=1}^{7} P_i(\textit{Commuter train crash case } i \mid K)$$

Using Monte Carlo simulation, we establish the distribution of probability in figure 38. The interpretation of the probability is the same as before, following Lindley's uncertainty standard.

5.6.2 Consequence analysis

5.6.2.1 *Intermediate events identification and consequence scenarios modelling*

In a train crash scenario, we identified 4 intermediate events that may affect the severity of the outcome. The 4 are, the speed when crash occurred, hitting another heavy vehicle (including trains), derailing happened or not (can be the result of hitting another vehicles), and the occupancy of the train itself. We put together the intermediate events and assigned the outcome for every scenario in the event tree of figure 39.

Table 45 Consequence scenarios outcome of Commuter train crash

Scenario	Outcome		Scenario	Outcome	
1	0 injuries	0 fatalities	9	0 injuries	0 fatalities
2	0 injuries	0 fatalities	10	0 injuries	0 fatalities
3	15 injuries	0 fatalities	11	45 injuries	3 fatalities
4	25 injuries	0 fatalities	12	70 injuries	6 fatalities
5	15 injuries	0 fatalities	13	45 injuries	3 fatalities
6	25 injuries	0 fatalities	14	70 injuries	6 fatalities
7	35 injuries	0 fatalities	15	90 injuries	5 fatalities
8	60 injuries	0 fatalities	16	135 injuries	10 fatalities

5.6.2.2 *Intermediate events analysis*

In this analysis, we are assigning the probability for every intermediate event. The probability is based on our knowledge regarding the event and the probability is used to calculate the uncertainty distribution of every scenario identified in the event tree.

High-speed crash

The commuter train in Jakarta has the maximum operating speed of 100 km/h and an average around 40-50 km/h, means it is possible for the train to crash at high speed. From our data, only one crash in 6 years involves a high-speed crash and hitting a truck at the same time, resulting severe outcome. For us, both of this information implies two things, crash involving other heavy vehicle is a critical scenario for train crash and high speed increases the severity of outcome. Based on this knowledge, we use a probability of 0,15 and we have high uncertainty about this number, so we cover our uncertainty with uniform distribution with interval 0,05 to 0,25.

Hitting another vehicle

From the data, all severe train crashes involve other vehicles, one case involves a truck crossing the rail and one case involves another train. The source of this event is the level crossing present in the railroad of Jakarta, and two things may happen as the source, portal blocking the vehicles fails to close (as to what happen with the truck case) and the vehicle driver violate the rule in level crossing. Knowing the attitude of the vehicle driver in Jakarta as “not so good to obey the rule” as we study in 5.3 and 5.4, we believe there are many drivers violate the portal in level crossing when they should not.

In our data, almost every year the commuter train experienced crash with hitting other vehicles, an average of 1,6 cases per year out of 3,6 cases of train crash in a year. This leads to a probability of

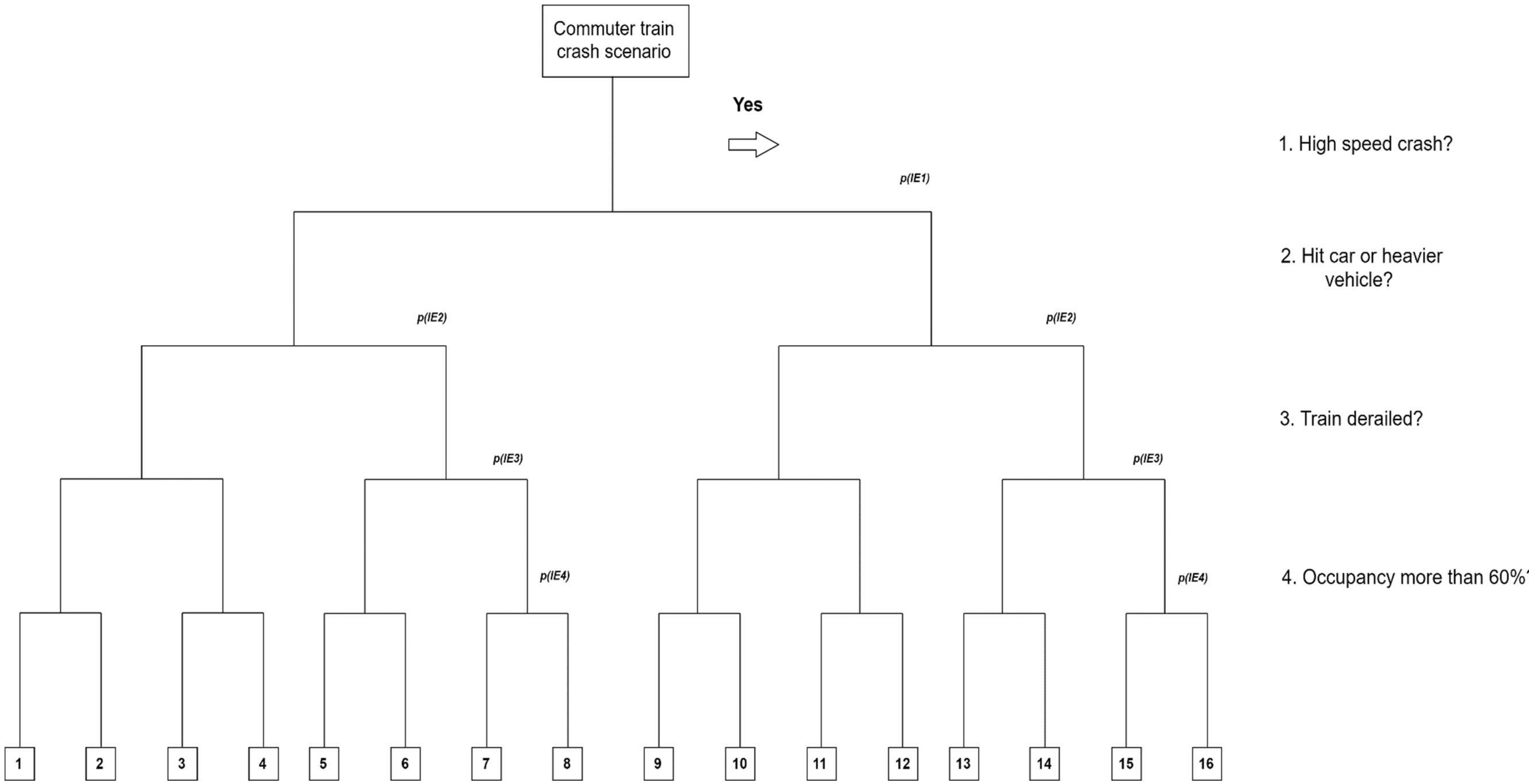


Figure 39 Event tree for Commuter train crash

0,46 for a train to hit other vehicle, we cover our uncertainties for this number with triangular distribution with minimum value of 0,36 and maximum value of 0,56, with the most probable value 0,46.

Derail

The derail in this problem is when the train hit another vehicle and causing it to derail. Our understanding is that when a train hit another vehicle it is very likely to derail, so we assign probability of 0,8 and in the model, we use uniform distribution in the interval of 0,7 to 0,9.

Train occupancy

The commuter system is very crowded during the peak hours, and even the non-peak hours are still crowded. For this condition, we use probability of 0,8 and uniform distribution of 0,75 to 0,85 to cover the uncertainties regarding the number.

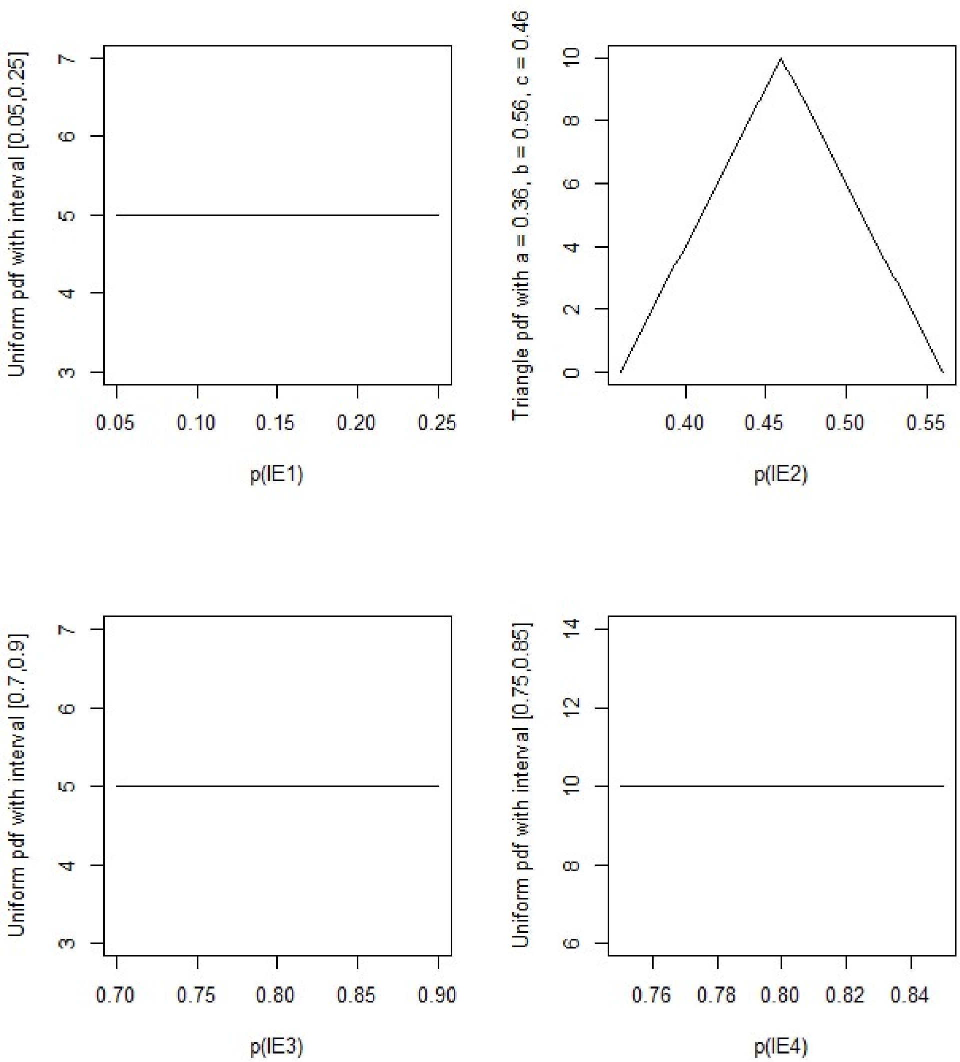


Figure 40 Intermediate events probability distributions for Commuter train crash

5.6.2.3 *Consequence scenarios probability calculation*

Using the same method as before (covered in 5.3.2.3) we calculate the uncertainty distribution for every scenario in the event tree. The summary statistics is presented in table 46 and the graph is covered in figure 52 and 53 in appendix B.

