PRE-COLLISION SAFETY RISK ASSESSMENT USING MULTI-BODY SIMULATION

EKO DEPRIANTO

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DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING SCIENCE

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Name of Candidate: Eko Deprianto [redacted]

Registration/Matric No: KGA120122

Name of Degree: Master of Engineering Science (M.Eng. Sc.)

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Name: Dr. Soong Ming Foong

Designation: Senior Lecturer

DR. SOONG MING FOONG
Senior Lecturer
Department of Mechanical Engineering
Faculty of Engineering
University of Malaya
50603 Kuala Lumpur

ABSTRACT

Road accident has become an alarming phenomenon across the country. Its negative impact does not only include loss of lives but also affects the economy. Hence, road safety assessment has become a crucial preventive measure. Several assessment studies have been developed and implemented. However, they are mostly conducted in the post-accident level, in which the accident has already taken place. A study using a vehicle dynamic simulation is then proposed to assess the accident at the post-accident level. In order to check its effectiveness, two accident-prone locations were chosen, its road segments are then generated into a simulated environment. Several combinations of the simulation parameters are then introduced to the simulation, such as road geometries, road profile, road condition, vehicle type, and driving characteristic. The outcome is then analyzed through visual observation and data analysis. Based on the study conducted, the crash report data obtained from the accident-prone location has almost similar output when the simulation parameter input matched with the crash data. An apparent visual indication, such as a vehicle crashing event, can also be seen from the simulation result. The vehicle dynamic data gives promising results by showing prediction in the form of an erratic response before failing. The vehicle dynamic response parameters are, namely, roll and lateral acceleration. It is concluded that this road safety assessment method can successfully replicate the actual type of accident that happens in the accident-prone location. Translating the actual road profile into a simulation form can be considered successful since it can imitate the particular road profile. The vehicle responses of roll and lateral acceleration can be used as a safety assessment key indicator in identifying the point of failure of a road stretch. Implementing similar methods to other road segments will result in the ability to find the dangerous combination of parameters used as a countermeasure for the particular road segment.

ABSTRAK

Kemalangan jalan raya telah menjadi suatu masalah besar yang tidak hanya melibatkan pihak terbabit, tetapi juga rakyat negara keseluruhannya. Perkara ini boleh dikecilkan atau dikurangkan dengan melaksasanakan pemeriksaan keselamatan jalan yang berkesan. Walau bagaimanapun, kaedah pencegahan ini hanya relevan sekiranya keadaan kemalangan dan risiko keselamatan yang berkaitan difahami. Terdapat beberapa pemeriksaan risiko keselamatan konvensional seperti "post-accident approach", di mana risiko keselamatan dinilai berdasarkan data kemalangan sebelumnya. Kaedah ini lebih kepada pendekatan reaktif berbanding proaktif, bermaksud kemalangan itu telah berlaku apabila pemeriksaan risiko keselamatan dijalankan. Kajian ini mengusulkan kaedah pra-kemalangan untuk memeriksa keselamatan jalan, dengan melaksanakan simulasi dinamik sebagai alternatif. Kaedah ini diuji terlebih dahulu untuk menentukan keberkesanannya. Kaedah pengesahan pula dilakukan dengan menguji di lokasi yang sering berlaku kemalangan. Nilai-nilai parameter kemudiannya diubah dan dilaksanakan dengan siri-siri gabungan unsur kenderaan, jalan raya dan pemandu di dalam situasi pemanduan. Berdasarkan keputusan simulasi tersebut, yang dilakukan di lokasi sering berlaku kemalangan, ianya ditunjukkan bahawa kemalangan luar kawalan yang berlaku di lokasi tersebut boleh diramalkan melalui simulasi ini, dengan meramalkan perlakuan tidak menentu respon dinamik kenderaan-kenderaan terbabit seperti "roll and lateral acceleration", di samping pemerhatian visual simulasi tersebut yang mana termasuk pemeriksaan perlepasan dari jalan dan pergolekan atau kemalangan luar kawalan yang jelas. Kaedah ini terbukti dalam menjadikan semula kemalangan yang berlaku di lokasi titik panas kemalangan, dengan sifat kemalangan yang berkaitan dengan respons dinamik lateral dan longitud yang biasa berlaku dalam trafik "Aliran-Bebas".

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LIST OF SYMBOLS AND ABBREVIATIONS

For example:

GVW	:	Gross Vehicle Weight
IMU	:	Inertial Measurement Unit
GPS	:	Global Positioning System
GPX	:	GPS Exchange Format
CG/CoG	:	Centre of Gratify
SUT	:	Single Unit Trailer

CHAPTER 1: INTRODUCTION

The world's population has increased tremendously; its number continuously grows from year to year. Continuous population growth has caused significant urbanization processes. More and more cities emerge due to this urbanization, which forced the government to develop or build more roads and highways to connect those cities. As a result, there is an increase in the number of fatalities caused by road accidents every year, which has raised the level of concern and awareness of road safety practices in developing countries like Malaysia. Several initiatives have been designed to improve road safety. One example of the safety assessment is by implementing a collision-avoidance system into the car. However, this technique cannot quickly reach since road accident is the product of the interaction of three factors such as vehicle, driver, and road environment.

Several factors need to be managed appropriately by highway management to achieve maximum highway system efficiency and fully functional safety. Road transport contributing to the high cost of the transportation management system, and road accident is the most increased contribution cost than another expense such as environmental cost and congestion cost. Reducing the number of accidents will automatically reduce the road accident cost on a particular highway. Road safety can be assessed or managed by applying the primary management method, which is risk management. The word "risk" assumes a measurable unit used to determine the level of security at a particular road section. It is typically identified by the number of accidents in that specific starch or road segment. This safety risk assessment can be conducted in three different phases, namely: (1) pre-collision, (2) collision, and (3) post-collision. As indicated by the broad utilization of the accident reconstruction approach, this typical road accident analysis approach at the post-collision level. The road accident is analyzed and rolled back to find its cause of the accident. This process can be achieved by studying the tire skid marks, indicating the vehicle's terminal velocity during the accident. The second analysis is during the collision itself, while the third phase is the pre-collision phase, where the accident’s breakdown happens before the accident occurred.

1.1 Assessments Approach

The research project discussed in this thesis is a pre-collision analysis employing a virtual simulation approach. Safety risks at several accident-prone road sections along the highways will be evaluated through dynamic vehicle simulations. The input parameter will be based on the actual physical system and environment. Three major factors contribute to road accidents, which are;

(1) Vehicle characteristics, e.g., Gross Vehicle Weight (GVW), vehicle classification, vehicle speed, and vehicle specifications (engine types and capacities, transmission systems, tires, suspension systems, braking systems.).

(2) Driver's characteristics: age, gender, driving experience, driving behaviour/style (defensive, typical, or offensive), and average perception-reaction time.

(3) Road environment: road geometry (curvature, slope, and super-elevation), and surface condition (wet or dry).

With the help of vehicle simulation, all of the above factors can be easily simulated and analyzed to determine the appropriate mitigation approach, which can contribute to extensive safety risk assessment at locations worldwide.

1.1.1 Visual Observations Approach

There are several ways to draw the safety risk assessment value or result. The first approach is by implementing visual observation. Here, the simulation result will be run in great detail of the visual environment, complete with the camera angle, to achieve the vehicle responses' full visual compliance. Even small changes in vehicle behaviour need to be easily observed.

1.1.2 Vehicle Dynamic Observation Approach

Another assessment method is by drawing its risk value based on the vehicle dynamic's responses obtained from the simulation. This method is useful to have due to the nature of the data provided. Unlike the result obtained from the visual observation, this dynamic vehicle result can show more on how, why, and what happened during the simulated accident, if there is any.

1.2 Problem Statement

It is mentioned that there are several methods for assessing road safety. However, a full risk assessment is challenging to conduct due to the many factors discussed above. Most of the conventional risk assessment is typically identified after the accident has occurred (post-collision). Risk assessment and prevention need to be conducted on a pre-collision level on the particular highway stretch based on the parameter mentioned above to maximize results. However, those experiments are challenging to perform and dangerous, and resources are cost-consuming. A simulation procedure needs to be developed to develop a set of risk assessment results based on the parameters mentioned to avoid such problems. This vehicle simulation needs to accurately represent the actual road section to maximize its output result. As a result, it can fulfil the thesis's final goal: achieve the pre-collision safety risk assessment of the simulation environment's actual road profile. It is then will help to make safety road assessment become more efficient and less cost consuming.

1.3 Objectives

The general aim of this thesis is to establish the necessary stimulation parameters for pre-collision safety risk assessment in the selected area as a case study sample by developing that selected area’s road profile in the simulation environment. This simulation is then run to study its road safety risk based on the visual and vehicle dynamic result,

The detailed objectives are as followed;

- To develop a virtual road profile based on the actual road profile

- To identify, evaluate, and validate the vehicle simulation process in terms of its road profile as well as its vehicle responses.

- To assess the safety risk (pre-collision) under different scenarios based on the developed virtual road profiles on the selected road segments by analyzing its visual identification and lateral acceleration over distance.

1.4 Research Scope and Limitations

The research will be conducted in several stages of development to achieve the thesis’s objective. First, the evaluation method of selecting the safety risk assessment is chooses based on the available data that will be obtained in the future phase. Several validation methods were also conducted to validate the virtual road profile. The road characteristic was first to be collected, analyzed, then digitized. The virtual road will undergo several optimization approaches to establish road profile relations close to the actual road profile after it's done. These road profiles will be used as the base parameter that will be analyzed to assess its safety risk.

Several limitations need to be highlighted. The thesis mainly focuses on the safety impact produce when there is a change in road, driver behaviour, and road or nature condition. We are neglecting the vehicle model changes and leave it to the preset model obtain from the simulation software. The road type modelled in this experiment is only limited to one kind of road that is concrete. Therefore, the result will revolve around one particular road type. The simulation conducted should represent the actual model on the topographical scale, in which small scale abnormalities will not be recorded. Even though the surrounding model is presented in the simulation, but rather only its landmark, e.g., not all trees and building will be modelled in the simulation

1.5 Thesis Organization

This study is divided into five different chapters, which provide a diverse scope of discussion.

Chapter I will describe the experimentation's development, the background, problem statement, objective, research scope and limitation, and research overview. Chapter II first describes the previous work done in road safety assessment, the technology used in this experiment, and the virtual road development.

Chapter III shows the methodology used in the development of the road profile, which then continued with the safety assessment drawn from the simulation. The methods of collecting empirical data are also explained in this subsection and its analysis method. For example, parameterization procedures, data adjustment and enhancement, visual implementation, and traffic parameter setup are described in these sub-sections.

The result and discussion of the whole studies are presented in chapter IV. Each parameter and simulation are recorded and analyzed accordingly. The result of the empirical data collection is also shown in this subsection. All work is presented in an orderly manner, starting from the virtual model development result, followed by the risk assessment validation result and discussion, and end with the analysis and the implementation of the risk assessment itself.

Chapter V will provide a conclusion and recommendation obtained from the studies' results and analysis and what can be achieved in the studies' extension.

1.6 Research Overview

As an overview, this study will involve evaluating the safety risks at several selected accident-prone or dangerous road sections along the expressway. The work involved in this project can be divided into three stages or activities, namely: (1) virtual road development, (2) empirical data collection, (3) simulation and data analysis. Below is the list of highlights or brief methodology of each of every stage;

(1) Virtual Road Development

- We identify accident-prone locations or road sections, determining features such as the posted speed limit and road furniture along the defined road sections.
- Input on the selected road geometry, such as the radius of curvature and gradient.
- Obtaining digitized road profile
- Developing the selected road profile in the virtual dynamics simulation system
- Fine-tuning of the virtual road models as well as the vehicle model and parameters.

(2) Empirical Data Collection (vehicle dynamics and driver behavior)

- Instrument preparation, installation of Inertial Measurement Unit (IMU) as a sensor, data acquisition system, and the associated calibration and testing of the measurement system
- Vehicle preparation, including measurement of the center of gravity for sensor installation
- Data collection using the instrumented vehicle for selected road location for experimental validation purpose.
- Data collection device preparation for driver behavior. This includes selecting the best installation location, supporting equipment preparation, and a checklist.

(3) Simulation and Data Analysis

- Execution of virtual simulation using a vehicle dynamic simulation software, covering various factors, including vehicle speed, vehicle load or GVW, vehicle classification, and road surface condition.
- Data validation against experimental data, including virtual road validation and vehicle dynamics simulation validation.
- Data analysis and interpretation of results for safety risk assessment, including location-specific vehicle response analysis, lateral acceleration data, out-of-control occurrences, and the effect of the vehicle speed and conditions.

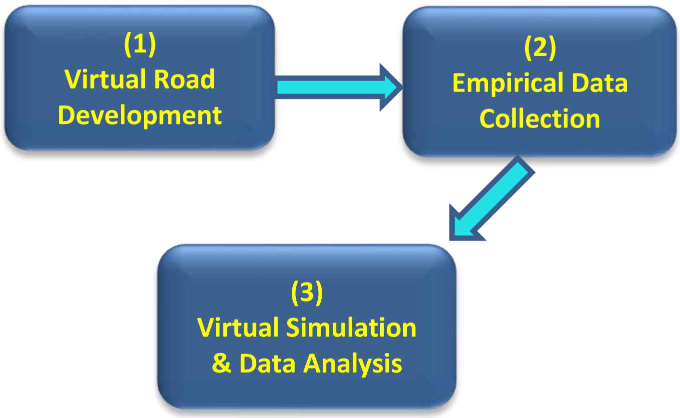


Figure 1.1: Overall Methodology of Road Safety Risk Assessment

1.7 Chapter Summary

The increase in road accident statistic has reached an alarming number and need to be resolved accordingly. This research stated that one of the approaches to resolve this is by conducting a safety risk assessment in one of the three road accident phases, which is pre-collision. This is done by assessing the road profile and analyzing the vehicle response to that particular road, considering vehicle characteristics, drivers' characteristics, and the road environment. This assessment is then approached in two different observation, which is visual observation and vehicle dynamic response observation. Hence, drawing the objective as previously mentioned.

CHAPTER 2: LITERATURE REVIEW

This chapter will elaborate on the background of the thesis, understanding the development of the risk assessment, which also includes the discussion of the virtual simulation's how to.