Table 46 Summary statistics for the probability distributions of Commuter train crash scenarios

Scenario	**Uncertainty distributions quantiles**					**Mean**
	0,05	**0,25**	**0,50**	**0,75**	**0,95**	
1	0,0093	0,0133	0,0179	0,0227	0,0296	0,0183
2	0,0391	0,0549	0,0727	0,0912	0,1114	0,0735
3	0,0523	0,0627	0,0722	0,0829	0,0976	0,0733
4	0,2351	0,2663	0,2914	0,3187	0,3597	0,2934
5	0,0078	0,0114	0,0151	0,0193	0,0253	0,0156
6	0,0334	0,0464	0,0619	0,0776	0,0956	0,0627
7	0,0438	0,0533	0,0616	0,0707	0,0847	0,0625
8	0,1963	0,2255	0,2485	0,2736	0,3100	0,2503
9	0,0010	0,0019	0,0029	0,0042	0,0065	0,0032
10	0,0042	0,0078	0,0118	0,0171	0,0253	0,0129
11	0,0049	0,0083	0,0124	0,0169	0,0228	0,0129
12	0,0204	0,0339	0,0510	0,0683	0,0862	0,0517
13	0,0008	0,0016	0,0024	0,0036	0,0055	0,0027
14	0,0036	0,0067	0,0101	0,0146	0,0215	0,0110
15	0,0041	0,0070	0,0106	0,0143	0,0196	0,0110
16	0,0174	0,0289	0,0431	0,0582	0,0744	0,0044

6 Risk Picture for commuting in Jakarta

6.1 Crash occurrence probability

The crash occurrence probability is calculated by predicting the occurrence frequency, divided by the total hours of the vehicles used in Jakarta, the number is reflecting the information of how likely every vehicle is involved in a crash. The formula to calculate the probability is as the following

$$P(crash) = \sum_{i=1}^{n} \frac{F_i}{VH}$$

F_i is the frequency of crash case i and VH is the total vehicle operating hours in 1-year we calculate it using $VH = H \times n \times 365$, with H average hours used in 1-day and n number of vehicles. The frequency is covered in section 5, in the cause analysis of every vehicle type accident. For the total vehicle operating hours, we use the number in table 47.

Table 47 Variables for calculating total operating hours (VH)

Vehicle type	Average hours per day (H)	Vehicle number (n)
Car	4	3 525 925
Motorcycle	3	13 310 672
Bus rapid transit	18	910
Commuter train	20	80

With all variables set, we calculate the crash occurrence using the formula, and we have the following result

Table 48 Summary statistics for crash occurrence probability

Vehicle type	**Occurrence probability distributions quantiles**					**Mean**
	0,05	**0,25**	**0,50**	**0,75**	**0,95**	
Car	$2{,}76 \times 10^{-7}$	$3{,}16 \times 10^{-7}$	$3{,}44 \times 10^{-7}$	$3{,}72 \times 10^{-7}$	$4{,}12 \times 10^{-7}$	$3{,}44 \times 10^{-7}$
Motorcycle	$2{,}91 \times 10^{-7}$	$3{,}44 \times 10^{-7}$	$3{,}81 \times 10^{-7}$	$4{,}17 \times 10^{-7}$	$4{,}69 \times 10^{-7}$	$3{,}81 \times 10^{-7}$
Bus rapid transit	$4{,}53 \times 10^{-5}$	$5{,}03 \times 10^{-5}$	$5{,}36 \times 10^{-5}$	$5{,}70 \times 10^{-5}$	$6{,}20 \times 10^{-5}$	$5{,}36 \times 10^{-5}$
Commuter train	$4{,}77 \times 10^{-6}$	$5{,}67 \times 10^{-6}$	$6{,}26 \times 10^{-6}$	$6{,}88 \times 10^{-6}$	$7{,}72 \times 10^{-6}$	$6{,}26 \times 10^{-6}$

With the result in table 48, we understand that the bus rapid transit system (BRT) has the highest probability of crash and car has the lowest probability of crash occurrence. We interpret this probability, for example, the BRT system is predicted to have a mean of 5,36 crash in 100 000 bus operating hours. We would like to emphasize that; the bus operating hours is the total hours for all buses combined not the operating hours of every bus. Comparing the number to other vehicle, the car crash probability is interpreted to have a mean of 3,44 crash for every 10 million car-hours in Jakarta, where in 10 million of BRT-hours, BRT will have a mean of 536 crash.

For the quantiles, the 0,05 quantiles can be interpreted as best case as it has the lower probability of occurrence and 0,95 quantiles may be interpreted as the worst case. The CDF can be seen in figure 41.

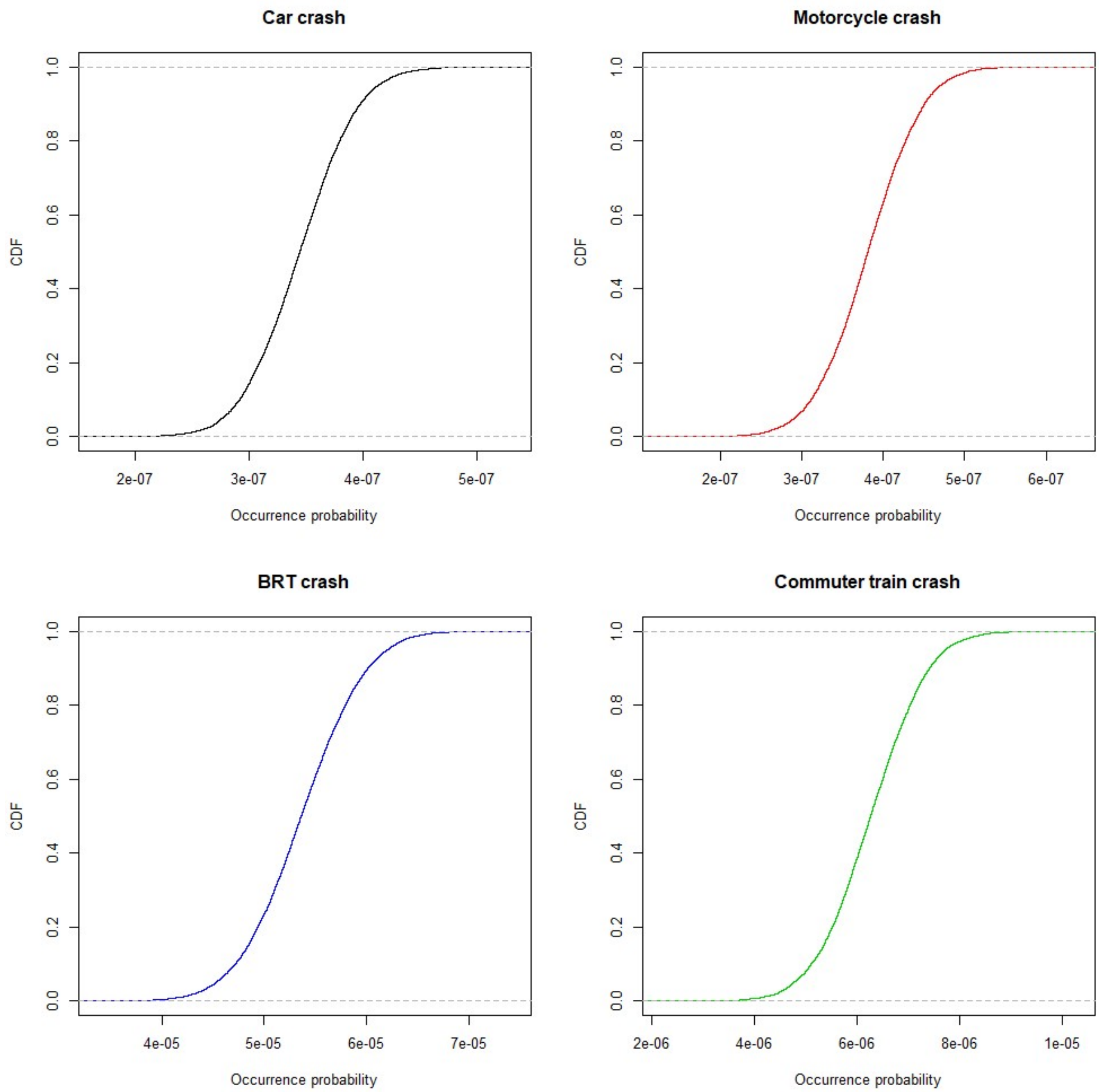


Figure 41 Cumulative distribution function for crash occurrence probability

6.2 Potential injuries and potential loss of lives

We analyzed the consequences for vehicle crash in consequence analysis in section 5. We assigned the probabilities for every intermediated event, calculated the probability distribution for every scenario and determining what is the outcome. Based on the three components, now it is possible to calculate the potential injuries (PI) and potential loss of lives (PLL). To calculate the potential injuries, we use the formula

$$PI = \sum_{i=1}^{n} p_i N_{I_i}$$

p_i denotes the probability of scenario i happening and N_{I_i} denotes the number of injuries resulting from scenario i. We have the probability distributions of every scenario and the injuries outcome in section 5, and based the numbers, we get the following result