2.1 Road Safety Assessment

Derrick (2007) mentioned that the number of fatal accidents accounted for 2% of the death toll in a year. Road injuries accounted for 22.8%, with more than 50 million for one year. All these accidents and deaths contribute to 1%, 1.5%, and 2% of the gross national product or (GNP) for low-income, middle-income, and high-income countries. It shows how vital highway risk assessment is, not only to provide security to the road user but also to reduce the highway authorities' cost waste. Based on the report issued on road safety 2013, road injury is the number 8th leading cause of death worldwide. It also reported that in 477,204 recorded road crashes in one year, 6,915 are fatal, meaning 19 deaths per day and about one death every hour. It is shown that the high vitality index is 2.9 per 10,000 registered vehicles; however, this value is lowered in the developing countries such as the United Kingdom, Sweden, and Australia, with fatality index, is lower than 2.0. While in Malaysia, according to the crash report data published by the Malaysian Ministry of Transport (MIROS, 2016), the number of road accident has been increased tremendously for over a decade, comparing its number from the year 2007 and 2016, amounted to 369,319 and 521,466 accidents respectively, with the number of death increasing from 6,282 to 7,152 for the same period. This increase also contributed by increasing the number of private vehicles used as a primary transportation mode (Abdelfatah et al, 2016).

The accident's primary contributors can be identified as three: human behaviour or the driver, road environment, and vehicle failure (Evans, 1991). Human behaviour or driver characteristics can be parameterized by age, gender, driving experience, driving behavior, and average perception-reaction time. These factors contribute up to 60% of road accidents. The road environment parameter, such as road geometry, including curvature, slope, super-elevation, and surface condition, wet or dry, contributes up to 30% of road accident cause (Mohan et al, 2006), (Muhlrad & Lassarre, 2005). Risk assessment can be established by identifying dangerous road sections along a particular stretch by analyzing those factors.

Highway risk can be assessed in many ways, subjectively and also objectively. The previous study has been conducted in the field of road assessment. One of the examples is and accident prediction method studied by Cafiso et al, (2010). It is the implementation of an accident prediction model in which the studies' parameter is based on the exposure, geometry, consistency, and context variable related to the road's safety performance. The crash report is generally analyzed by categorizing its variable of the road profile such as signing and marking, road design consistency, shoulders, lighting, and sight distance specified by road authorities (ATJ, 2015). Kloeden (1997) testified that speed and crash are directly proportional; the crash risk increases as the speed increases. The accident happens because most drivers do not understand stopping distance, which leads to the close following driver behaviour. From here, Kloeden (1997) came up with the risk assessment by investigating the relation to speed, stopping distance, and impact speeds. He mentioned that the vehicle's speed could determine the risk of the crash. Its jeopardy is doubled for every 5 km/h over the speed limit on a particular road. Apart from the speed factor, the driver can also contribute to the accident. For example, an inexperienced driver will have a higher tendency for the crash due to its lack of experience. They have reduced perceptual skills, judgment, and unavailability to react to the risk and distraction while driving (Williams et al., 2006). The accident risk can be considered high because new drivers tend to fail to distinguish risk and low ability to judge hazard in, at least, their first six months of driving. From an environmental standpoint, several factors have been studied to determine the risk. Some of the ecological factors are road friction condition, road surface design, and road profile. In his research, Turner (2005) mentioned that road design elements such as the radius of curvature directly correlates with the relative risk, represented in the diagram below.

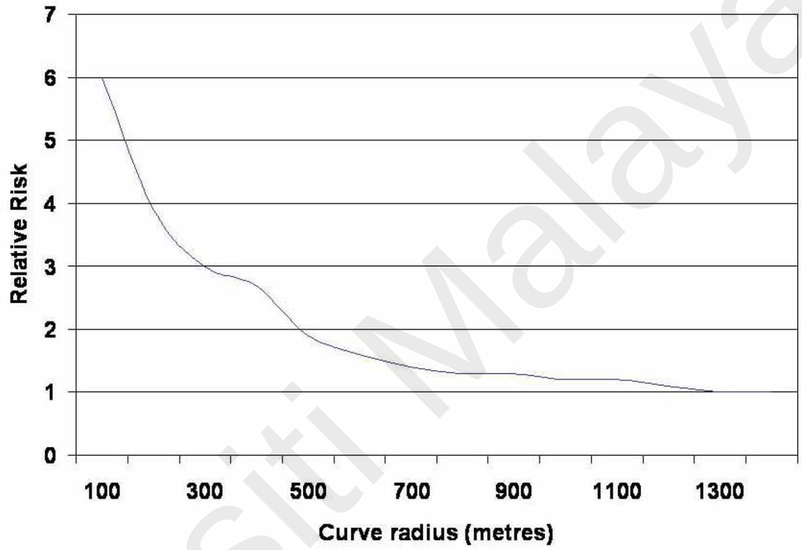


Figure 2.1: Graph of Curvature Radius vs Relative Risk (Torbic et al, 2004)

This risk is closely related to the point of view or sight. Small radius curvature is identical with a large angle of central, which resulting in low sight distance. Hence this will increase the risk of accidents during such maneuvers (Torbic et al., 2004). Another road design-based risk assessment study is super-elevation and side friction. Super-elevation is closely related to the speed of the vehicle, travel speed, to be specifics. Super-elevation needs to be determined correctly based on the curvature radius since it will directly affect the vehicle's travel speed. Higher super-elevation on the small curve radius will make the driver misjudge the required speed, increasing the accident risk (Dunlap et al, 1978). In terms of road profile, curve location is also essential to reduce risk. The threat is high when the curve is located after a straight road or after a series of small light curves (Seneviratne & Islam, 1994).

Referring to the above factors, it is clear that an accident can happen because of many reasons. Hence, it is hard to conduct a risk assessment based on the road observation itself. Moreover, it is almost impossible to perform an actual test on the road because it is dangerous and impractical due to the cost needed to implement it; this is where vehicle simulation comes into play. All of the previous studies mentioned in the last paragraph are only held based on the accident record. It means that it already happens, which contradicts the safety risk assessment's purpose, analyzing the risk before it happens. Here is where this thesis comes into play. By developing a pre-accident safety risk assessment method through virtual simulation, we can create a guideline or benchmark for any designated road profile.

2.1.1 Post-Accident Phase

Accident Investigation is a road safety studied in the post-accident phase. The safety risk assessment of the particular road area will only be conducted after the accident happens. This is done by investigating the sequence of the event before, during, and after the accident. Relating data then conclude the accident factor such as road, vehicle, and driver. Accident investigation starts typically from the report obtained from the people involved in the accident or government authorities such as the Response team. Here necessary accident data is collected, such as type of accident, the number of vehicles, and the severity of the accident. These data are then used to construct an accident classification. The next step is to conduct an at-scene investigation, where unavailable data from the report are added; this includes examining the accident location, such as debris and tire marker. Those data are then developed or added to create technical parameters, such as the vehicle's acceleration and speed, visibility during the accident. After all the data has been collected, the accident is then reconstructed based on road, driver, and vehicle factors. It is then analyzed to determine the cause of the accident (ANSI D, 2017).

2.1.2 Impending/ During Accident Phase

In the impending or during the Accident phase, the crashworthiness study has become a sensible choice. Its rapid development has caused a tremendous decrease in car occupant fatalities by 31% in the course of the year 1990 to 2010, as mentioned by Thomas (2013) in his paper. The term crashworthiness itself refers to the vehicle's ability to protect its occupant (Hoye et al., 2017). These research studies fall under the accident phase since it focuses on what happens when the vehicle is exposed to the accident. Its analysis typically comes in experiment and simulation results. The difference from the previous road accident studies method is that it focuses more on minimizing the occupant injury or event fatality and heavily focused on improving the vehicle factor rather than another element such as road geometry. Other mitigations are focusing on increasing driver's awareness of the impending danger during particular vehicle operational maneuvers. Several examples of this approach by using a lateral load transfer ratio to indicate rollover risk (Thomas & Woodrooffe, 1990)

Another widely available study is on the Advance Collision Avoidance System. This system will help the driver by increasing their awareness, and this is done by providing the driver with a warning when the vehicle is entering a possible collision scenario. This situation usually happens when two cars travel in the same direction, and one vehicle follows the other with only a little headway distance. This system prevented the accident by alerting the driver when its headway is less than 4 seconds, which is the suggested Time-To-Collision by Van der Host (1991), supported by Farber's (1991) studies. However, based on the survey conducted by Sultan (2002), the minimum Time-

To-Collision will always change the decrease in the observer vehicle's travelling speed, resulting in a reduction of the minimum TTC. It is similar to the process discussed in the previous paragraph. This type of study targets accident prevention from the vehicle point of view. The studies are doing their best to improve the vehicle responses and characteristics to minimize accident probability.

2.1.3 Pre-Accident Phase

The Pre-accident phase is the phase on which this thesis heavily leans on. As previously mentioned, although the risk assessment is at the pre-accident level, most of the current studies rely on the crash data collected for several years.

One of the most common studies on road safety in the pre-accident phase is the Accident Prediction Model. Its primary function is to predict the impending accident frequencies by identifying the geometric, environmental, and roadway operational and relation between them (Reurings et al., 2005). In the study conducted by Kumar (2012), using a negative binomial model and log density function is the most appropriate statistical model in predicting road accidents. Their analyses identified the relationship between highway with and condition, median with the condition, shoulder's condition, road marking, marker post, and many more. The dependent variable accident count per kilometre per year is used as a dependent variable. After careful analysis, the study showed that most accidents occur due to traffic speed, the truck's percentage in a traffic stream, and misleading signs. It is shown that although the accident prediction models are able to give reliable road safety assessment, its date is still based on the previous accident data even though it is not at the same spot but still in the same stretch; hence, this evaluation and data collection still needs to be done for the different road segment. This accident prediction will also not work correctly in the brand-new road segment since there will be no crash data present.

This Accident Prediction Model's limitation is the need for sizeable historical traffic accident data for the road designer and manager to Screen out high-risk coefficient, indexing, and integrating the risk model (Sun, 2011). In other words, although it is a pre-accident phase of safety assessment, the traffic accident data need to be present first. This is also resulting in the safety assessment that cannot be implemented in another road section or area, as previously mentioned. The application of this assessment is by quantitatively analyze the road safety index of the particular road section. This road safety index naturally expresses in five different race-level and determined by its range of risk indicators value. These risk indicators are obtained from the risk impact model combined with the degree of traffic condition index (Wu, Qian, & Wang, 2014).

Another road safety assessment method that currently studied is the application of machine learning technique (Habibullah et al., 2019) (Mafi et al., 2018), it is a branch of artificial intelligence in which a constitute model is developed, and the result is calculated and then estimated under a new condition by using previous gained data. It is not far fetched from other accident prediction methods. This technique also relied on the last crash data feed by the user or highway authorities, which may vary depending on its approach. Previous studies, such as a study conducted by Elahi et al., (2014), propose a method of predicting accidents by using vision-based techniques. They are using a roadside video as a material for their machine learning material. Although this accident prediction method can predict up to 85% of accuracy, its limitation is in the preparation of data. The observant needs to be on standby for at least 24 hours to record the video on the side of the road. Although it is doable, it is impractical for specific situations, such as in very harsh location or weather.

2.1.4 Virtual Simulation Concept Description

The concept of this road safety risk assessment through vehicle simulation relies heavily on the ability to turn the actual road profile into a virtual road profile. Although other input parameters such as driver behaviour model and vehicle model are also among the input parameters, its data is keyed in the software and based on the simulation software's mathematical calculation. This thesis will emphasize the critical input parameter of the Road Model and let other input such as driver behaviour and vehicle model calculated by the simulation software.

Two basic analysis methods will be used to implement this thesis's concept perfectly, one is analysis through simulation, and the other is from an actual vehicle test. The analysis input will be fed with the information mentioned in the previous paragraph. The results obtained from the two analyses are then compared to validate the output from the simulation analysis. These data are then further analyzed to achieve the thesis's final objective, assessing the risk present on a particular road stretch based on the simulation result.

As previously mentioned, this thesis will only emphasize the Road model's parameter input; hence, vehicle development and human behaviour will lie outside of this thesis's scope. However, to increase the analysis's accuracy, the vehicle model used in both simulation and vehicle test analysis will be based on the same car with a similar model and specification, including similarity on the powertrain, gear ration, and other vehicles mechanical aspect.

2.2 Safety Assessment Key Indicator

The concept of obtaining the term of safety risk assessment is from identifying its failure or breaking point of the particular vehicle run. This identification is more comfortable presenting the apparent visual indication, such as visible vehicle sideways skidding, vehicle rollover, and vehicle line departure. Apart from the visual observation, more in deep identification can be achieved by extracting its vehicle stability indication aspect. This is done by extracting the data during the manoeuvre such as vertical motion in the z-direction, lateral movement in the y-direction, longitudinal motion in the direction y-axis, and rolling motion around the x-direction, pitching motion around the y-axis, and lastly, yaw motion around the z-axis (Rajamani, 2006). This information of the car's behaviour, which is an interconnected rigid and flexible body that undergoes extensive either translational or rotational, is called Multi-Body Dynamic Response.

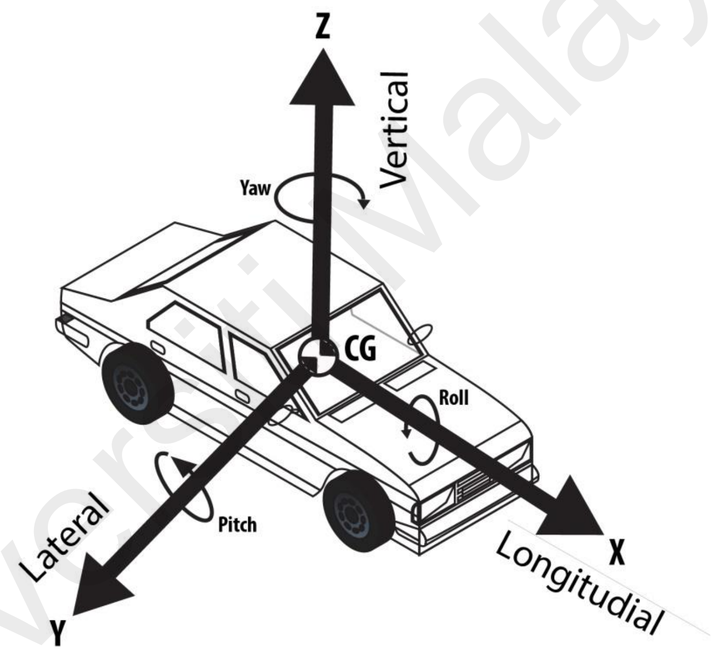


Figure 2.2: Vehicle Dynamic Axes (Guo H et al, 2018)

The assessment used in this thesis is based on the dynamic models to predict the vehicle's movement. This process identified different forces acting on the car, such as longitudinal and lateral tire forces or even the road banking angle (Rajamani et al., 2006). Implementing it to the simulation, single trajectory simulation can be achieved (Brannstrom M et al., 2010). This is mainly used fully in computational efficiency since the simulation is bound firmly with the real-time parameter. The dynamic vehicle response is a robust observation tool since it can show when the accident will happen.