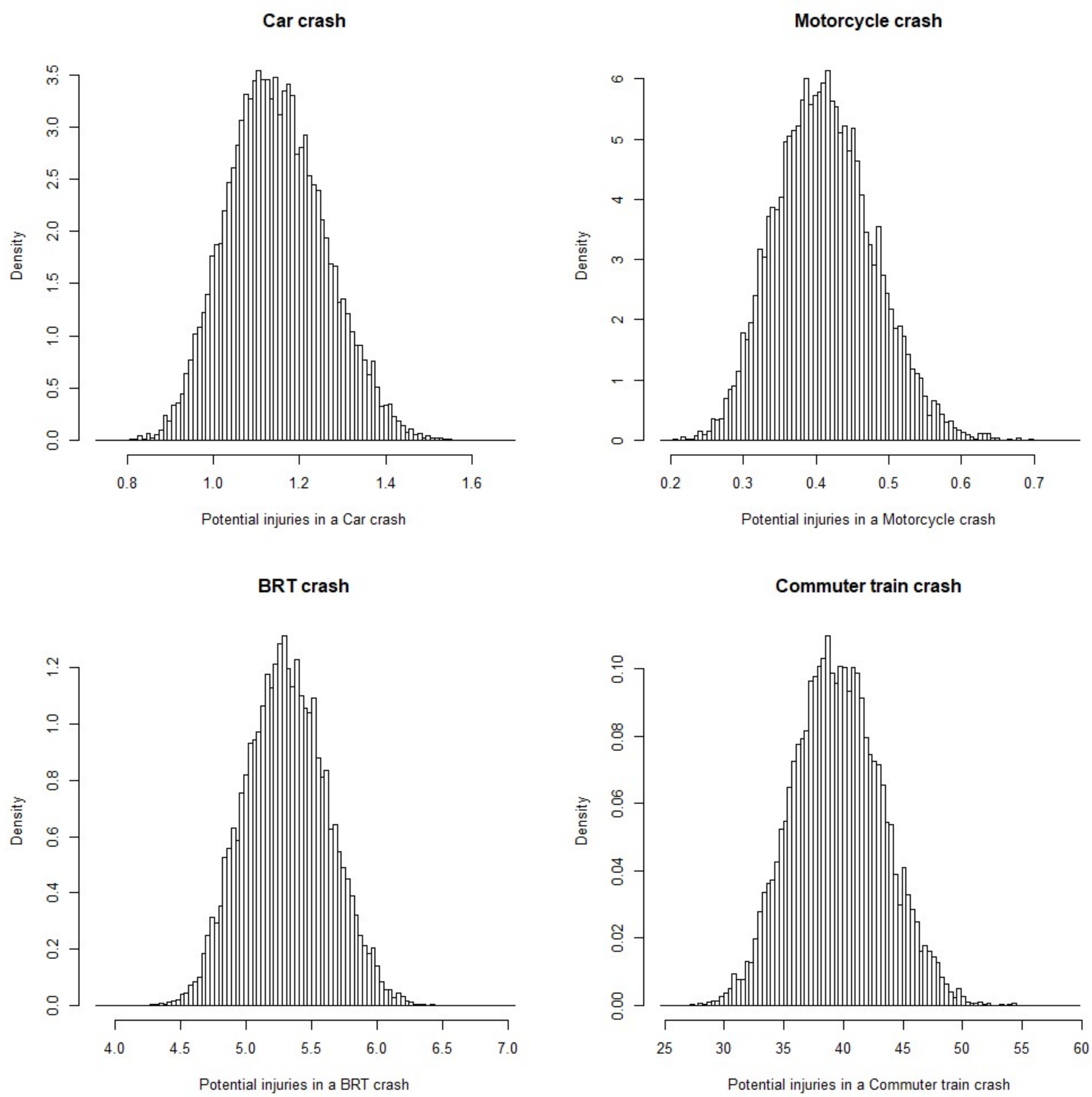
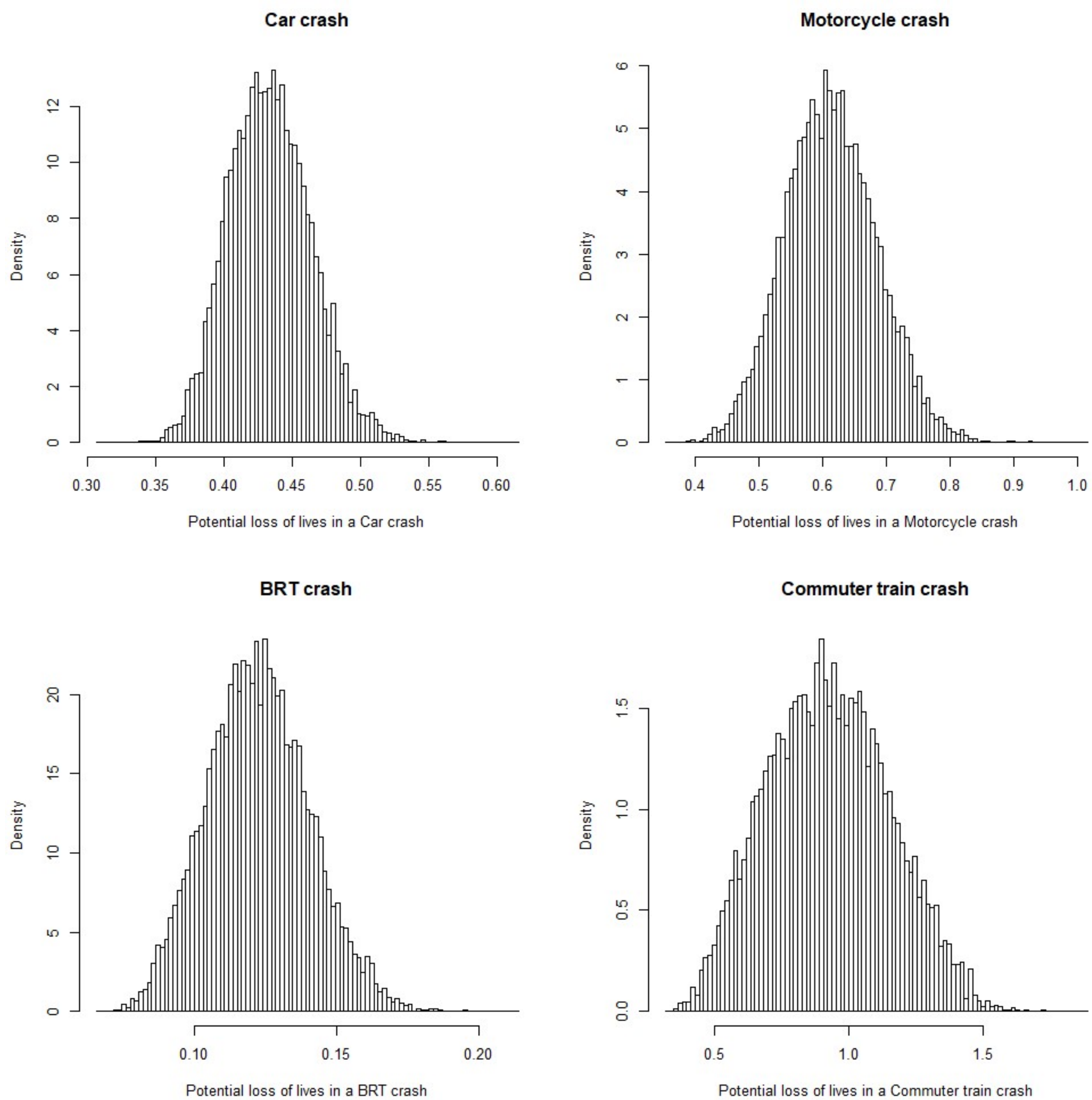


Figure 42 Potential injuries for every vehicle type crash

For the potential loss of lives, we use the formula

$$PLL = \sum_{i=1}^{n} p_i N_{F_i}$$

p_i here also denotes the probability of scenario i, and N_{F_i} is the total fatality from scenario i happening. We have the probability distributions of every scenario and the outcome in section 5, and based the numbers, we get the following result



To get a better comparison, we summarize the expected value using the mean of PI and PLL of every crash in table 49. The table 49 shows us the expected number of injuries and fatalities that may come out from a vehicle crash. The data implies that if a public transportation vehicle (BRT and Commuter train system) crashed, the potential of injuries is higher relative to the private-owned vehicles, this may due to the capacity of the vehicles itself. But in the PLL side, BRT have the lowest of all, our understanding is that because a BRT is unlikely to go to a speed above 65 km/h, the speed when it is considered a high speed, hence resulting a low PLL.

Table 49 Expected value of potential injuries and potential loss of lives

Crash type	E[PI]	E[PLL]
Car crash	1.14	0,43
Motorcycle crash	0,41	0,61
Bus rapid transit crash	5.30	0,12
Commuter train crash	39.50	0,92

6.3 Individual injury risk

Individual injury risk is calculated to give an information about the size of risk we are having when we are travelling one time using the transport mode of choice. Similar with Meng et al. (2010), where we use the frequency of crash, the potential injuries, and the total passenger, we formulate the individual risk of injury IR_I using

$$IR_I = \frac{f_{crash}\, PI}{N_{passenger}}$$

f_{crash} is the frequency of crash for one type of vehicle, PI is the potential injuries related to the outcome of the vehicle crash and $N_{passenger}$ is the number of total passenger for the type of vehicle being analyzed. All the variables must be specified in what time period, we are using a time period of 1-year. We get all the variables from section 5, and we got the following result for individual injury risk in table 50,

Table 50 Summary statistics for individual injury quantiles

Vehicle type	**Individual injury risk quantiles**					**Mean**
	0,05	**0,25**	**0,50**	**0,75**	**0,95**	
Car	$6,85 \times 10^{-7}$	$8,04 \times 10^{-7}$	$8,96 \times 10^{-7}$	$9,92 \times 10^{-7}$	$1,14 \times 10^{-6}$	$9,03 \times 10^{-7}$
Motorcycle	$2,63 \times 10^{-7}$	$3,33 \times 10^{-7}$	$3,86 \times 10^{-7}$	$4,46 \times 10^{-7}$	$5,43 \times 10^{-7}$	$3,93 \times 10^{-7}$
Bus rapid transit	$9,30 \times 10^{-6}$	$1,04 \times 10^{-5}$	$1,13 \times 10^{-5}$	$1,21 \times 10^{-5}$	$1,21 \times 10^{-5}$	$1,13 \times 10^{-5}$
Commuter train	$3,17 \times 10^{-7}$	$3,84 \times 10^{-7}$	$4,35 \times 10^{-7}$	$4,86 \times 10^{-7}$	$5,65 \times 10^{-7}$	$4,37 \times 10^{-7}$

The calculation result of the individual injury risk shows that bus rapid transit system has the highest injury risk, the other vehicle type has probability in the area of 10^{-7} but only the BRT system has 10^{-5}. The mean of the distribution for BRT system injury risk is 1.13×10^{-5}, the interpretation of this number is, we expect 1.13 passenger will experience injury for every 10 000-passenger riding the BRT system in 1-year. Comparing to motorcycle, which has the lowest risk, we expect 3.93 injuries in 10 million passengers, the BRT has almost 100 times bigger injury risk than the motorcycle.

This risk number is only covering the risk if we ride the vehicle of choice 1 time, the number of total passenger we used is obviously will not be a different person in every number recorded, it may be the same person who frequently used the mode of transport and if he/she ride 100 times in 1-year, then he/she will be recorded as 100 in the total passenger number not one. By this understanding, the risk will increase if a person travels frequently using the vehicle of choice, it will multiply by how often the person is using the vehicle.

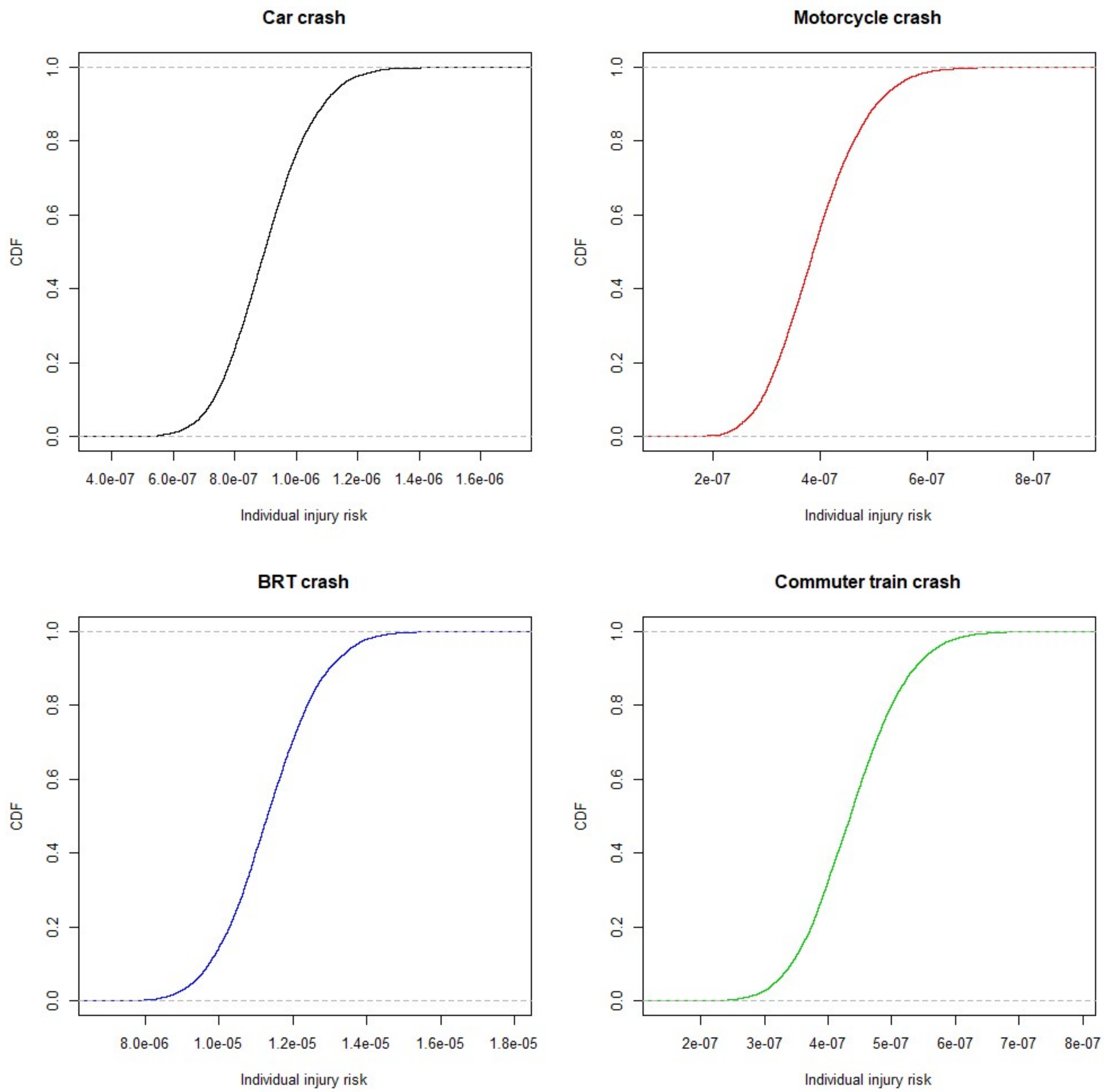


Figure 43 Cumulative distribution functions for individual injury risk

6.4 Individual fatality risk

Like section 6.3, the individual fatality risk is using the frequency of crash, the potential loss of lives, and the total passenger, we formulate the individual risk of fatality IR_F as

$$IR_F = \frac{f_{crash}\, PLL}{N_{passenger}}$$

The difference in the formula is that we use potential loss of lives PLL, so it will result as the individual fatality risk. The numbers for the variables involved is covered in section 5 for the crash frequency, and 6.2 for the potential loss of lives. Using the numbers, we got the following result for individual fatality risk

Table 51 Summary statistics for individual fatality risk

Vehicle type	Individual fatality risk quantiles					Mean
	0,05	**0,25**	**0,50**	**0,75**	**0,95**	
Car	$2{,}67 \times 10^{-7}$	$3{,}09 \times 10^{-7}$	$3{,}40 \times 10^{-7}$	$3{,}73 \times 10^{-7}$	$4{,}22 \times 10^{-7}$	$3{,}42 \times 10^{-7}$
Motorcycle	$4{,}19 \times 10^{-7}$	$5{,}09 \times 10^{-7}$	$5{,}80 \times 10^{-7}$	$6{,}52 \times 10^{-7}$	$7{,}71 \times 10^{-7}$	$5{,}84 \times 10^{-7}$
Bus rapid transit	$1{,}90 \times 10^{-7}$	$2{,}29 \times 10^{-7}$	$2{,}58 \times 10^{-7}$	$2{,}90 \times 10^{-7}$	$3{,}39 \times 10^{-7}$	$2{,}61 \times 10^{-7}$
Commuter train	$5{,}76 \times 10^{-9}$	$8{,}08 \times 10^{-9}$	$9{,}98 \times 10^{-9}$	$1{,}21 \times 10^{-8}$	$1{,}53 \times 10^{-8}$	$1{,}02 \times 10^{-8}$

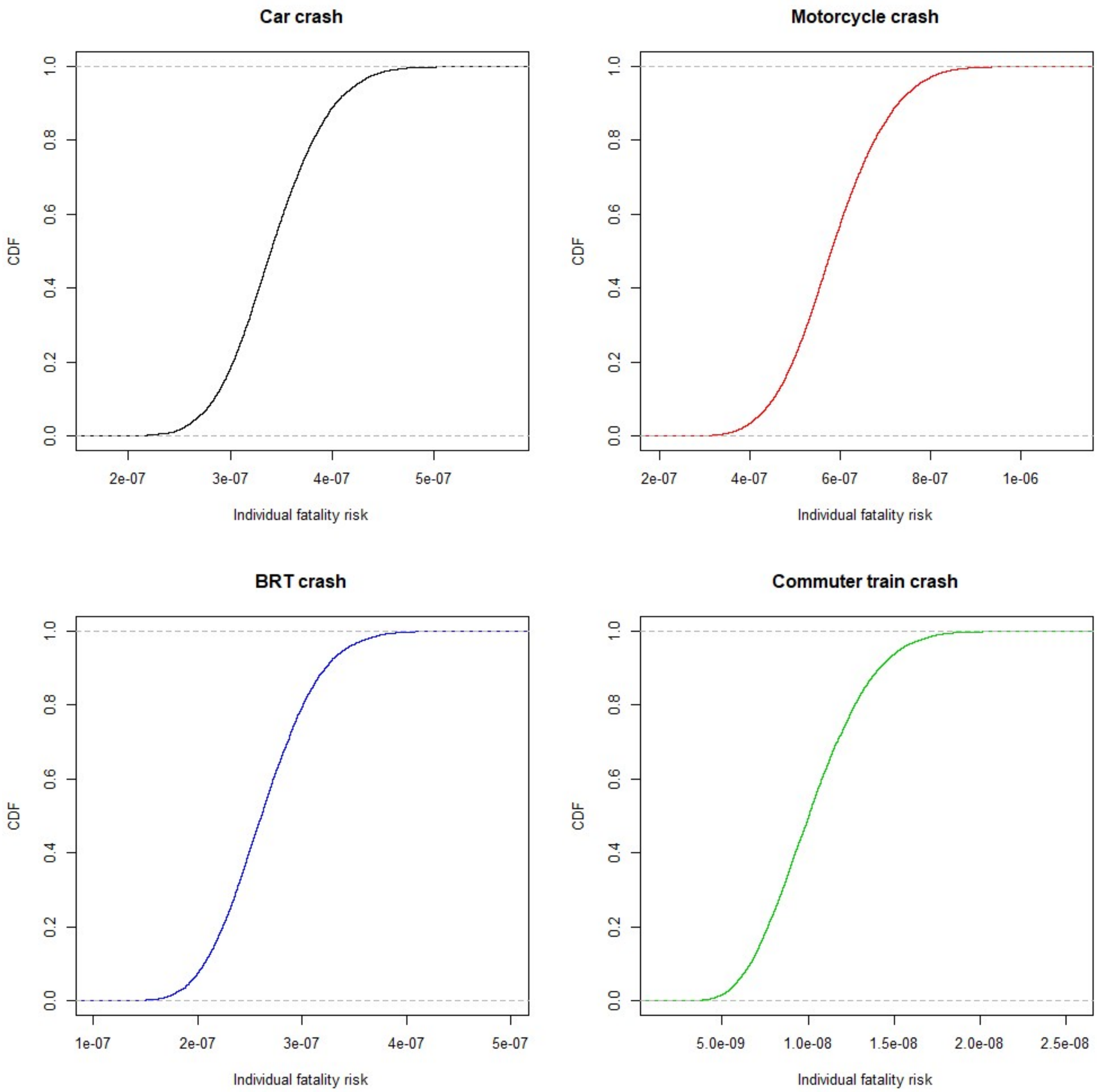


Figure 44 Cumulative distribution functions for individual fatality risk

The interpretation of the number here is the same as section 6.3, only it involves fatality. The highest individual fatality risk is when commuting with motorcycle, it has a mean of $5{,}84 \times 10^{-7}$, with the interpretation, we expect there will be 5,84 fatality in 10 million motorcycle passengers. And of course, the risk is higher the more frequent a person commute using any vehicle of choice. The cumulative distribution function of the individual fatality risk is shown in figure 44.

6.5 Risk reducing measures

Based on the risk assessment we done in section 5, we identify a possible risk reducing measure for the significant factor contributing to the crash occurrence frequency in every vehicle type. The risk reducing measures must have an objective to reduce the risk numbers in section 6.1-6.4. If we look at the formula of our number to describe risk, two factors are possible for applying the measures, the frequency of crash and the potential injuries (to reduce injuries) or potential loss of lives (to reduce fatalities). In this section, we focus on identifying the measure in the crash frequency side.

Table 52 Risk reducing measure to reduce the crash frequency

<table>
<tr><th>Crash type</th><th>Most significant factor</th><th>Risk reducing measure</th><th>2nd Significant factor</th><th>Risk reducing measure</th></tr>
<tr><td>Car</td><td>Violating traffic rule</td><td rowspan="2">1. Enhancing traffic control system
2. Developing a more proper driving education</td><td>Distracted</td><td rowspan="3">Implementing a more robust system to ensure driver does not perform secondary task when driving</td></tr>
<tr><td>Motorcycle</td><td>Violating traffic rule</td><td>Distracted</td></tr>
<tr><td>Bus rapid transit</td><td>Vehicle in exclusive lane</td><td rowspan="2">Controlling system to ensure another vehicle not present in exclusive lane/railroad</td><td>Distracted</td></tr>
<tr><td>Commuter train</td><td>Vehicle in level crossing</td><td>Bad rails</td><td>Improve the rail inspection system</td></tr>
</table>

The most significant factor in a private-vehicle crash is when the driver violates the traffic rule, including speeding. For us, this is a behavioural problem, and we must take corrective and preventive action by implementing a stricter traffic control system to give punishment for driver at fault. This can be a fine or warning that a license may be revoked if they violate it so many times. The preventive measure may be in a form to develop a better driving education, and to get a full license, the driver must reach some level of experience with a teacher guiding the driver.

For the public transport, the biggest problem is when another vehicle type is interrupting the exclusive lane (for BRT system) and violating the rule in level crossing (for commuter train system). If this problem can be solved by implementing control system, the crash frequency will be decreased, especially for the bus rapid transit system.

7 Discussion and conclusion

7.1 Discussion

We now have established the risk picture in section 6, where we can compare the risk indices associated with every vehicle type. In this section, we discuss our thoughts regarding the risk indices.

How much accident is too much for commuting activities?

For what we understand, the most straightforward answer will be the use of *risk acceptance criteria (RAC).* In this approach, we define an upper limit for the risk indices used, (in our study it is the occurrence probability, potential injuries, potential loss of lives, individual injury risk and individual fatality risk), and if we use this approach, we compare the result of the indices against the upper limit of every risk index, and if the number is above the limit, then it will be considered as unacceptable and measure should be implemented. The risk acceptance criteria approach is considered as giving too much focus to the limit itself, as Aven and Vinnem (2005) discussed in their study. If we implement a measure, then the focus is to reduce the risk indices to be below the limit, it is not wrong, but then we only focused to the number, not the phenomena behind the numbers itself.

It is also presented in Aven and Vinnem (2005), where we may use a risk analysis without thinking about risk acceptance criteria. The result is we are focused in what is the tradeoff between high risk and the following consequences. We may choose to proceed in a high-risk situation knowing the benefit behind the situation, and making the risk considered acceptable. Political and management process are involved here, not the acceptance criteria. Then in this sense, accepting risk means that we accept the negative consequences and the benefits behind the high-risk situation. This view is of course applicable in any situation, but in commuting activities we are not seeking the benefit of wealth, it is best viewed as a daily need for every individual.

When we are considering commuting as a daily need, the risk attached to it, for us, must be reduced until it is non-existent. In practice this is impossible, as risk is always present, but a *Vision Zero* thinking may be suitable to reduce the risk greatly. As studied by Fahlquist (2006), if vision zero is implemented as a policy, then any accidents, injuries and fatalities happened as a result of commuting activities is not acceptable as it is a basic need. In the study, vision zero is associated with *forward-looking* and *backward-looking* perspective in responsibility. Responsibility here is important for the thinking, what is the cause, who to blame and what to improve in a transportation accident. The backward-looking responsibilities apply to individual accident and forward-looking means to improve the system. Individual crash may provide information to the whole transportation system to improve it. In this sense, the best improvement to reduce transportation accident is best through more robust regulations and transport design system, with the support of every individual. And so, our risk-reducing measures suggested in section 6 is mostly a system and regulations controlling every vehicle.

Perceiving risk in commuting activities

Risk is always attributed in every kind of activity, every action will always have a consequence, as in the risk concept itself. As an offshore platform and nuclear reactor worker, they are exposed to accidents and the resulting outcome, so do a car and motorcycle drivers in a road somewhere. But do we really need to think about risk every time? It would be a great burden in our mind if all we think is accident to come for us – and we really doubt it is a common thinking in the morning, having breakfast and get into a car thinking we may experience accident in this trip to work, no, all we think is we need to arrive at the office.

As an individual, we see commuting as basic needs, and we need that every day to get our activities done. In our opinion, the risk attached to the commuting activities is not something to worry about, but it is something to understand. Before we do this study, we never know the injury risk of bus rapid transit passenger is 25 times more than motorcycles. We always feel that motorcycle is a lot more dangerous than any other vehicle, but turns out it is almost the same with car and commuter line in injury risk, and yes, it has a bigger potential loss of lives than car and also the highest fatality risk of all, but not with big margin as we perceived before we do this study. And understanding this number may reduce the risk to our self as a daily commuter.

Perceiving risk when we act as a driver (maybe of a private car or motorcycle or even bus and train) can greatly boost our attitude towards the rules, and this is the most common accident cause in our study (violating traffic rules), if we understand the risk we have more respect to the system, therefore the risk number should decrease greatly. And of course, the risk indices established should give better understanding for the transport system provider, where they are in control of the regulations and the system design. They should be aware of what can be improved and implementing a more robust regulation and better system.