From here, we can investigate more to find the accident's roots, which leads to evaluating the accident's cause.

Vehicle dynamics can be used as an indicator since a vehicle accident such as a spin-off happens when the yaw stability is lost. Hence, by looking deep into the dynamic vehicle response, the yaw responses' disturbance can indicate the accident. Skidding is also commonly caused by the loss of traction of the tier. The failure of friction at the front tire first will cause an understeer situation, where lost at the rear tire will cause an oversteer situation that both cases can quickly identify by visual observation and the simulation data in the form of out-of-normal vehicle response.

Another key indicator from the dynamic vehicle response that can be used is lateral acceleration. This lateral acceleration or side-to-side acceleration is closely related to the rollover accident. This occurrence happens when a vehicle is experiencing constant acceleration or deceleration in the forward and backward manner, but it then changes its direction. This change in direction has caused an acceleration in the direction of turning, leading to a lateral force's upsurge. The rollover occurrence can quickly pinpoint the obvious vehicle response, which is the lateral acceleration's sharp increase. In previous studies, this lateral force has been used as a key indicator for early warning indicators. Implementing this lateral force with load transfer creates a ration that becomes fundamental for today's rollover warning (Chou & Chu, 2014). Such an indicator is then developed and used as our reference point in deriving the safety assessment for the particular parameter.

2.3 Virtual Road Development

The project begins with the virtual road profile development. This road profile development makes use of the simulation software to be after the actual road profile.

Hence, the simulation road profile closely resembles the road profile and the road attribute found in the real road profile.

2.3.1 Backgrounds

The most important aspect of this thesis is the virtual road model. This virtual road model will closely represent the actual road profile closely to 100 percent of characteristic and attribute accuracy. Hence, it has to be correctly developed to ensure its accuracy. There are many ways to come up with a road model. One way is by using velocity profile as the road profile indication developed by the EPA Federal Test Procedure. This application uses a driving cycle to identify the road profile, such as elevation and corner, and can be done by analyzing the velocity profile since it changes based on the road's shape; for example, the velocity will decrease as the vehicle climb the slope. This method has been proven to work but not applicable, since it is difficult to draw the link between road profile and the speed profile, especially on the public road; where we have no complete control over the environment, specifically toward another motor vehicle, which has a direct influence on the speed of the test vehicle.

2.3.2 Virtual Road Model Development

This experiment uses different approaches to road profile development. After deciding which multi-body vehicle simulation software to use and analyzed the software's capability, then we can determine which road profiling method is suitable for this test. The CarMaker software can draw the road profile as accurately as the parameter data provided by the user. Several approaches can be made to develop a road profile through CarMaker; One is creating a road section by defining and connecting the road segment shapes such as straight, 90-degree turn, and corner. The other method is plugging in the coordinate of x, y, and z into the software. All these points are then connected and plotted to the shape of the desired road section. The difference between the two methods is evident; one required more effort than the other. The segment-based road is straightforward and easy to use; however, when it comes to the actual road profile, where the road does not always have a constant straight line and turn, it becomes difficult to obtain the road segment's proper shape. This method is suitable for the road segment with a consistent form such as highway exit and race circuit, where Road Mountain and curly road segment need much extra effort for the development.

This method is then abandoned in this thesis since some road segments have irregular road shapes, such as the mountainous road segment. Hence the digitized road segment method is used instead. The digitized road segment method is able to map an involved road segment since it derives its road segment by connecting the input coordinate of x, y, and z. The real challenge comes from the initial development of the coordinate's points itself. Many steps and workaround need to be done before the x, y, and z, or customarily called Cartesian coordinate, can be developed. It was starting from the road coordinate data, usually in the form of latitude-longitude and altitude, followed by the conversion that changes those geodetic coordinate data into Cartesian coordinate, which is then keyed into the simulation software.

2.3.3 Geodetic Data Collections

There are several ways to collect geodetic data; every method had its strength and limitation. In this thesis, three modes of geodetic data collection can be considered. One is through Light Detection and Ranging or LiDAR. The second is by using a GPS data logger from an Inertial Measurement Unit, lastly, by extracting existing data obtained from Google Earth's database through the commercial website. All three methods will then be discussed in these sections.

2.3.3.1 Light Detection and Ranging (LiDAR)

A possible means of information regarding road geometry data can be obtained using Light Detection and Ranging (LiDAR) technology, as illustrated in Figures 2.1 and figure 2.2 (Vincent et al., 2012). LiDAR belongs to one of the several Digital Elevation Model (DEM) technologies, including Sonar technology for underwater surface mapping, Radar system employing Shuttle Radar Topography Mission (SRTM) satellite, and thermal method (ASTER). Fundamentally, LiDAR is a measurement method by using light energy. LiDAR is commonly installed in an aircraft because an airborne LiDAR system can cover much more area than a ground LiDAR system. LiDAR makes use of light energy by sending its pulse to the ground. The sensor will pick the bounce light pulse, giving the airborne LiDAR unit distance to the ground.

The elevation profile from LiDAR data is derived from a calculation of the travel time of the light pulse from the airborne unit back and forth. There are three different elements of the LiDAR measurement system. First is the LiDAR unit itself, which emits a pulse of an infrared signal and recaptures it. The second is a GPS, which helps track down the x, y, and z positions of the aeroplane that carry the LiDAR unit. This will then help to determine the location of the reflection. The third is the IMU device, which allows tracking the plane's yaw, roll, and pitch to accurately calculate the elevation profile. Combining all the data obtained from the three elements mentioned, the ground elevation can be obtained from the plane's altitude, derived from the GPS, minus the distance of ground to the airborne unit, obtained from the LiDAR Unit. However, since the plane moves up and down due to the turbulence when flying, this information needs to be accounted for. This is why IMU is used to compensate for the elevation based on the data from the IMU.

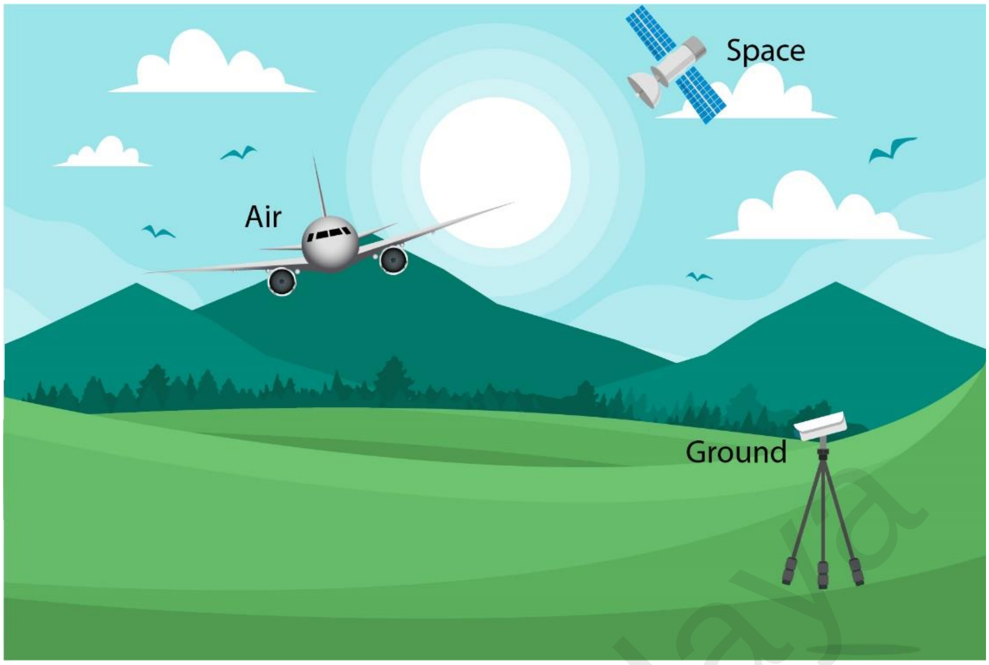


Figure 2.3: Illustration of LiDAR Data Collection (Molino, 2012)

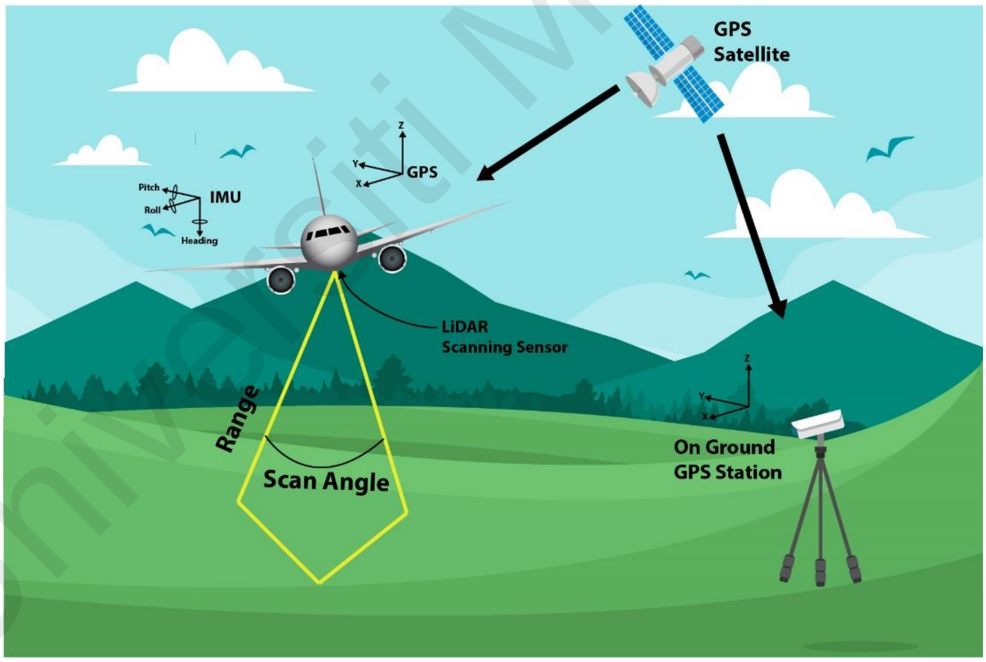


Figure 2.4: LiDAR Method Depends on Three Independent Technologies, i.e., IMU, GPS, and LiDAR Scanner (Molino, 2012)

(a) (b)

Figure 2.5: Example of Ground Data Collection Using (a) Mobile LiDAR (Ontario et. al., 2013) and (b) Fixed LiDAR (Wikipedia, 2007)

By cooperating with all the data to obtain and select only geodetic coordinates needed, a road section can be digitized, complete with its altitude data. The disadvantages of the LiDAR as a geodetic data collection method are that in its practicality, a large scale LiDAR data collection that involves collecting data from the air is typically costly since an aeroplane is needed in the arsenal of data collection along with the LiDAR unit itself. Thus, only a limited area with the geodetic data is present because private and government sectors usually collect data using LiDAR only when they need it, also not very often. This data is also typically not accessible to the public, and if it is present, the information usually is outdated. Several alternatives can also be used, as mentioned above, such as ground LiDAR data collection. This method is cheaper than the air LiDAR data collection, but it is still not practical due to its price. The data can only collect infrequently instead of annually, and the current development technology only happens in the western country such as the United States.

2.3.3.2 GPS Data Logger

Global Positioning System data logger (GPS) has a function to log or save the device's position regularly. It tracks the coordinate location of the device and holds it in the internal memory. In the year 2000, differential GPS or DGPS has more superior accuracy than regular GPS with an error rate below 0.1 km/h. However, this test was conducted when the US Department of defence devalued the satellite signal and where the high-quality signal was used by the military GPS devices (Schutz et al., 2000). It is also mentioned that standard GPS has good accuracy when the receiver travels in a straight line but not so good when travelling in a circular motion (Witte et al., 2004). However, in early 2000, the US Department of Defence removed selective availability, which causes the guarantee of high-quality GPS signals for civilian use (Terrier et al., 2005). And like 2015, the US government mention that the high-quality FAA Grade GPS receiver can provide horizontal accuracy of 3.5 meters (GPS. Gov, 2015). This accuracy may vary based on the satellite availability, the receiver's quality, and atmospheric pressure during the connection processes.

How GPS works can be explained in a simple form, the three-dimensional position of the GPS receiver can be easily identified by sending the time of the signal transmitted by the satellite to the GPS receiver; this is called Time of Transmission (TOT), then, the receiver will record the time when the signal reception by it, it's called Time of Arrival (TOA), hence from here the Time of Flight or TOF can be found. By plugging it into the navigation equations and considering the speed of light, the subject's three-dimensional location can be mapped. However, the satellite conceptual TOF is resembled by the hyperbolic of revolution. Thus, more satellite is available to the GPS receiver, more accurate its mapping location, since it is located where all the single satellite's hyperboloids intersect.

There is a lot of brand and type of GPS data logger, each with their pros and cons. The logged data from the device need to be as accurate as possible since high-quality data is required to create the virtual road accurately. The refresh rate alone is not enough as a benchmark or reference to choose a GPS product. Several factors need to be considered when selecting the right GPS data logger; some of it are,

- Size- a relatively small or compact size data logger is a somewhat prominent feature needed for small vehicle data logging media such as bicycle or motorbike since small form factor means it can be mounted practically anywhere.