A better driver licensing system

In our cause analysis, the cause of private vehicle is dominated by the human error, and the error related to traffic rule violation is high. We believe that this is related to the regulation regarding education and the system related. In Indonesia, to get a license, we only need to fulfill the age requirement, the theory test and practical test. If you passed the test, then you are assumed to be as good as any driver legally driving on the road. For us, this system is too lenient, a better driver licensing system should be implemented.

We find a better system in Begg and Stephenson (2003) about the *Graduated driver licensing (GDL)* in New Zealand. The system introduces a 3-steps of licensing, learners permit, restricted license and full license. And the study shows a significant decrease of crash rate of driver in the young age since the implementation of GDL system. The GDL is a better system because it emphasizes the importance of driving education and driving experience to get a full license. If the drivers are educated to comply with the rules better, then crash related to traffic rule violation should be decreased greatly. Driving experience requirement should give the driver a more complete understanding on how to behave and what to be aware on the road and therefore, distracted driving and speed limit violation related crash should also be reduced.

7.2 Conclusion

In this study, we established the framework of quantitative risk assessment for transportation accident with the basis of risk analysis principles from Aven (2012) and some studies on vehicle accidents. First, context must be established, as this step contains the defining basis of the assessment. Then hazard should be identified for the starting point of accident cause and consequence analysis. In the cause analysis, three common main sources of accident should be included, human error, environmental factor and vehicle mechanical failure. Consequence analysis should include the intermediate events identified that may escalate the accident, some of the events are, vehicle speed, functionality of safety feature, traffic situation and passenger condition on vehicle. The results from cause and consequence analysis are presented in the risk picture. Monitoring, review and update are important to keep the validity of the assessment, while communication and consultation are critical to understand the view of every stakeholder involved.

We performed the risk assessment to 4 types of vehicle accidents in the city of Jakarta, using our QRA framework transportation accident. 4 risk indices are calculated, the crash occurrence probability, potential injuries and loss of lives, individual injury risk and individual fatality risk. Our assessment result shows that the private vehicles have lower probability of crash (expected probability of $3{,}44 \times 10^{-7}$ for cars and $3{,}81 \times 10^{-7}$ for motorcycles) than the BRT system ($5{,}36 \times 10^{-5}$) and commuter train ($6{,}26 \times 10^{-6}$). Potential injuries from commuter train (40) and BRT (5.2) are also the higher than the private vehicles, this is due to the maximum number of passengers the vehicle can carry. The same reason also applies to why the commuter train have the highest potential loss of lives, considering how much passengers the train can carry. These numbers imply that when a public transport is having an accident, the outcome will be more severe.

Individual injury and fatality risk are the indices that shows the risk to one passenger/occupant of the vehicle when travelling one time. The results in individual injury risk for BRT system is the highest ($1{,}13 \times 10^{-5}$) almost 25 times more than motorcycles ($3{,}93 \times 10^{-7}$), the lowest in individual injury risk. Highest individual fatality risk is with the motorcycles ($5{,}84 \times 10^{-7}$) and the lowest is the commuter train ($1{,}02 \times 10^{-8}$). Overall, we have injury risk higher than the fatality risk for every individual.

We introduced some of the possible risk reducing measures with focus to reduce the crash frequency. Violating traffic rule on the road (private vehicles) and bad systems (public transport) are the most significant in causing the crash. From this thinking, we understand that risk reducing measures for vehicle accident will be effective in the form of a more robust regulations and a better-designed system.

APPENDIX A

Quantifying uncertainties using probabilities

A.1 Probability

Probability often used as a tool to measure uncertainty, especially in a risk analysis setting. Probability gives us a quantified insight of which event is more likely to occur, so we get clearer picture of the risk considered and to get to that point, we must understand how we should interpret the probability itself. Watson (1994) gives us 5 contenders on how to get the meaning of probability. And in Aven and Reniers (2013), 3 of them categorized as "objective" probabilities (classical probabilities, frequentist probabilities, logical probabilities) with the addition of propensity theory, and the last one is "subjective" probability.

A.1.1 Subjective probability

If a person faced with two events A and B, and we ask, "which of the two events is more likely to occur?" and that person can answer, event A is more likely to occur than event B, then the number associated with each of the event is what we call subjective probability. And that the number must obey the rules of probability (Watson, 1994).

There are two types interpretation to associate a number to the subjective probability from Aven and Reniers (2013), the betting interpretations and probability based on uncertainty standard. The betting interpretation faces some problem because when we interpret the probabilities, we might be distracted by the value judgement involved. Subjective probabilities interpretation by uncertainty standard is used because it is more practicable in most fields.

The uncertainty standard is based on Lindley (2014). Subjective probability definition is using the uncertainty standard, the example is from an urn. Probability of 0,1 of event A means that the person is comparing his/her degree of belief towards event A to draw one specific ball from an urn containing 10 balls.

This type of interpretation is easier to understood and we can easily compare between probability. Say, $P(B) = 0{,}3$ compared to $P(C) = 0{,}4$, it is easily said that event C is more likely to happen. How likely? $P(B) = 0{,}3$ is drawing 1 red balls from an urn containing 3 red balls and 7 blue balls and $P(C)$ is drawing 1 red balls from an urn containing 4 red balls and 6 blue balls. And we can apply this interpretation of probability to any kind event, even the unique and repetitive ones, we can still say which of the events is more likely to occur.

A.1.2 Coherence in probability

In practice, the events we consider will not only be a simple one, it will be combination of one event after another and will led to a complex set of events. When we do all those probability calculations, we need the probability to stay consistent and that is why we need the rules of probability. One's belief must be *coherent*, and to be *coherent* is as Lindley (2014) said in his book "A person's beliefs are *coherent* if, when those beliefs are expressed in terms of probabilities, they obey the three rules" with the three rules are addition rule, multiplication rule and convexity rule.

A.2 Quantifying uncertainties

In risk analysis, we are dealing with a lot of uncertainties regarding the phenomena considered. Based on principles and methods of risk analysis, we may quantify our uncertainties in the measurements available, commonly as probabilities. In this study, we want to focus on quantifying the risk we are facing, as Quantitative Risk Assessment. The QRA has various benefits compared to the traditional safety analysis, and we want to use that benefits as a better way to give insight on the situation faced. To quantify uncertainties means we must comply to some general rule and criteria, and after that we can assess the uncertainties with several approaches available.

A.2.1 Important issue when specifying probabilities

Assessing uncertainties in risk analysis must always be based on some available information, and with this principle we must understand what issue must be noted to improve the goodness of probabilities assignment. Aven (2012) points out four issues to note when specifying probabilities:

a. Evaluation of the probabilities
b. Heuristic and biases issue
c. Evaluating the assessor
d. Standardization and consensus

a. Evaluation of the probabilities

There are three types of criteria of how to evaluate probabilities:

- syntactic
- pragmatic
- semantic (calibration)

Syntactic criteria mean that we are obeying the rules of probability. When we are doing a risk assessment, we are dealing with lots of scenario. Each scenario will have a specific probability and the relationship between scenarios must obey the rule of probabilities. Therefore, using the syntactic criteria means we are evaluating whether the probabilities assigned to our case are *coherent* or not. We refer to section 2.3 about subjective probability.

Pragmatic evaluating means we compare our assigned probability with the real-world value. For example: we assigned a specific probability for a class to get A in an exam, because the population is clearly defined (number of students in the class) then the proportion of student that got an A can be calculated. The proportion of exam result to get an A is treated as a "real-world value" and compared to the probabilities we assigned. The problem here is the same as the *relative frequency* issue, not every case has a clearly defined population thus this type of evaluation will not do well in a more general case.

The semantic or calibration method means we are evaluating the probability specified based on how well-calibrated the person assigning the probabilities. The person is said to be well-calibrated if they can "correctly" assign probabilities to several assignments. From these assignments, we give a score to how well the person is calibrated. And the goodness of probability depends on how well the person scored. The problem with this criterion is we are only able to evaluate in the future, after the situation considered happened, when the evaluation is needed before the observation time, to provide decision support.

b. Heuristic and biases issue

We understand that knowledge-based probabilities are the most suitable when dealing with various situation in risk analysis. But with the subjectivity comes the *heuristic* problem. When the assessor assigning probabilities subjectively, they are not using the best available information but mixing their perception towards the situation assessed. There are three different heuristics:

Availability heuristic: when the assessor can recall similar event to situation being assessed, and they are biased because they may assign a higher probability than the other situation being assessed but not available in the assessor's memory.

Anchoring and adjusting heuristics: the assessor specifies a "base" value for the occurrence probability of an event. In this case, the assessor's is biased towards the base value that it is "anchored" to it. The extreme values might take place just around the anchored value therefore making the assessment have a lower probability for the extreme outcome.

Representativeness heuristic: when assessing probabilities, the assessor biased towards the stereotypical properties that is attached to a certain condition. This heuristic could make the probability unnecessarily higher because the similarity between the properties in the analysis.

c. Evaluating the assessor

The use of probabilities as a measure of uncertainty in risk analysis must always have a background knowledge. In contrast with the principle of observable quantity, where the true value existed in the future, there is no true value in the assigned probability. We cannot assess the value of assigned probability itself, what we can do is to evaluate the knowledge behind it which come from the assessor. In our study, the assessor might not be evaluated, but the key point is that we must be putting our best resources to close the gap between the assessor's state of knowledge and the best information available.

d. Standardization and consensus

This issue is important when we need a standardization for the probability distribution of an element in risk analysis. The main point is to be careful when we standardize a distribution, different view needs to be accounted and not to choose unsuitable distribution.

A.2.2 Assessing uncertainties

The main objective of this study is to give a quantified risk insight regarding the phenomena considered, the activity of commuting in Jakarta. To quantify the uncertainties, we need a set of background knowledge as the basis. Now the question is, what counts as background knowledge? Aven (2012)suggested several approaches to assign the probabilities in our assessment:

- Classical statistic methods
- Judgement using all relevant information
- Formal expert elicitation

a. Classical statistical methods

Consider that we are interested of failure probability of a lightbulb in a room and we have some number of data regarding failure of a lightbulb of a same type that we judge similar in a room during a specific time period, say, 1 year. For this case, the observable quantities Y are all the lightbulb working or failed in the room. And if we are applying the classical statistical method, we can consider where lightbulb failure is a "success observation" and for success we assign $Y = 1$ and failure (lightbulb still working) is $Y = 0$ and we may calculate the probability of lightbulb failure as

$$P(Y = 1) = \frac{1}{n}\sum_{i=1}^{n} y_i$$

This can be interpreted as the proportion of the lightbulb that failed in the room we are interested in, where there are n lightbulbs working in the same time during one year with the observation of $y_1, y_2, \ldots, y_n$. Any value obtained from this approach must always be interpreted as subjective probability we covered in 2.3, as it is the assessor's belief towards the phenomenon considered.

It is emphasized that the value in the classical method cannot be viewed as the estimate of probability. Here, we do not estimate the probability, as there is no true probability. And within the risk framework, this probability we calculate is assessor's measurement of uncertainty with the background knowledge of available data. And in our lightbulb example, we must have a sufficient number of observation n otherwise it will not give a good background knowledge.

b. Judgement using all relevant information

In practice when we are conducting risk analysis, not all situation we are interested in have a fully available data. We may face a situation where it is a unique one or the data is limited. Then the assessor is responsible for gathering every bit of relevant information that might be useful for the analysis. The state of knowledge and summarizing the information behind the assigned probability must always be comprehensive. Every derivation from the relevant information to the form of probability distribution rests with the hand of the analyst. And it is very likely that two analysts will give a different probability given the difference of the state of knowledge

To derive the probability from the relevant information, the analyst must understand the concept of probability itself. If we are considering the occurrence of particular event A, we must understand what the gap can be between $P(A) = 0{,}1$ and $P(A) = 0{,}2$. What we need is reference points, this reference point may give us the information whether the event A is more likely or less likely than the reference point itself. For this approach, the rationale of assigning probability is the most important thing to give attention to.

c. Formal expert elicitation

In this approach, the analyst is getting the help from the expert of the subject in risk analysis. The responsibility of gathering the experts lies with the analyst. The analyst must informed the expert about the subject that matters and they will establish a rationale for the subject. The expert specified their own distribution, and they may state on what level their expertise are on – how good they are – or the analyst may specify a weight regarding the quality of the experts. But ultimately, the risk analyst is the responsible for the subject matter.