- Battery and battery live- this is one of the most important factors since we do not want to lose our data and need to re-run the process just because the battery has run out. Long last and rechargeable battery available is the best solution for GPS data logger.

- High Capacity- GPS data logger is saving waypoints. The longest the course, the highest waypoints are needed, but more waypoint means more memory is required to store it; therefore, a suitable GPS device should also have an extensive memory. 2Gigabyte memories can save approximately 2500000-waypoints.

- Robustness- the data logger needs to be robust since it is mounted on the moving vehicle. Hence, it has to be vital to prevent losing the data due to impact or shock.

- Sensitivity- this is the most crucial aspect of the GPS data logger. A good data logger must have high accuracy and sensitivity with at least 158dBm. This sensitivity may also affect the ability of the data logger to log on to satellites. The highest the sensitivity, the hardest the satellite to lose its connection with the data logger.

- Extra feature- GPS data logger today provides the user with coordinate logging and some extra feature. Digital compass, location finder, cycle computer, and heartbeat sensor are some of the new future offered by the data logger.

A portable GPS data logger such as MRINNAV is a suitable candidate for the user that needed its small and low profile form factors. However, the absence of the external antenna may cause a hiccup. This is due to the limitation of the GPS signal itself. GPS signal isn't able to penetrate solid objects. In the absence of the external antenna to enhance the receiving signal, it may have difficulty to lock into the GPS satellites hovering over the earth, especially when it is inside the car.

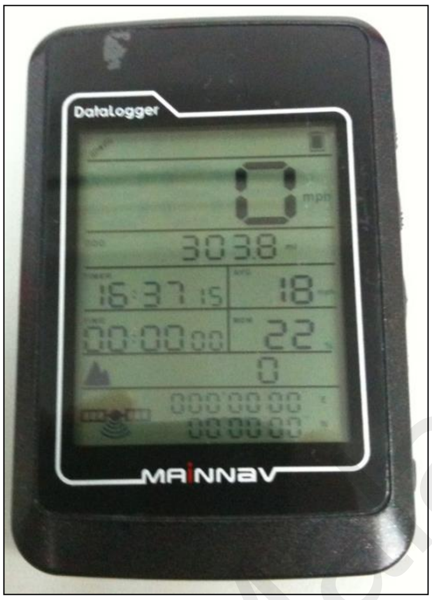


Figure 2.6: Portable GPS Data Logger

2.3.3.3 Google Maps/ Earth GPS DataBase

Google is one of the vast multinational companies that focuses its specialization on Internet-related services. Founded in 1996 by Larry Page and Sergey Bin, it became one of the most influential company as we know today. Their reach and development have created a layer of innovation in many fields; the geodetic area is one of them. Google Earth and Maps quickly became the most popular maps application on personal computer and mobile devices. Google earth promptly became the most resourceful geodetic data provider because it is updated regularly and even free of charge.

Google Earth provides the user with a very high-resolution image of the earth's surface. Since its launch in 2005, Google Earth has gained popularity among public users and scientists (Hernandez et al., 2013). Because of that, people tend to neglect its credibility and believe that it is an accurate source of data, and this is also supported by the statement provided by Google representative, which mentioned that Google Earth's coordinate system is just an approximation. They do not claim their accuracy (Flanagi et al., 2008) (Banker et al., 2011) (Google, 2008,2009). Although an only approximation, Google has been conducting several upgrades to increase the accuracy of the approximation by launching a "Ground Truth" program, which is a program help improve the accuracy of Google's geographic products by celebrating with several geographic associations in term of the data sharing (Google, 2012). Some of the examples of what Google Earth usually use by scientists are collecting ground control point or GCP for predicting the vegetation cover in the urban area and helping to map the landslide location for search and rescue operation (Yousefzadeh et al., 2012), (Duhl et al., 2012), (Peruccacci et al., 2012).

2.3.4 Geodetic Data Conversion

In this experiment, the geodetic data cannot be used directly in its native form since there is a limitation of the file input on the simulation software. Tackling this problem, a geographical solution is implemented. The answer is to use a widely available mathematic law called "Spherical law of cosine" to calculate the shortest distance between two geographical coordinates, commonly known as "Great Circle Distance."

$$d = \text{acos}\{\cos\,[rad(90-\alpha_1)] \times \cos\,(rad[90-\alpha_2])) + \sin\,(rad[90 - \alpha_1]) \times \sin\,(rad[90-\alpha_2]) \times \cos\,(rad[\beta_1-\beta_2])\} \times R$$

Where d is the shortest distance

α is the latitude of the two coordinates

β is the longitude of the two coordinates

R is the estimated maximum diameter of the earth, which is 6357 km

This formula is derived from interpreting earth as a spherical shape. Although it is an inaccurate interpretation, this assumption is still used and developed in geography, navigation, and astronomy, as mentioned in Frost's (1988) work and Earl et al., (1999). To find the shortest distance in the spherical, Das et al. (2001) mentioned that it could be achieved by solving its spherical triangle. Referring to figure 8, when the arc c is formed by linked two points A and B, it is on the sphere's surface. The angled form by its intersection with two arcs, pulled from the centre of the globe a and b, will form a spherical triangle, where the great distance between the two points measured by the angle form by the two arc a and b. The arc a and b is naturally present on the earth as an equator and longitude line. As mentioned by Ross (2002), a geodetic or excellent circle distance will always become the shortest path,

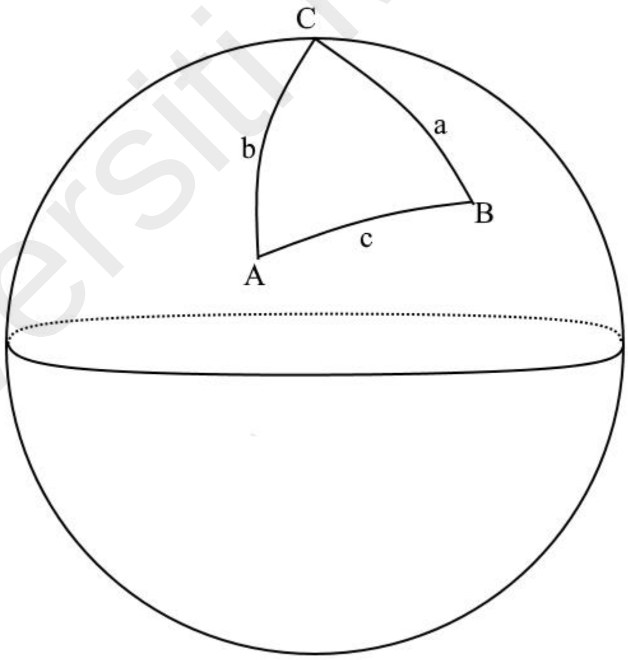


Figure 2.7: Spherical Triangle

2.3.5 Traffic Flow Characteristic Data Collection

The traffic flow characteristics are a traffic stream consisting of several different drivers in similar or different vehicle types. Traffic flow characteristics typically consist of parameters such as speed, volume, and vehicle composition (Peerzada et al, 2016). The relevant data of the traffic characteristic used in this project is speed and vehicle composition, as the simulation will only run at an individual vehicle level. The data collected using a non-intrusive device called Wavetronix can record up to 22 lanes simultaneously, regardless of its direction, downstream or upstream. The device implements two radar beam that continuously shoots, making it has better detection range and accuracy.

Figure 2.8: Vehicle Detection Radar (Wavetronix, 2008)

The radar works by emitting a dual-beam which detects individual vehicle lane placement and speed, and length. It works by creating a two-speed trap barrier from the beam shot; both of the beams will see the vehicle's speed one after the other. From there, the device will calculate the data to get the mentions parameter such as vehicle classification, per vehicle speed, 85th percentile speed, and much more (Wavetronix, 2014).

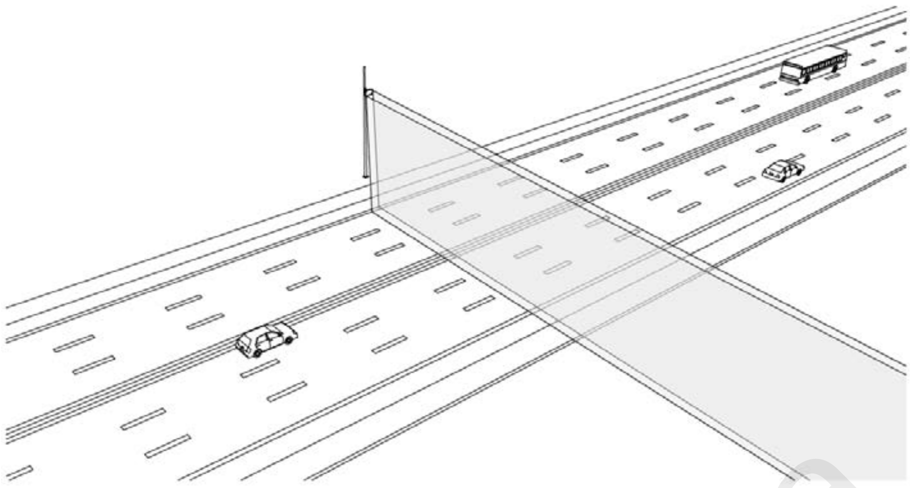


Figure 2.9: Wavetronix Vehicle Detection Concept (Wavetronix, 2008)

2.3.6 Test Vehicle Data Collection

Test vehicle data collection is done by fitting a data collection device into the test vehicle. This data collection device will measure and collect vehicle response data such as lateral acceleration, yaw rate, and roll angle. This can be done by combining the data logger and an Inertial Measurement Unit or IMU for short. This IMU unit will help detect and measure those vehicle response data mentioned by combining the accelerometer and gyroscope function. Accelerometer, derived from the word acceleration, in which this device helps measure the rate of change in velocity relative to its immediate rest position concerning time (Rindler, 2013). Today's accelerometer technology uses Silicon Micromachining. Its small size, low cost, and high volume make silicon micromachining make this technology more favoured over other development such as piezo-ceramic type (Fatatry, 2004). The gyroscope will help measure the device's rate of rotation, generally in the unit of degree/sec, respecting its reference coordinate (Fatatry, 2004). This technology has been applied in many of today's devices such as vehicle navigation, vehicle dynamic control system, vehicle roll-over prevention system, and even in the medical application. The IMU data logger used in this thesis is from Race Technology, an automotive company from Germany.

The model used is DL1 with 13 external inputs; its high accuracy comes from the built-in GPS, accelerometers, and gyroscope. Its 2-axis accelerometer can record a maximum of 2g full scale, with the maximum measurable speed of 1000 m/h. It can also calculate the speed 100 times every second, with GPS location update every 100 times in 1 second (Race Technology, 2009).

Figure 2.10: DL1 IMU Data Logger from Racing Technology

2.3.7 Software

Several software combinations need to be used to generate the desired road model, starting from the data collection software, data conversion, and simulation software because geographic coordinate data is unusual since it comes in the angle's unit, which is difficult to understand simulation software.

2.3.7.1 Plotaroute.com

Plotaroute.com is not software; it's a free web application that is used to plan a route. As reflected by its domain name, this website provides the user with tools for road plotting used for biking, walking, running, or any other outdoor activities. This process can be achieved by integrating the website with Google Maps using their various API, which means that the coordinate mapped by this software is based on the Google Maps database (plotaroute.com, 2017). This website required the user to search for their desired location, followed by clicking the preferred route. What makes it different is, it provides the user with the elevation data, which isn’t available in the native google earth software. This elevation data is crucial for this project since the road parameter is significantly affected by the hills and mountain, which draw a road segment's elevation profile.

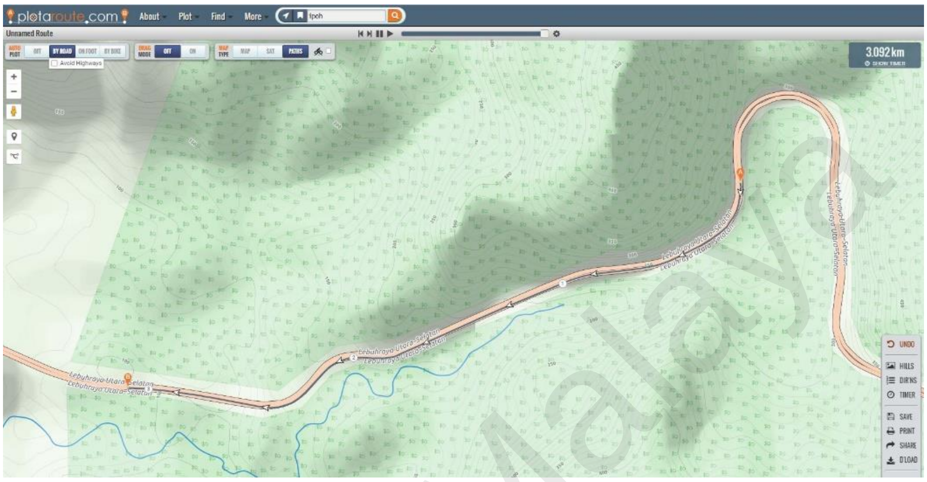


Figure 2.11: N5 Route 2 Road View Through Plotaroute.com

2.3.7.2 GPS Visualizer

Similar to the Plotaroate, GPS Visualizer is also a web-based application dealing with geographic matter. GPS Visualizer function is varied. However, only one feature is used in this thesis. It is used to transfer the GPX file format obtain from the plotaroute website and converted it into a text file, as shown in figure 2.9.