APPENDIX B

Probability distributions for outcome scenarios in consequence analysis

In this part, we present the figures from the result of scenarios probability calculations in the accident assessment of every vehicle type in Section 5. The summary statistics are shown in Section 5, in this appendix, we only show the figures related to every accident scenario the vehicle involved.

B.1 Car accident

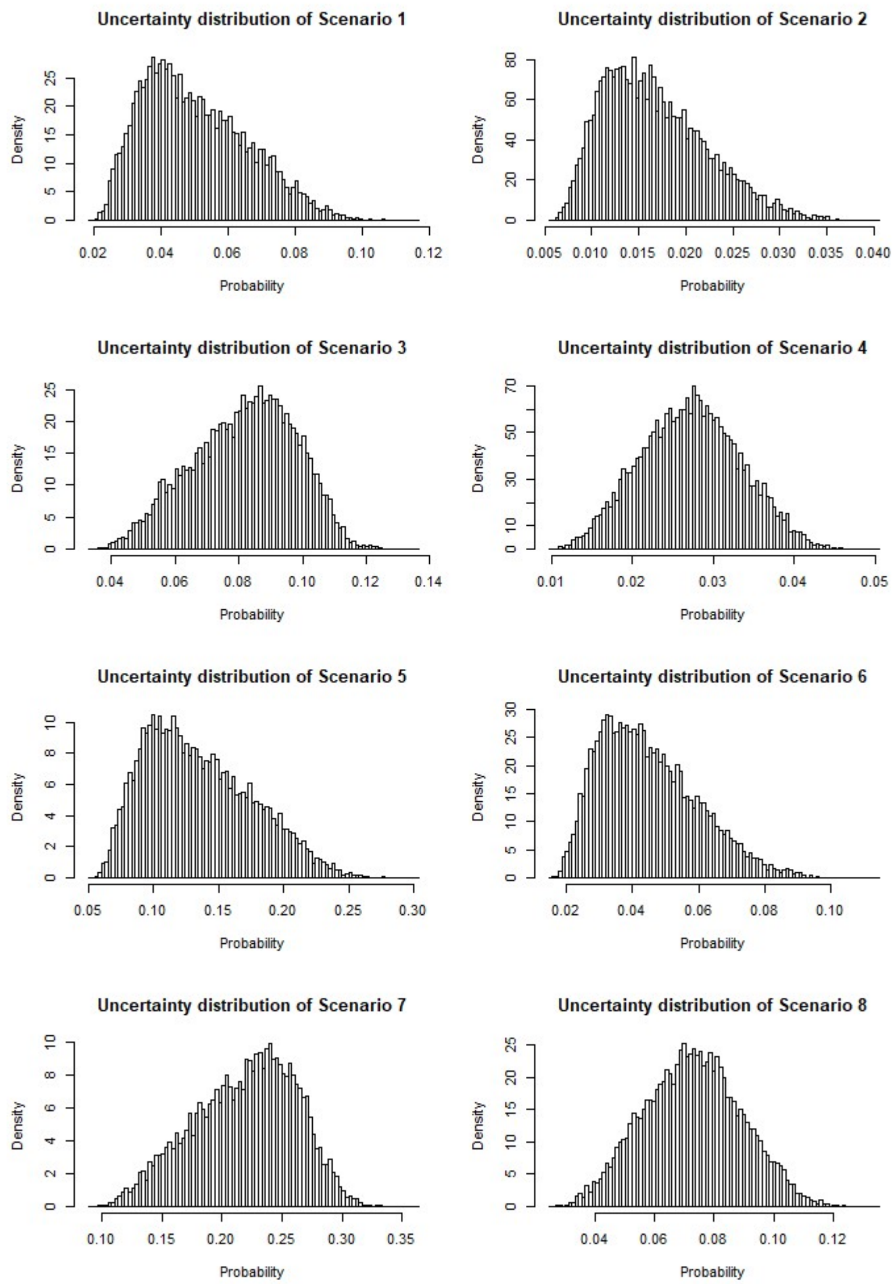


Figure 45 Probability distributions for car accident scenario 1-8