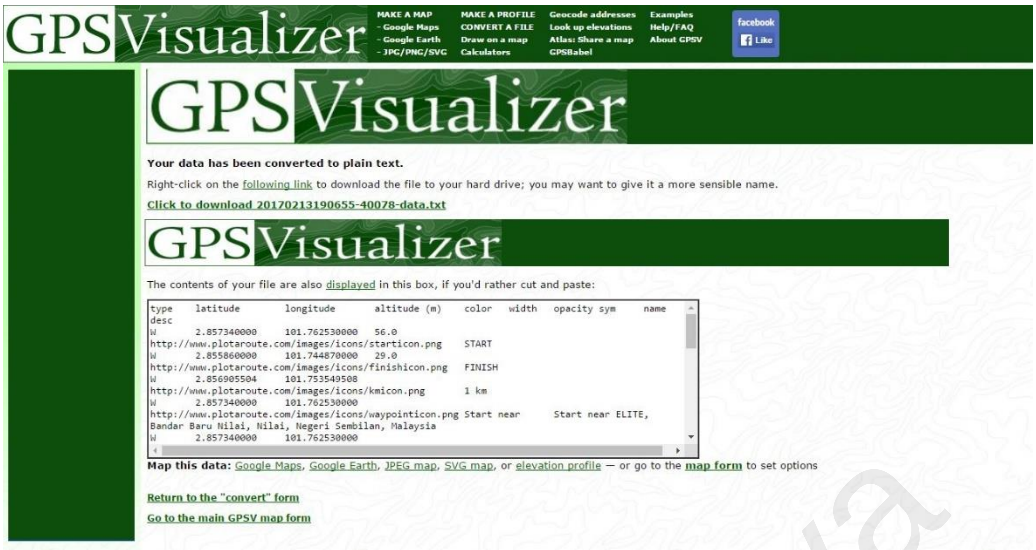


Figure 2.12: GPS Visualizer Plain Text Interface (GPS Visualizer, 2019)

This text file is then saved and opened in Excel, converted into the desired file format. GPS Visualizer launched its web-based application in 2002 and was registered in March 2003. This website relied on the Perl script series, which contains several modules such as GD, ImageMagick, XML: Simple, and much more (Schneider et al., 2016).

2.3.7.3 IPG Car and Truck Maker Simulation Software

CarMaker and TruckMaker are software developed by IPG Automotive in Germany as virtual test driving tools. Like other manufacturing software, Car and TruckMaker are used to increase the automotive development and production team's efficiency. Taking a step further by exploiting the software's functionality, we managed to assess the road accident that can be achieved by using its road development function in the software. Virtual road profile can be done in several ways. One uses the straightforward method of creating the road straight from the road segment creator interface inside the software. However, this function is hard to use for creating an involved road segment since it only requires the user to key in the straight-line section's size and degree of turning part. For more complex road shapes, extra effort needs to be done using software discussed in the previous articles.

Figure 2.13: Image of Simple and Complex Road in IPG Software

2.4 Virtual Driver Model

This software's driver model is based on the predefined generic model available in the software itself. It is derived based on the industry's commonly known control algorithm, named Proportional-integral-derivative (PID) controller. However, the user is free to input the driver model based on the project's requirement; this thesis will use the predetermined setup since the variable parameter used is constant speed, road environment, and vehicle type. All of the parameters will be run on the same driving model.

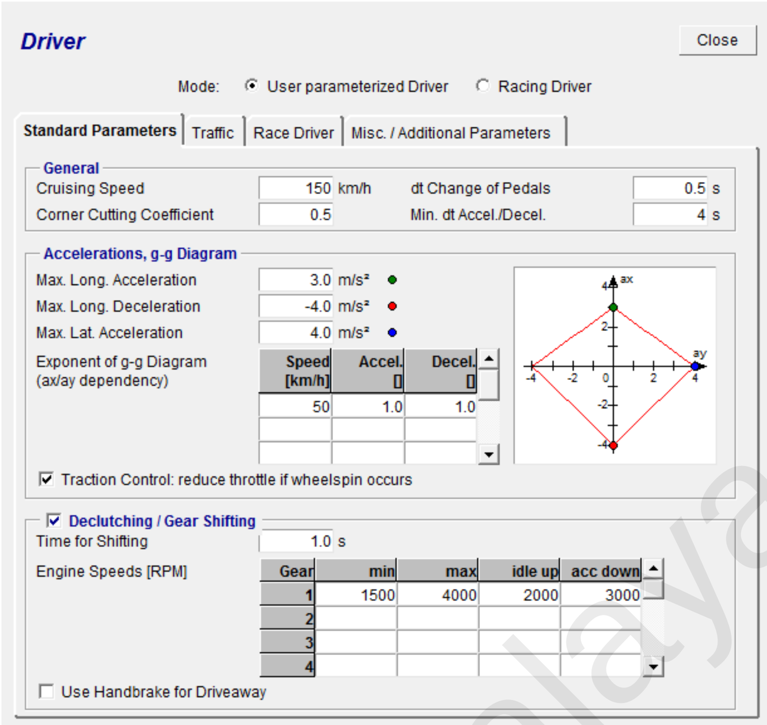


Figure 2.14: Driver Model Setting in IPG CarMaker

There are three different settings of the driver model, aggressive, routine, and defensive. These three different configurations have another value in the longitudinal and lateral acceleration. Because other driving characteristics can be represented in how the driver can withstand the vehicle's acceleration, the defensive driver will tend not to overshoot its vehicle when driving, which is different from the aggressive driver that will conduct sudden manoeuvre change (IPG driver user manual., 2009).

2.5 Virtual Vehicle Model

This thesis will use the vehicle model preloaded on the IPG Car maker. This preloaded vehicle model has been parameterized by the IPG team, which involves multiple measurement processes (IPG., 2015). Hence, there will be no change conducted to the vehicle model but rather to the road parameter. There may be small differences between the virtual and the actual model. A virtual vehicle model can represent the actual vehicle if it gives the same measurement result when undergoing the same load testing (Marin & Jens., 2015). The visual validation method can also be used in this process; lateral acceleration can be taken as critical indicators. It is the most apparent data fluctuations during test and simulation.

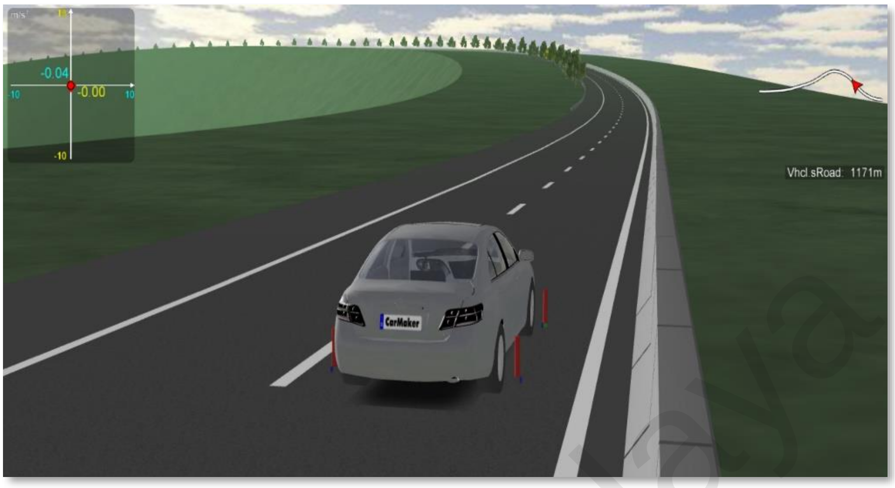


Figure 2.15: Vehicle Model of Toyota Camry

2.6 Safety Risk Assessment Optimization

The road safety assessment can be done in many ways. A different assessment has a different limitation, and not all of these safety assessments can be easily conduction in may also not available or almost impossible to conduct. This is because not all roads have a similar characteristic, there is also assessment requirement that can limit the choices of the assessment technique used, such as road network, connecting road, or individual road sites, the preferences of the old or new road also contributing to the choices of the assessment technique used. This can become a limitation for the road safety assessment field. Also, most of the available assessment techniques are focusing more on the post-accident level. Even though it works, this technique required an accident to happen before action can be taken, and data can be analyzed.

As previously discussed, that limitation can be overcome by implementing a road safety assessment through multibody simulation. This can be achieved by combining all the advances of software and hardware available today and creating a promising assessment method that does not hinder the available safety risk assessment. Limitations such as deciding the best way to tackle risk assessment on the new or existing road can be overcome. This simulation technique will project any current or even a new road profile onto a 3d environment. This simulation technique can also use to evaluate the road even before it was built.

As we know that there are three phases in which road safety can be assessed, which are pre-collision, during the collision, and post-collision. The vehicle simulation technique and technology used and implemented today are mostly concentrated on the collision phase. Its development and studies only focus on keeping the passenger safe in the event of a collision. Such growth is the crash-protective design and the development of other safety devices. In this thesis, we use simulation to assess the risk by analyzing not only in the post-collision but also in the pre-collusion. In which we environment factor corresponding to the vehicle and human factors.

2.7 Chapter 2 Summary

Many accidents have been recorded over a year, with an increased increment of 40 percent in one decade. For many reasons, the accident can happen; inexperience drivers, unpredicted road profiles, and driver behaviour are among the examples. Driven from that, a road safety assessment needs to be established by studying and analyzing the combination of factors and possibilities. These safety assessments can be categories into three different phase; post-accident phase, in which the cause of the accident is analyzed just after the accident happens and use it for road safety mitigation for that particular road. Second is an impending or during the accident phase, where the mitigation is drawn, in the level of during the accident. An advanced collision avoidance system implemented in most high-end vehicles is one of the examples. The vehicle mintage the risk by providing the user with warning and information regarding the vehicle situation. Thirdly is the pre-accident phase, where the safety risk is studied and analyze before the accident happens. The method of safety assessment used in this thesis aims to solve accident prediction at the pre-accident level.

In conclusion, the accident prediction method relies heavily on the last crash data on that particular road section or other section with similar crash causes. The data is then analyzed using machine learning and the development of a prediction model. Although this method works, it is not practical since enough crash reports need to be present to assess those particular road stretch. The virtual simulation concept bypasses this problem by providing enough vehicle response and behaviour for any road section, with or without a previous crash report. The idea is simple. The actual road is digitized using a series of geological data collection combinations with several online and offline software transformed into a virtual road profile. The geodetic data collection is collected using current technologies available, as described in this chapter, such as LiDAR System, Portable GPS Data Logger, and Google Maps Data extraction. These data are then transformed from geodetic coordinate data into Cartesian coordinate data. These based theories also elaborate in this chapter.

CHAPTER 3: METHODOLOGY

This chapter will elaborate more on the overall process of the safety road assessment. The first subchapter will discuss the development of the base parameter and the structure of the assessment.

3.1 Virtual Road Development

The task of virtual road modelling or road profile development consists of several steps, as shown in the general workflow of developing virtual road profiles illustrated by the flow chart below,

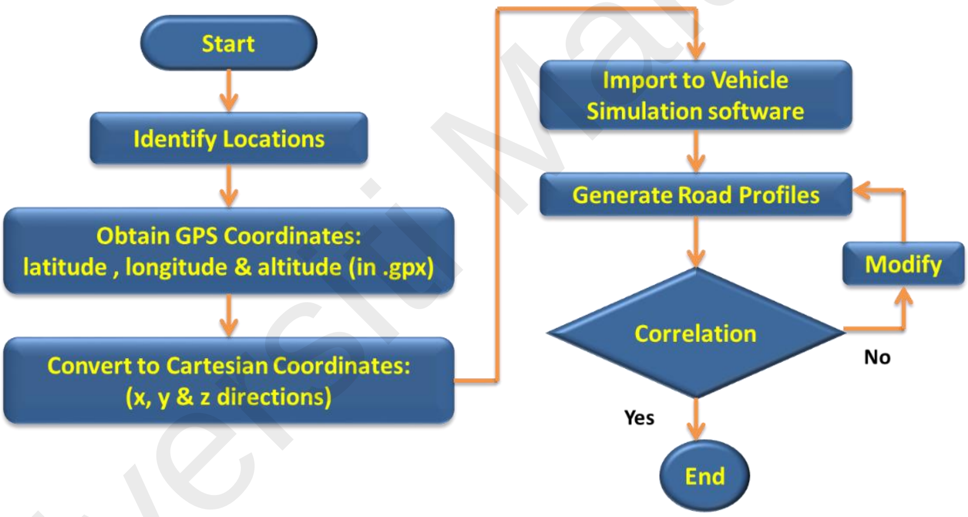


Figure 3.1: Workflow of Virtual Road Profile Development

A virtual road development fundamentally requires information on the road geometry, such as curvature and elevation, all represented by coordinate data. Road environments such as road marking, barriers, and signage. Can be added to the virtual road model to emulate the actual environment further. Therefore, all relevant road characteristics, namely road geometry, road furniture, and the posted speed limit, are obtained post-identification of accident-prone locations.

The next step of the process is collecting the coordinate data, which is empirical data since this data will be used as a primary source of road profile parameters. Hence several sources of data collection methods are engaged to compare its effectiveness and accuracy, which then be used for further road safety risk assessment. As previously discussed, geodetic data collection can be done in three different ways, using LiDAR, GPS Data Logger, and based on the Google Maps Database; however, only one will be used as the primary GPS data source. This GPS data is then adjusted to fit the dynamic simulation software's road parameter input required. The dynamic simulation software use is IPG CarMaker®, and the virtual road develops through its road profile generation module named IPG Road. The IPG Road is capable of creating realistic road profiles, in addition to discrete-segment-based roads, by accepting the detailed coordinate data as input. For illustration purpose, Figure 3.2 shows the user interface of the IPG Road of IPG CarMaker®

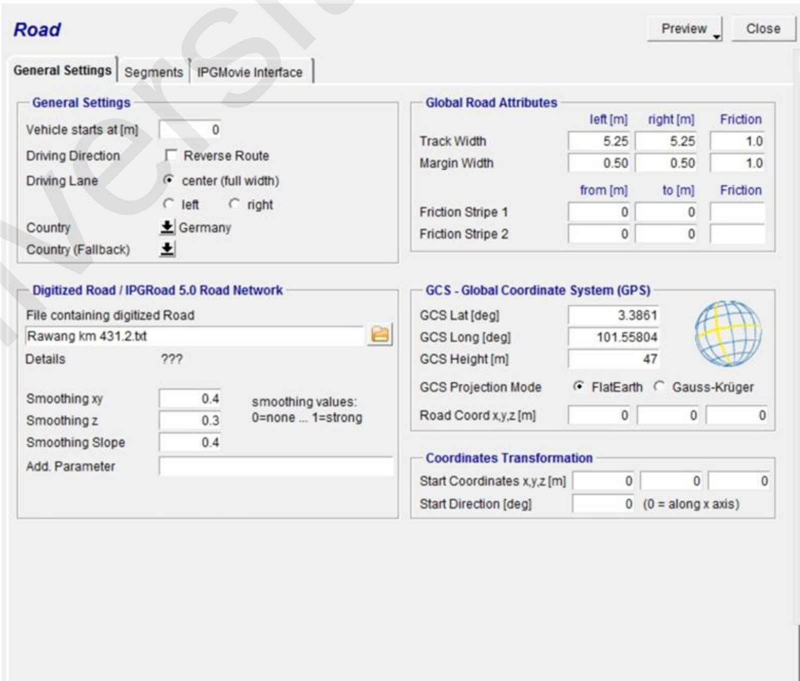


Figure 3.2: User Interface of the IPG Road Module

Referring back to Figure 3.1, the road geometry data in the form of GPS coordinates is required as the initial form of road data. Generally speaking, the virtual road profile development utilizes road data from GPS (the longitude and the latitude data) and translates it into a Cartesian coordinate system that defines the same road section. With this information, virtual road models can be created.