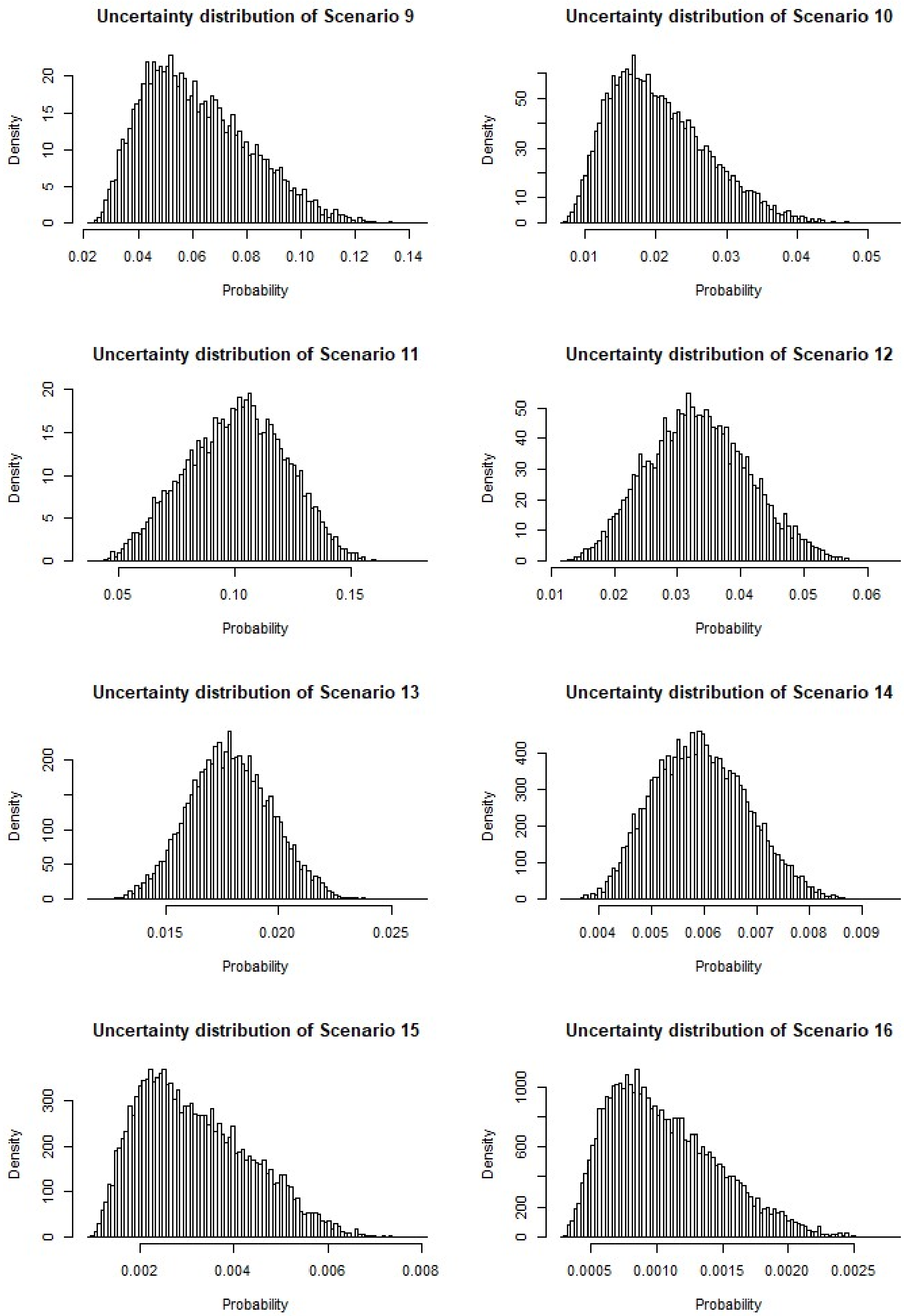


Figure 46 Probability distributions for car accident scenario 9-16

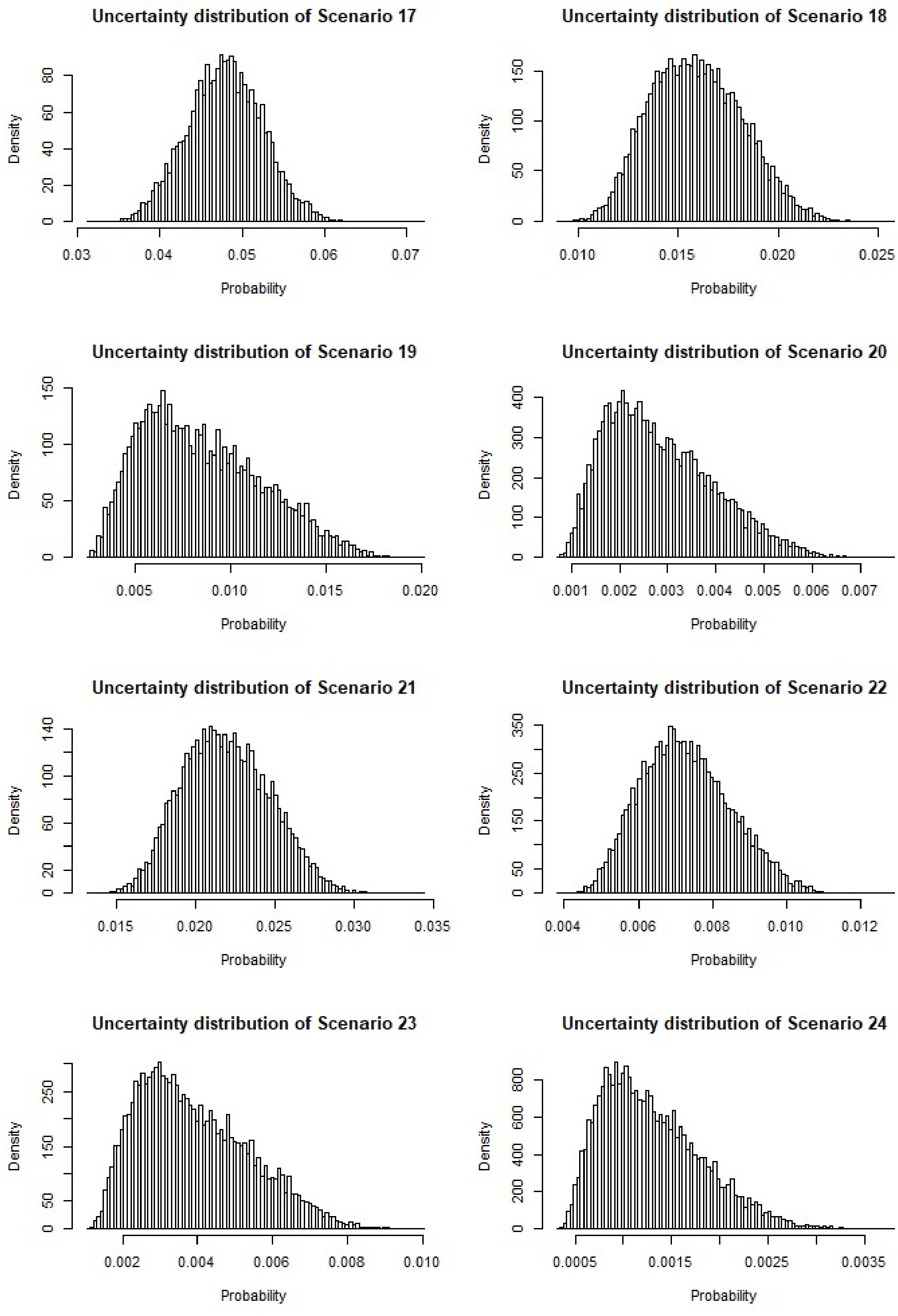


Figure 47 Probability distributions for car accident scenario 17-24

B.2 Motorcycle accident

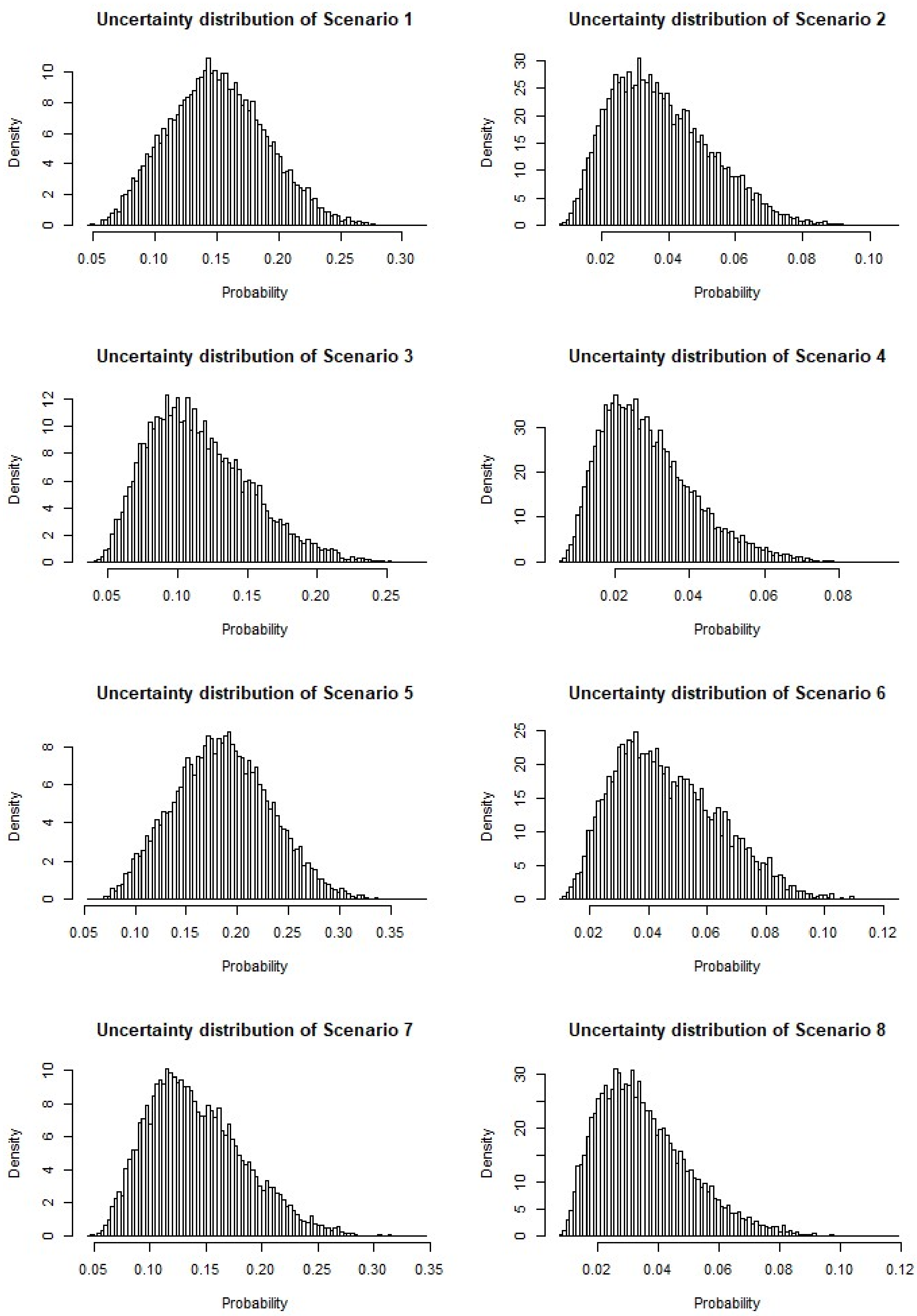


Figure 48 Probability distributions for motorcyle accident scenario 1-8

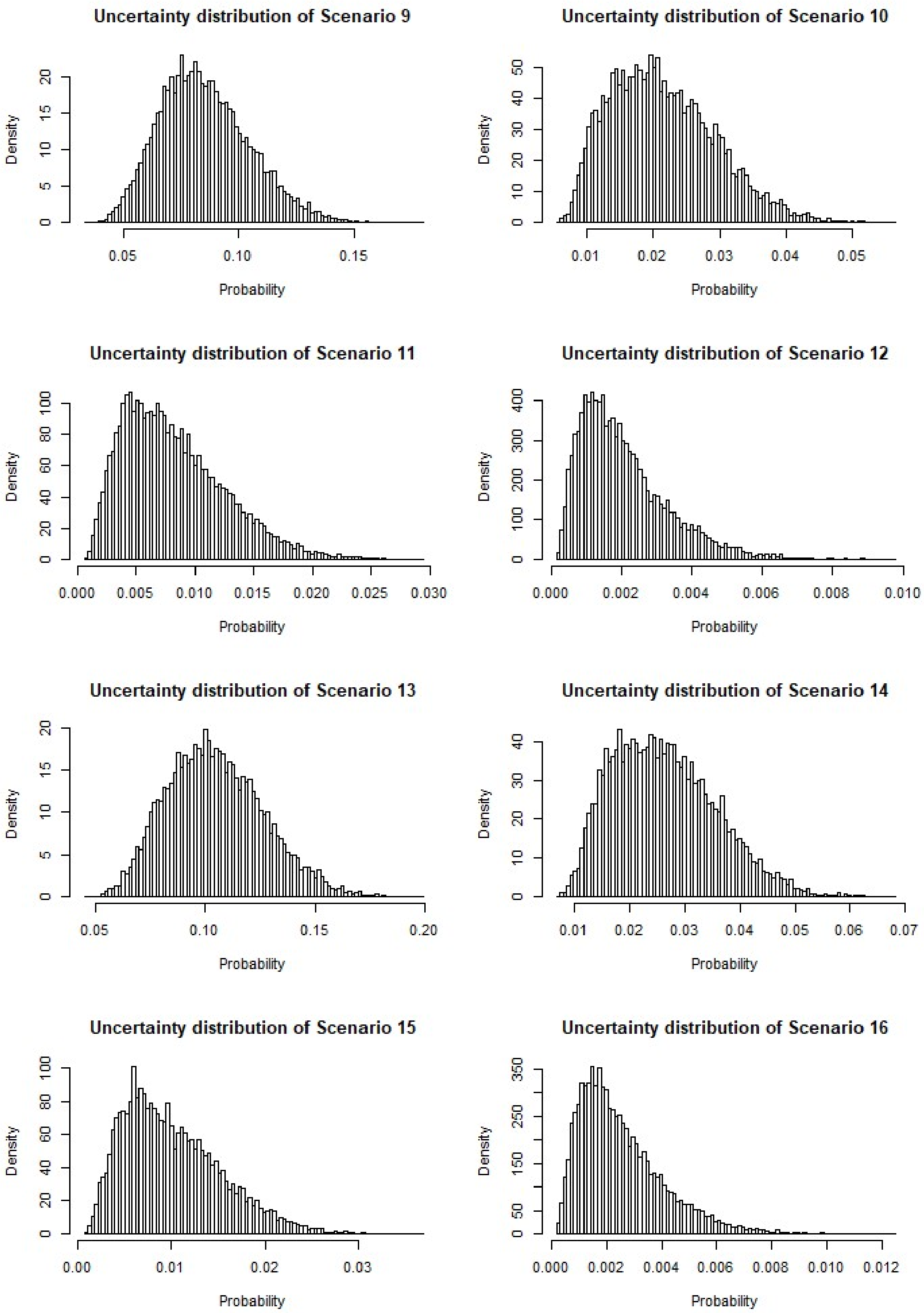


Figure 49 Probability distributions for motorcycle accident scenario 9-16

B.3 Bus rapid transit accident

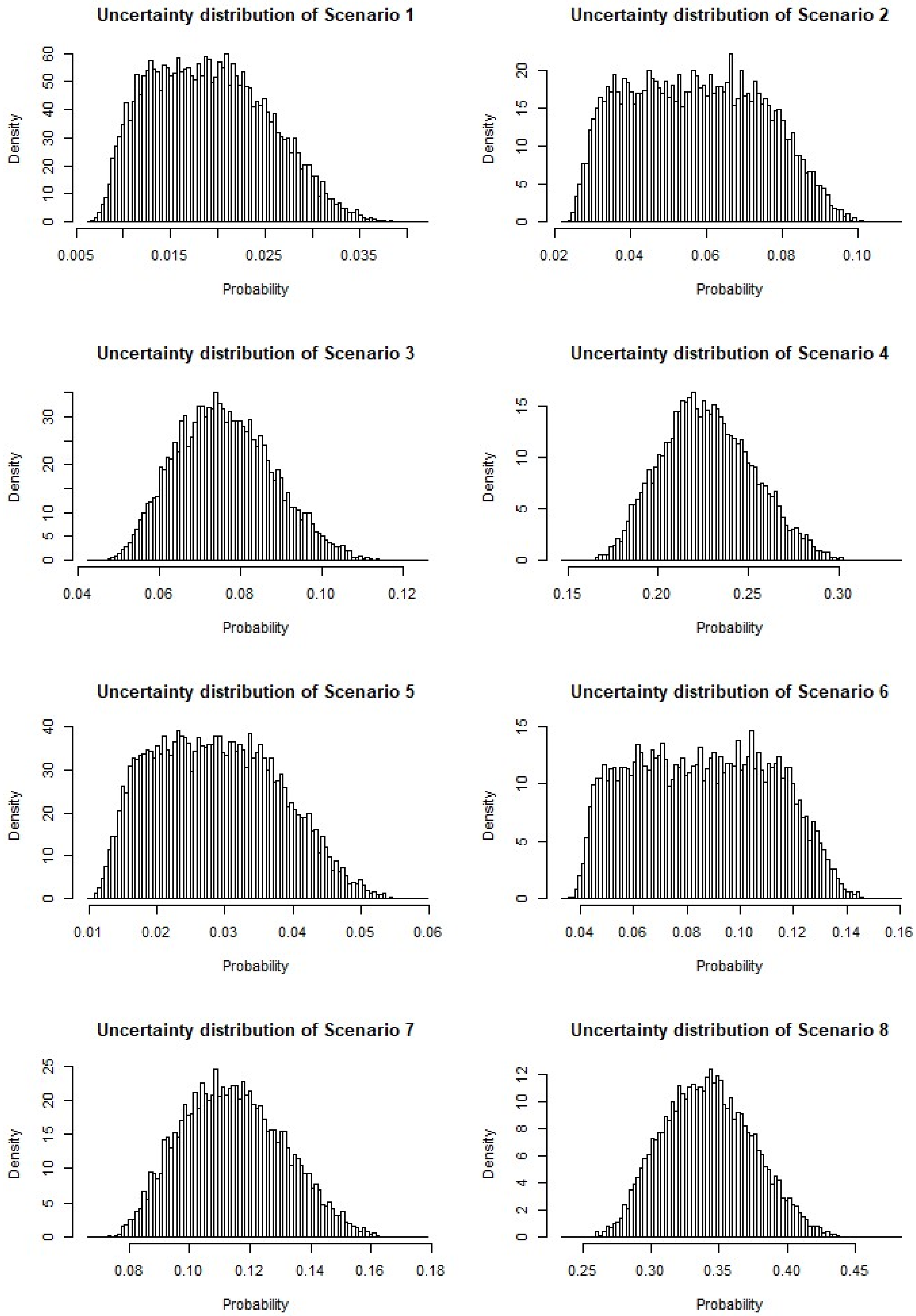


Figure 50 Probability distributions for bus rapid transit accident scenario 1-8

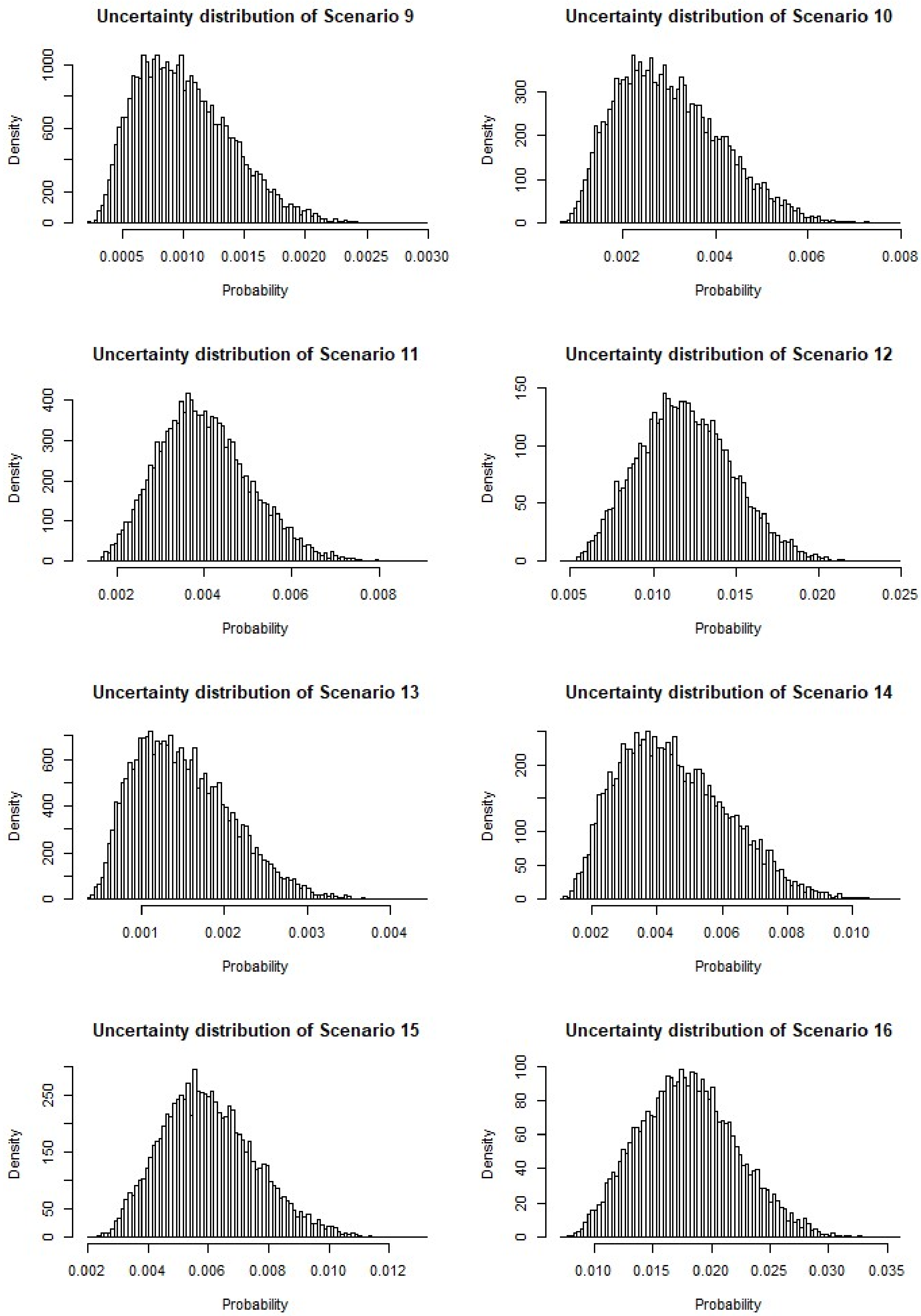


Figure 51 Probability distributions for bus rapid transit accident scenario 9-16

B.4 Commuter train accident

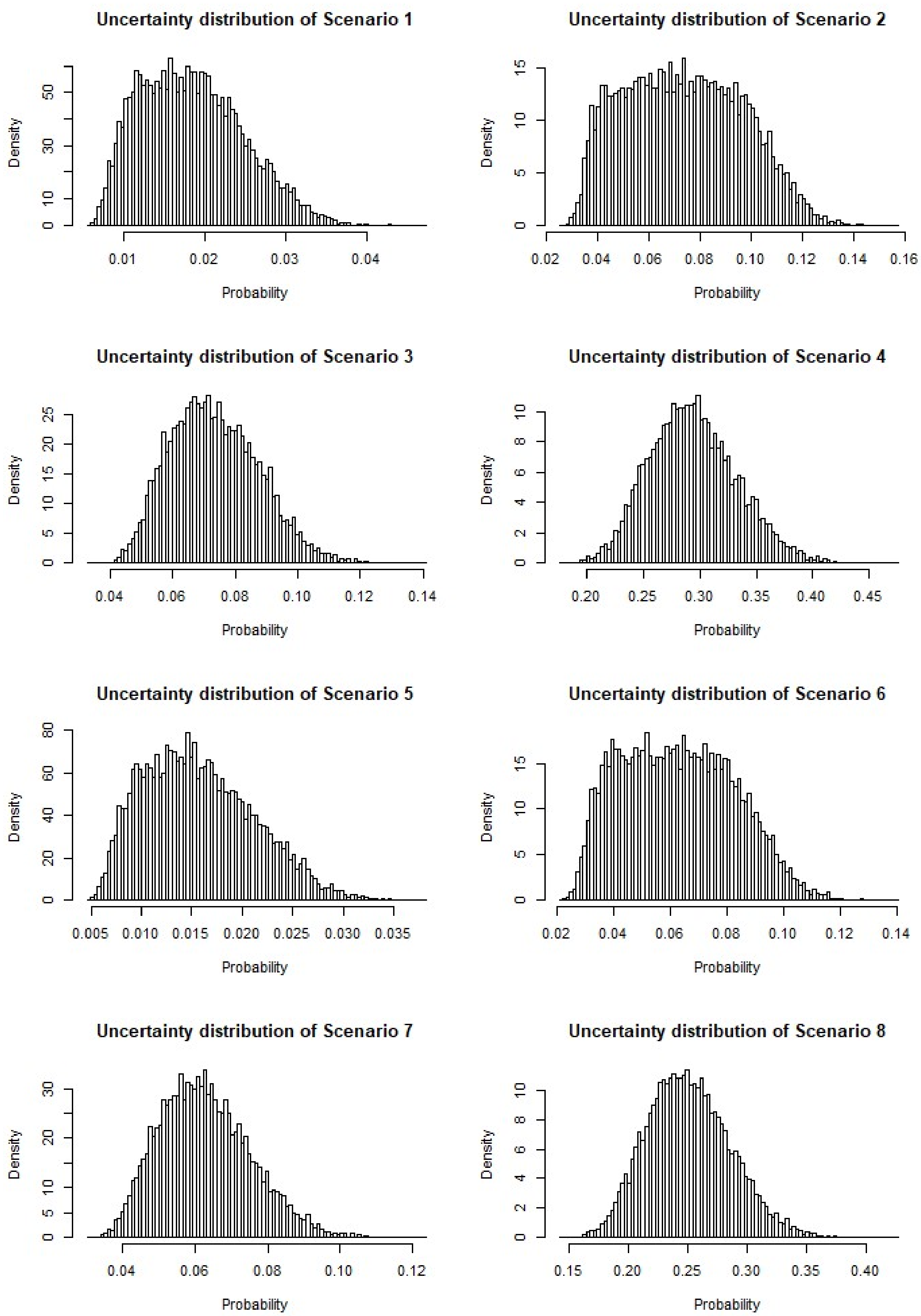


Figure 52 Probability distributions for commuter train accident scenario 1-8

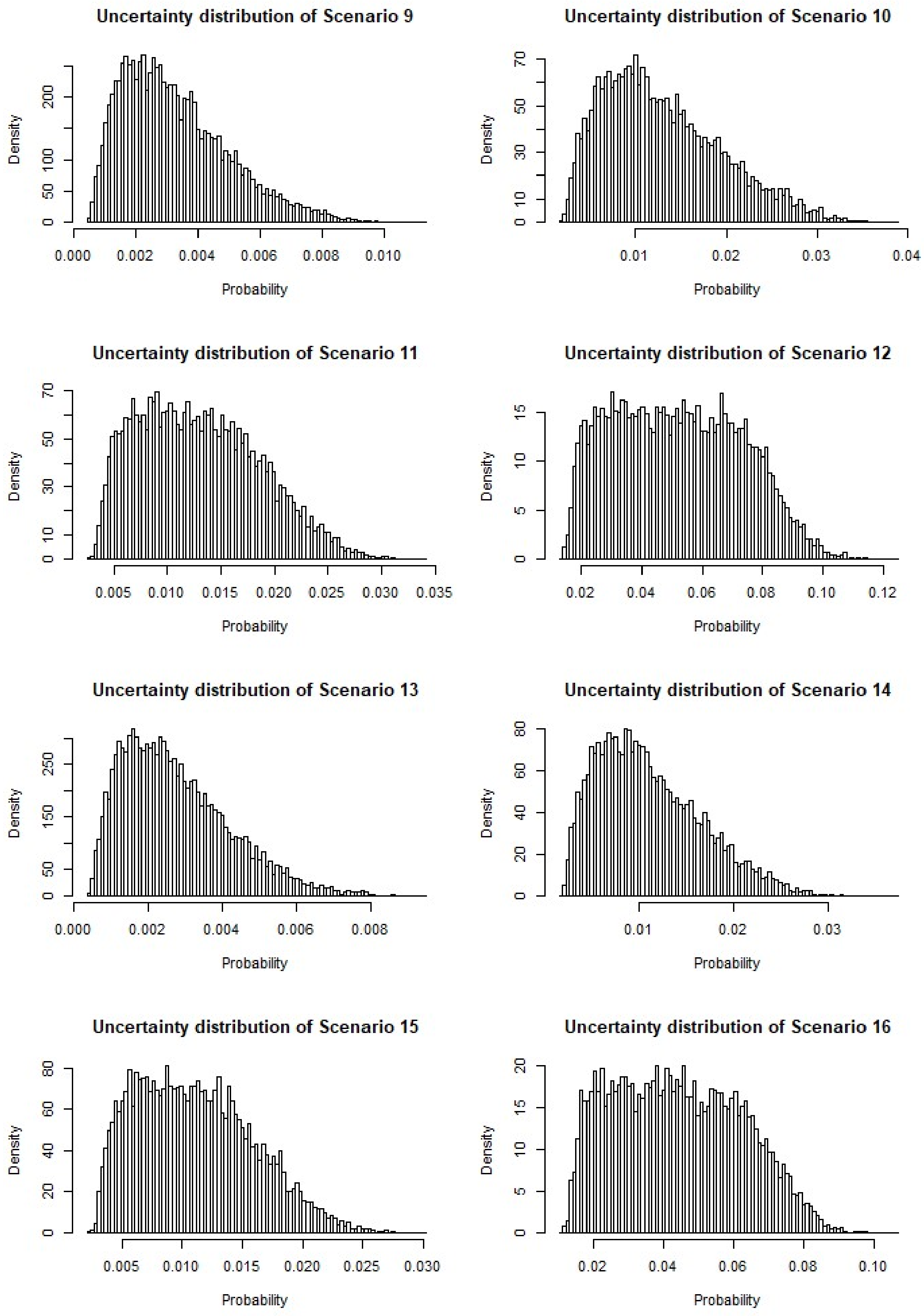


Figure 53 Probability distributions for commuter train accident scenario 9-16

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