3.1.1 LiDAR Coordinate Data

LiDAR data are widely available in every country, especially in developing countries, since it can be used as a reference point for people in the agriculture industries. Unfortunately, these GPS data are not freely available in Malaysia. However, several local companies offer such services, but it does not come cheap. This is because LiDAR mapping requires the surveyor to be on a plane, which the rent cost is not affordable. Therefore, to obtain the LiDAR data for this project, joint research has been established with the major local expressways. The company has provided us with a set of raw LiDAR data for N5 Route with the coordinate of *4° 39′ 33.3523″ N, 101° 05′ 00.6686″ E*. LiDAR data come in the set of measured points created by the laser beam. To be mapped, LiDAR software is needed to translate and grouped those points in the correct position; below is an example of decrypted LiDAR cloud data.

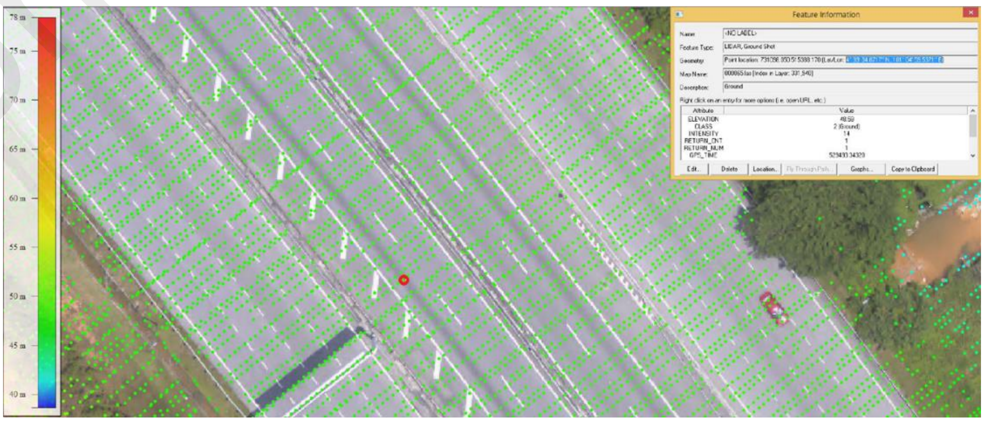


Figure 3.3: An Example of LiDAR Cloud Data from One of Malaysian Expressway

In this thesis, only some of the data will be used, and all these data are all the points in the middle road that will form a road profile following the actual route if lined together. This point is then collected and tabulated in the form of its longitude and latitude.

3.1.2 Google Earth DataBase

Google Earth Database is the second method of GPS data collection. Here, we used publicly available google maps and earth data. Developed by Google Inc, Google Maps, and Earth has become our go-to application for location-based application. Its extensive database library of maps has put Google in the top place that driven us to explore more on expanding this database library's function. Google Maps data are available freely, but apart from Google Maps' application, its data functionality is limited to the map's observation. We need an application that can extract the GPS data of a particular road stretch and save it in the GPS data file form. That was when we came across, in our search, a web application called plotaroute.com. This web application can extract any road stretch data in a different part of the world as long as it is available in the Google database. Like GPS data logger, our task is to use the applications to run the logger on the predetermined stretch. The output files obtained are similar to the GPS data logger; the only essential difference here is that we do not need to go to the desired location to log the data. We only need a computer and internet connection. What makes these web applications unique is that they automatically include the elevation data similar to the data logger. Hence, only the conversion form of data is needed once the gpx file is obtained from the application.

Figure 3.4: Plotearoute.com User Interface

3.1.3 GPS Data Logger

GPS data logger is Similar to LiDAR data collection, GPS data logger also collecting a set of GPS coordinate points; the only difference is its source of high or elevation data. Elevation data obtained by LiDAR is calculated from the time taken for the laser to travel from the plane to the ground and back. However, the data logger's elevation profile is calculated from the reference GPS coordinate system prior to the locked satellite location.

GPS data logger used in this project is from the company named Race Technology. The GPS data logger also provides other vehicle dynamic data as it also functions as an Inertial Measurement Unit. The GPS data are collected on the 5 km stretch of N5 Route 1, *4° 39' 33.3523" N, 101° 05' 00.6686" E*, following the LiDAR data's availability so that these data can be compared.

Figure 3.5: GPS Data Logger Antenna

The Race Technology data logger requires the antenna to increase its accuracy, and it is mounted at the top of the car to maximize the satellite locks on the devices. It can typically lock into five to six satellites at a given time, which is more than sufficient. After the 5 km stretch of GPS data has been collected, it is then translated into a tabulation form. The raw data obtained by the GPS data logger, ".gpx," is in Metadata, unreadable by using native windows program such as notepad. This forced us to search for a translation program or a web service, to be specific. GPS visualizer, explained in the previous chapter, can convert that .gpx file into other interpretation mapping forms such as google maps and earth map interpretation, elevation profile presentation, and the one that we use, GPS data tabulation. Once the data are translated, we need to copy it to a statistical analysis software such as Excel or SPSS.

3.2 The Empirical Data

Following the initial virtual road development work described in the preceding section, the next phase of the project involves empirical data collection at the specified location, as mentioned previously. The empirical data collection is done using a regular passenger vehicle fitted with onboard IMU and GPS. The empirical data input will then serve as actual data in the subsequent virtual simulation and analysis of the dynamic simulation system. This empirical data collection activity serves two purposes concurrently:

- To obtain road measurements of the predetermined road section as a geographical road profiling experiment for validation or confirmation of the virtual road models. The measures include longitude and latitude coordinates and road elevation.
- To concurrently conduct a vehicle's dynamic experiment using the tested vehicle to obtain vehicle responses when driven on the selected road section, which includes lateral acceleration, longitudinal acceleration, and vertical acceleration.

For both geographical road profiling and vehicle's dynamic experiments, a Toyota Camry, a 2.0L variant, the model year 2012, is used as the test vehicle, one of the commonly seen D-segment sedans on Malaysian roads. Therefore, this model's use as the test vehicle represents a typical scenario on the pre-determined road sections. With sufficient specifications, this car can be modelled virtually in IPG CarMaker® for evaluating vehicle responses using ADST. Figure 3.6 shows the employed vehicle model's illustration and the virtual model created in the IPG CarMaker® simulation environment. Some of the technical information about this vehicle, for instance, the various dimensional parameters and overall vehicle weight, while others like the centre of gravity (CG) position will have to be determined through measurements.

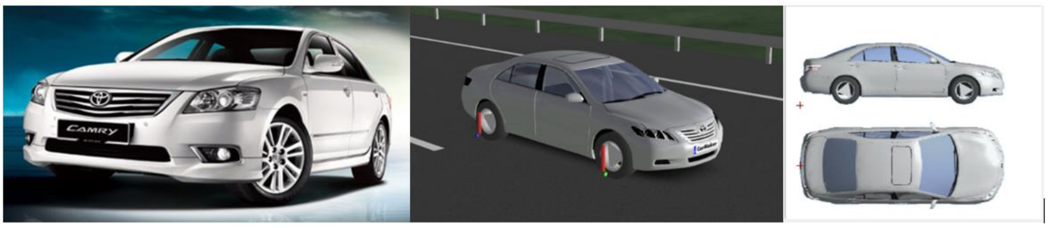


Figure 3.6: A Toyota Camry and the Representation of the Vehicle Model in the Virtual Environment

3.2.1 Preparatory Work Setup

Before conducting the experiments, some preparatory work is done on the vehicle. In particular, the relevant sensors, such as the IMU, need to be installed in the test vehicle. Because the measurement of vehicle responses is based on the CG as the reference point, one of the preliminary tasks involves determining the vehicle's CG.

A vehicle's CG can be represented by its longitudinal position (x-axis), lateral position (y-axis), and height (z-axis) from specific reference points. For the longitudinal position, the location of CG can be specified by the distance from the vehicle's rear axle, b. Referring to Figure 3.7, b can be determined with knowledge on the wheelbase, L, and the front and rear tire normal reactions through the following mathematical derivations:

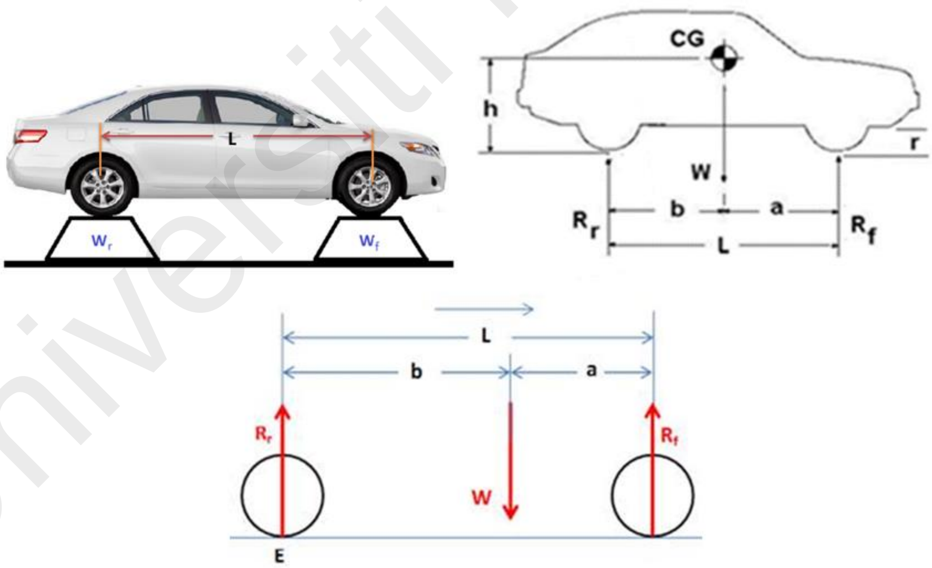


Figure 3.7: Determination of a Vehicle's Longitudinal CG Position

$$L = a + b, \qquad (1)$$

$$W = R_f + R_r, \qquad (2)$$

Taking a moment about Point E:

$$\sum M_E = 0,$$

$$R_f L - Wb = 0,$$

$$b = L(R_f/W), \tag{3}$$

Hence, the longitudinal position of CG can be determined by measuring the vehicle's overall weight, wheelbase, and the normal front reaction.

For lateral position, theoretically, the location of CG can be specified by the distance from the left wheel to the centre of the vehicle, y, as shown in Figure 3.8 and the following derivations:

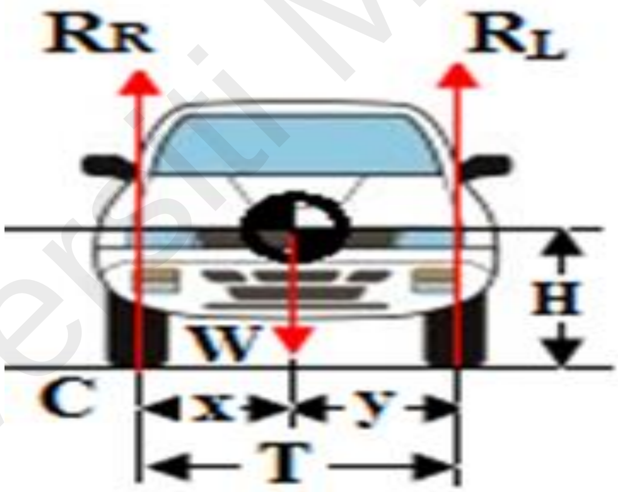


Figure 3.8: Determination of a Vehicle's Lateral CG Position

$$W = R_L + R_R, \tag{4}$$

Taking a moment about Point C:

$$\sum M_C = 0,$$

$$Wx - R_L T = 0,$$

$$x = (R_L/W)T, \text{ and } y = T - x, \tag{5}$$

In most cases, however, the assumption of left-right symmetry is valid since the slight asymmetry, such as the driver's position, is negligible. Therefore, the lateral part of CG is usually simplified to be half of the track width, T. This is a fair approximation for most vehicles.

Finally, the height of a vehicle's CG is usually referred to as the ground and is determined from the schematic diagram shown in Figure 3.9 by the following derivations:

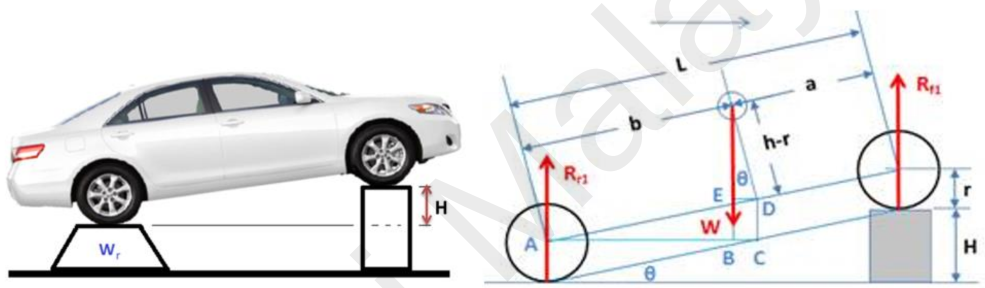


Figure 3.9: Determination of the Height of a Vehicle's CG

$$W = R_{f1} + R_{r1}, \tag{6}$$

Taking a moment about Point A:

$$\sum M_A = 0,$$

$$R_{f1}(L\cos\theta) - W(AB) = 0,$$

$$R_{f1}(L\cos\theta) = W(AB), \tag{7}$$

From Figure 14, it is known that:

$$AB = AC - BC,$$

$$AB = b\cos\theta - (h - r)\sin\theta, \tag{8}$$

Substitute Equation 8 back to Equation 7:

$$R_{f1}(L\cos\theta) = W(b\cos\theta - (h - r)\sin\theta),$$

$$W(h - r)\sin\theta = Wb\cos\theta - R_{f1}(L\cos\theta),$$

$$h = \left(b - L(R_{f1}/W)\right)\cot\theta + r, \tag{9}$$

Where $\theta = \sin^{-1}(H / L)$, $(h - r)$ is the distance of CG above the axle plane, and h is the distance of CG above the ground is the parameter to be determined.

From the theoretical derivations, the determination of the CG location of the tested vehicle involves the measurement of a few vehicle dimensions and the measurement of vehicle weight and the individual normal reaction load at each wheel. This preparatory work is done within the Faculty of Engineering, University of Malaya (UM). The measurement setup is shown in Figure 3.10,

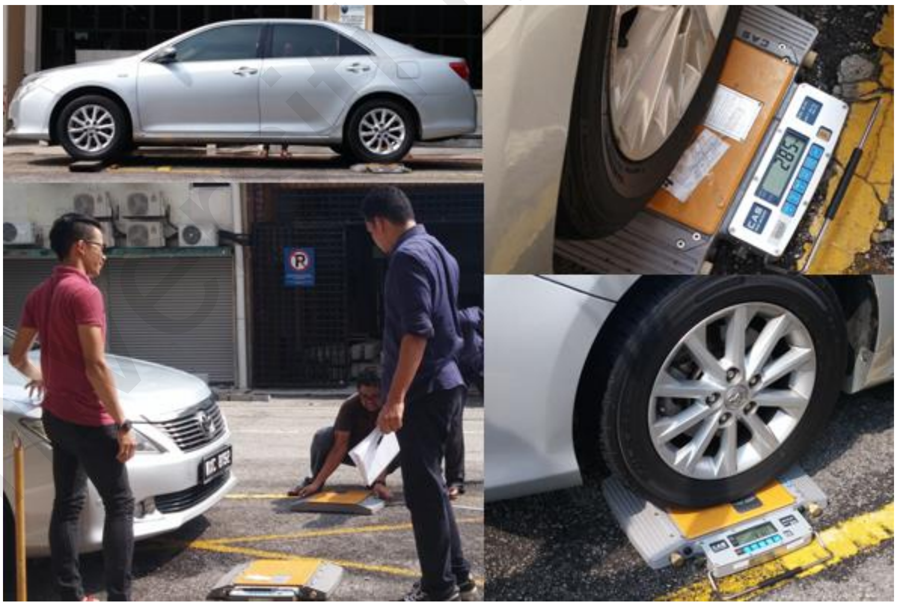


Figure 3.10: Measurement Setup for the Determination of the Vehicle's CG

This measurement will correspond to a centre position inside the vehicle's cabin, as shown in Figure 3.11. The IMU is then placed as close as physically possible to the exact CG location. Note that there is a slight shift in longitudinal position (distance b) from the calculated position for driving safety.

Figure 3.11: The placement of IMU at the calculated vehicle CG

Elsewhere, in this preparatory work, the GPS antenna is placed on the vehicle's top and centre to ensure proper signal reception during the test. Finally, data is collected from the IMU unit and stored in a notebook computer through data acquisition software. The overall setup for the instrumented vehicle is summarised in figure 3.12.

Figure 3.12: The measurement system setup for empirical data collection

The experiments (empirical data collection) mostly focus on the N5 road section between KM 234 and KM 228.5 (both North-bound and South-bound), covering a length of about 5.5 km. The plan view of the road section is shown in Figure 3.13.

Figure 3.13: Overview of the N5 Route 1

The empirical data collection work relates to both geographical road profiling experiments and vehicle dynamic experiments concurrently, as already mentioned in earlier descriptions. For both purposes of data collection, measurements are recorded three times each for North-bound and South-bound directions at a few constant forward velocities, namely 90 kmh^{-1}, 100 kmh^{-1}, and 120 kmh^{-1}, giving a total of six runs for every forward velocity. For each run, the vehicle is driven from the starting point until the desired speed is reached. Then, the velocity of the car is maintained while data recording is in progress. The complete workflow for this task is shown in the following flow chart.

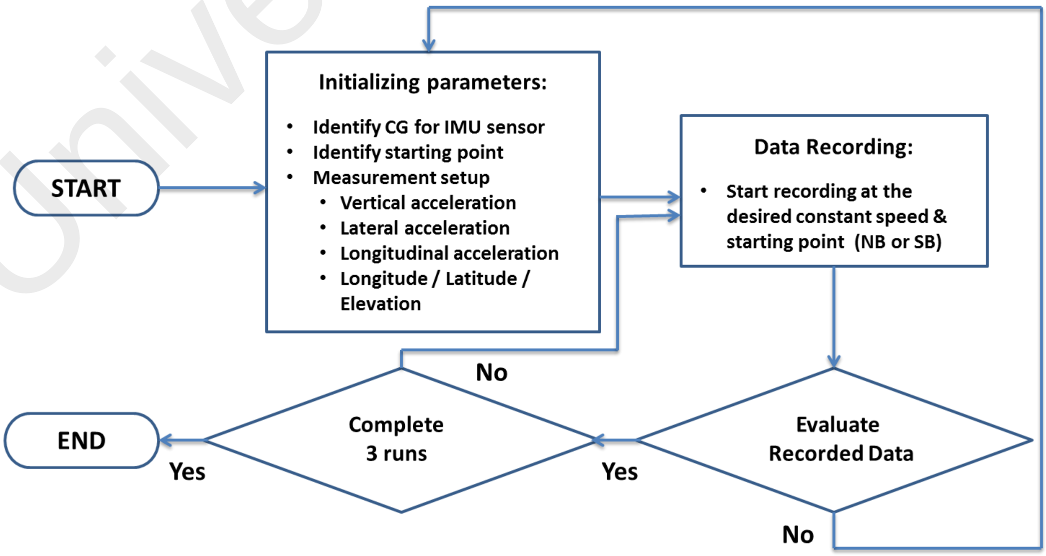


Figure 3.14: Workflow of Empirical Data Collection

3.2.2 Traffic Characteristics Data Collection

Traffic characteristic data is collected to parametrize the traffic behaviour at the simulated road stretch. This process will also increase the simulation's effectiveness since we will only run the simulation based on these traffic characteristic data. As previously mentioned, the data is collected using Wavetronix, a traffic detection device. The device consists of three main parts, Wavetronix radar, telescopic mounting pole, and a personal computer. The radar is installed approximately 25 to 35 meters from the first detection line with a hitting angle of around 45 degrees. The mounting height will depend on the distance from the detection line. It is usually installed approximately 26 to 30 meters above ground, and the sensor also needs to be installed perpendicular to the road.

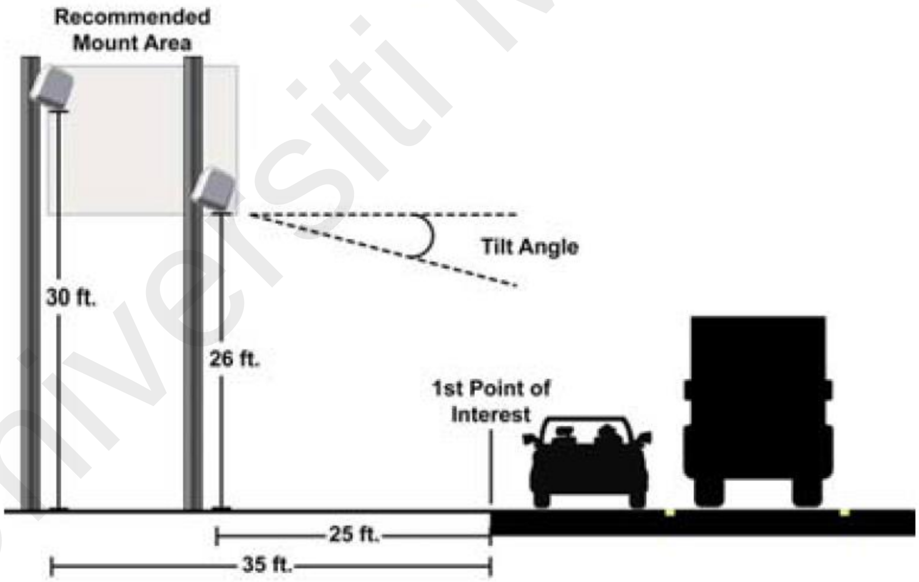


Figure 3.15: Wavetronix Installation Scheme (Wavetronix, 2008).

Once the sensor is up, it is connected to the personal computer for data collection adjustment and data storage. The adjustment starts with identifying the active lane, choosing which lane we want to record. Once it is done, the device will continue collecting data for 6 hours to ensure sufficient data to plot the traffic characteristic, which is then used as a parameter for the simulation process.

3.2.3 Data Analysis Method

Once the empirical data is collected, it is then analyzed. However, before the data can be used, it needs to be extracted and converted into a file format easily interpreted on the conventional analysis software such as Excel or SPSS.

3.2.3.1 Vehicle Characteristic Data

The processes start with data extraction since we connect the data logger directly into the pc so the data can be extracted directly from the pc hard drive. The file saved is in the .run format, which can only be opened by the data logger's software. Once it is opened, it will appear as follows,

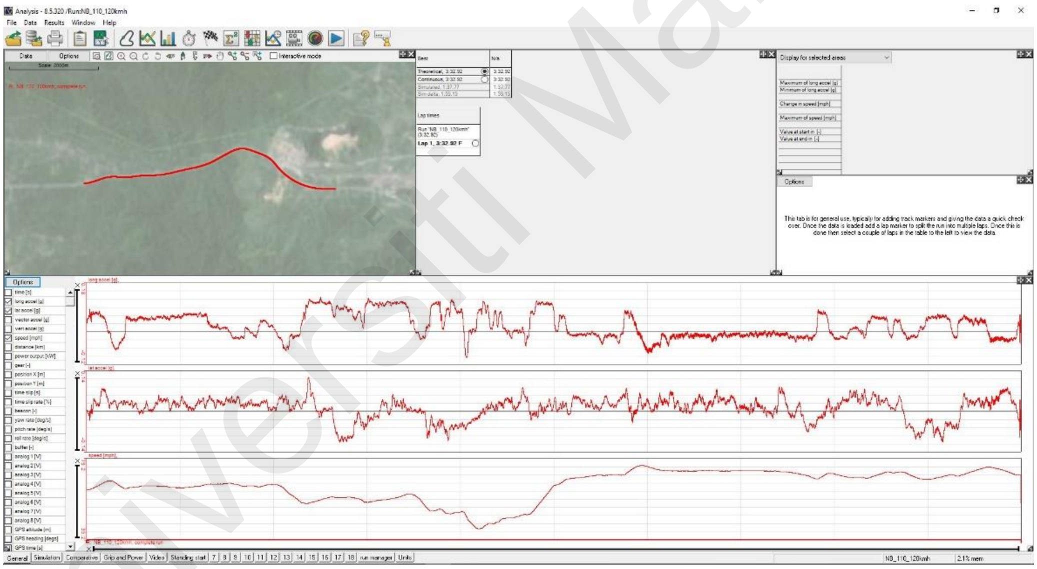


Figure 3.16: RaceTechnology® Analysis Software UI

From here, we can choose to save the raw data in the desired file format, in this case, excel file format or .xls. The data obtained is then selected in excel since not all the data will be used, such as speed, vehicle position, GPS longitude latitude and altitude, distance travel, and lateral acceleration. Since the validation processes are run at three different speeds, there will be three data sets. All these data are then plotted and compared with the simulation data.

3.2.3.2 Traffic Characteristic Data

Compared to the vehicle characteristic data; traffic characteristic is more comfortable to analyze in its data extraction. The data is saved in an excel form. Hence, we can directly open and analyze it. These traffic characteristic data will contain single measured parameter data, but the only parameter we use is vehicle speed for 6 hours for 6 or 4 lanes depending on the location. During the 6 hours data, there will be four-speed parameters that will be used, which are average speed, maximum speed, and 80 percentile. The extracted speed is then used as a parameter in the simulation, which then the result will be further analyzed.

3.3 Simulation Parametrization

Simulation parametrization is mostly done in the software itself, including input parameter data adjustment, visual enhancement, and traffic environment set up. All those parametrizations will be used in the software using the data obtained from the three sources mentioned previously.

3.3.1 Parameter Road Data Adjustment

Road data adjustment is the only process that isn't done in the simulation software; this process is used to convert the longitude and latitude input file from the GPS source into a Cartesian coordinate system or x and y-axis unit. This conversion is carried out by implementing the haversine formula mention in the previous chapter. The GPS coordinate data need to be copied to the prepared excel table. This step applies to all GPS data sources; once it is converted, the Cartesian coordinate system will be copied into a text file.

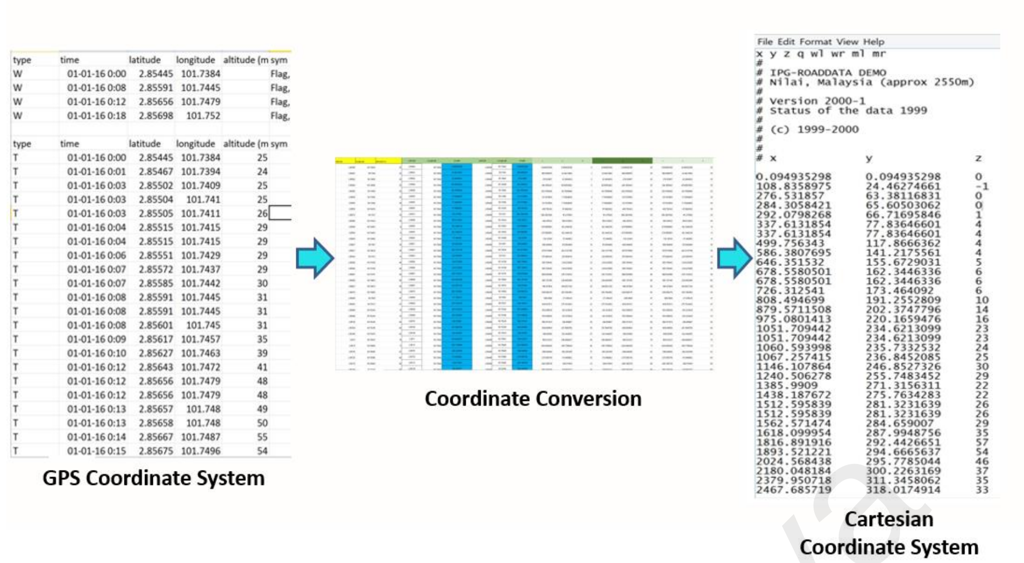


Figure 3.17: GPS to the Cartesian Conversion Process

3.3.2 Visual Enhancement

After the road has been converted and keyed into the software, additional steps are required to ensure that the virtual road resembles the actual route in terms of its representation and characteristic. The first step is to adjust its road width based on the reference road. Once it is done, its road visual enhancement parameter is set up next, including visual tweaks such as road infrastructure such as road signage, road barrier, road light, and roadside vegetation.

All these parameters are set and determined by directly comparing it with the image obtained from google street view, where the measurement tools measure its location and size on google earth. Every road element needs to be added manually; for example, if we want to set a road barrier for 100 meters, we need to manually key in the distance where it starts and where it will end. There are no visual settings, and all elements need to be installed similarly, which includes the installation of the vegetation. The simulation software comes with a pre-loaded road element. However, we are free to modify its aspect to suit our needs. The most common modified feature is the road sign since it is different from place to place.

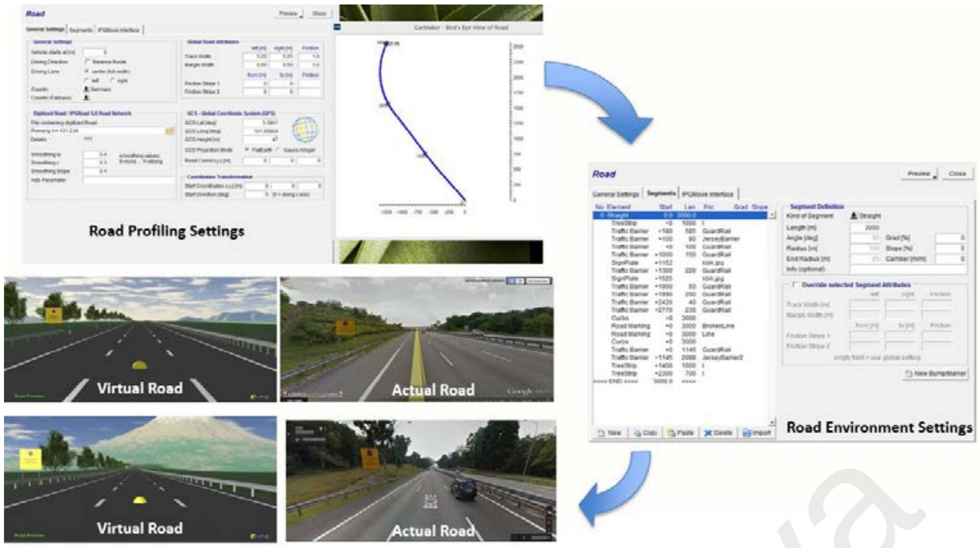


Figure 3.18: Virtual Road Visual Development Overview

3.3.3 Traffic Parameter Setup

Traffic parameter is keyed in based on the collected data using the Wavetronix radar system. The radar system output data that will be used is speed. The set of speed use is average speed, maximum speed recorded, and 80 percentile. All these speeds will help to draw a guideline on what are a speed run by vehicles on the studied road segment.

The speed data can be directly keyed into the scenario window of the simulation software. The simulation software then uses this speed as its constant speed. However, as in the actual driving situation, this continuous speed may vary depending on the road characteristic. However, it may not divert far away from the key in speed value.

As previously mentioned, there are three driver models available inside the simulation software. To be able to resemble the actual driving simulation, the normal driver settings will be used. It can be seen from the GG diagram representing the normal driving settings. Compared to another driving style, the normal driving style tends to not rash in line, taking a process that may cause line departure situation. However, it is also not prudent that may cause a speed decrease could jeopardize the predetermined constant speed. These driver settings have a functionality called the driver adaptation function. The software will consider the road and vehicle model during the simulation and adjust its running simulation to maintain its constant speed, similar to what we are doing during the model validation processes.

3.4 Risk Assessment Application

The risk assessment application will be conducted after the validation process, and its result will be based on the simulation data. The first step of this assessment is by choosing the appropriate location for sample purposes. Accident-prone locations are the most suitable locations; this also gives substantial evidence of whether the simulation can replicate the accident on a particular road.

The accident-prone locations are chosen based on the accident criteria that had happened in a particular location. There are two areas to be selected, and the accident criteria will be based on the following;

Table 3.1: Criteria Involved in the Identification of Road Sections

NO	Criteria 1 (Location 1)	Criteria 2 (Location 2)
1	Vehicle Out of control	Rear-end collision
2	Type of vehicle: car	Type of vehicle: car
3	Overspeeding	Overspeeding
4	Involving only a single vehicle	More Than One Vehicle

Based on the above criteria, the best locations for this road assessment simulation are N5 Route 1 (KM 234 – 228.5) and N5 Route 2 (KM 258 – 254.6). The next step of the process is to run a simulation several times with different input variables. This output of the simulation is then presented and analyzed. Details of these processes are shown in the following workflow:

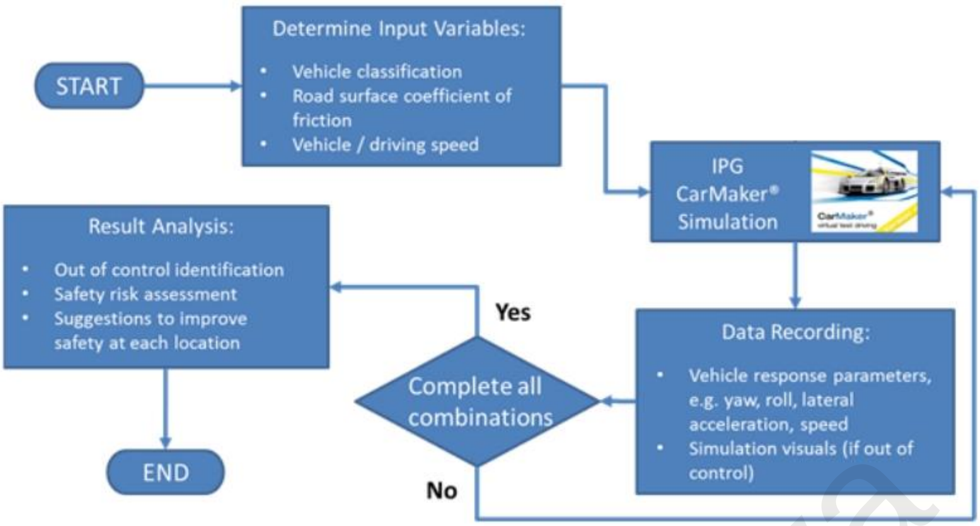


Figure 3.19: Workflow of Simulation and Data Analysis for Safety Road Assessment

The input variable mentioned in the above workflow was discussed in the previous chapter. This input variable will include; vehicle type or classification, road surface coefficient of friction, and vehicle or driving speed. These three variable factors cover the car, road, and driver element of a driving scenario.

3.5 Chapter 3 Summary

The methodology elaborates in this chapter was started with virtual road development. The data such as GPS coordinates and altitude were collected then converted to the Cartesian coordinate system in the X, Y, and Z-axis. Once it is done, the Cartesian coordinate system is then keyed into the simulation software, then adjusted and fine-tuned until it resembles the actual road profile. Several methods of collecting coordinate data, using LIDAR, Google Earth Data Base System, and using GPS Data Logger, each has its differences and limitation discussed in this chapter.

This chapter also discussed the methodology in obtaining the road measurement's empirical data to validate and confirm the virtual road model. This empirical data can also capture the vehicle response when the car is driven on a predetermined road. The preparation of this data collection includes calculating and finding the centre of gravity's location for the experimental vehicle use, in which the IMU data logger will be placed. Apart from the vehicle response and GPS coordinate's empirical data, another data of the traffic characteristic data is also collected using Wavetronix radar.

Once the data has been completed, it is then analyzed using the appropriate software, such as vehicle characteristic data and GPS coordinate, obtained from the IMU. These data are then compiled, plotted, and compared. Once the data are obtained, it is then clocked into the simulation software, while small adjustments are needed to be done in this stage of virtual road preparation.

The methodology chapter explained the process of road development, starting from developing the virtual road profile, which includes the GPS data collection method. The functions of collecting the empirical data for the simulation's validation are also described in detail in this chapter, along with the output file format obtained and a detailed method of analyzing and presenting the data. Processes of turning the raw empirical data into the virtual environment are also described in this chapter.

CHAPTER 4: RESULT AND DISCUSSION

The validation result of the simulation road model will be presented in this chapter. Starting from validating the virtual road model and vehicle model. These data are then used to develop the safety risk assessment, which is also elaborated and discussed in the last subchapter.

4.1 Virtual Road Model

The empirical data collection of the previous chapter's GPS data is used as comparison data for validation purposes. Its conversion is then compared with other sources of data such as LiDAR and Google database. The elevation profile will also be reached to have comprehensive validation. Below is the sample of the recorded data obtained from the IMU GPS data logger in the location of N5 Route 1 (KM 234 – KM 228.5).

Table 4.1: Sample Raw Data from IMU Datalogger

time [s]	long accel [g]	lat accel [g]	vector accel [g]	vert accel [g]	speed [mph]	distance [km]	power output [kW]	position X [m]	position Y [m]	GPS altitude [m]	GPS heading [degs]	GPS time [s]	GPS pos acc [-]	GPS vel acc [-]	GPS head acc [-]	GPS alt acc [-]	GPS vel raw [mph]	GPS long [degs]	GPS lat [degs]
0	0.019531	0.023438	3.05E-02	0.917969	54.90058	0	29.64355	99.82767	2.559017	89.591	270.8571777	301822.3	4.331999779	0.51	7.88E-03	3.973	54.7602	100.8328224	4.773161
0.01	0.019531	0.023438	3.05E-02	0.917969	54.90144	2.45E-04	29.83571	99.58249	2.548067	89.591	270.8571777	301822.3	4.331999779	0.51	7.88E-03	3.973	54.7602	100.8328202	4.773161
0.02	0.019531	0.023438	3.05E-02	0.917969	54.9023	4.91E-04	30.02797	99.3373	2.537117	89.591	270.8571777	301822.4	4.331999779	0.51	7.88E-03	3.973	54.7602	100.832818	4.773161
0.03	0	0.015625	0.015625	0.917969	54.90316	7.36E-04	30.22031	99.09211	2.526167	89.591	270.8571777	301822.4	4.331999779	0.51	7.88E-03	3.973	54.7602	100.8328158	4.773161
0.04	0	0.015625	0.015625	0.917969	54.90401	9.82E-04	30.41275	98.84691	2.515217	89.591	270.8571777	301822.4	4.331999779	0.51	7.88E-03	3.973	54.7602	100.8328135	4.773161
0.05	0	0.015625	0.015625	0.917969	54.90487	1.23E-03	30.47613	98.60172	2.504131	89.591	270.8571777	301822.4	4.331999779	0.51	7.88E-03	3.973	54.7602	100.8328113	4.773161
0.06	0	0.015625	0.015625	0.917969	54.90573	1.47E-03	30.53952	98.35651	2.493044	89.591	270.8571777	301822.4	4.331999779	0.51	7.88E-03	3.973	54.7602	100.8328091	4.773161
0.07	0.003906	0.035156	3.54E-02	0.964844	54.90916	1.72E-03	30.60291	98.11131	2.481957	89.591	270.8571777	301822.4	4.331999779	0.51	7.88E-03	3.973	54.7602	100.8328069	4.77316
0.08	0.003906	0.035156	3.54E-02	0.964844	54.91259	1.96E-03	30.66632	97.8661	2.470869	89.591	270.8571777	301822.4	4.331999779	0.51	7.88E-03	3.973	54.7602	100.8328047	4.77316
0.09	0.003906	0.035156	3.54E-02	0.964844	54.91601	2.21E-03	30.85881	97.62086	2.459781	89.591	270.8571777	301822.4	4.331999779	0.51	7.88E-03	3.973	54.7602	100.8328025	4.77316
0.1	0.003906	0.035156	3.54E-02	0.964844	54.91944	2.45E-03	31.0514	97.37562	2.448692	89.591	270.8571777	301822.4	4.331999779	0.51	7.88E-03	3.973	54.7602	100.8328003	4.77316
0.11	-0.00391	0.019531	1.99E-02	1.035156	54.91944	2.70E-03	31.24409	97.13036	2.437602	89.591	270.8571777	301822.4	4.331999779	0.51	7.88E-03	3.973	54.7602	100.8327981	4.77316

The above raw data contains geographical coordinates data and the vehicle dynamic data. The geographical data are represented in columns 11, 19, and 20, which are longitude, latitude, and altitude, respectively, and another column, such as columns

2 to 7, shows the vehicle's dynamic data. The result of the GPS coordinate conversion validation, the comparison between three running speeds during the experimental and comparison between three GPS data sources will be presented and elaborated in the following subchapter.

4.1.1 GPS Coordinate Conversion

For the GPS data to be used in the simulation software, its format needs to be adjusted. It is known that simulation software cannot handle GPS coordinate data due to its nature of the raw coordinate format. Hence, by converting it to the Cartesian coordinate, this road mapping can be achieved. As previously mentioned, this conversion is done by implementing the law of cosine formulation, where we calculate the shortest distance in the great circle for every logged point. It is then tabulated and mapped in the simple data analysis software.

Table 4.2: Sample GPS Data Logger Raw Data

Time [s]	Position X [m]	position Y [m]	GPS Longitude [degs]	GPS Latitude [degs]
0	99.82767	2.559017	100.8328	4.773161
0.01	99.58249	2.548067	100.8328	4.773161
0.02	99.3373	2.537117	100.8328	4.773161
0.03	99.09211	2.526167	100.8328	4.773161
0.04	98.84691	2.515217	100.8328	4.773161
0.05	98.60172	2.504131	100.8328	4.773161
0.06	98.35651	2.493044	100.8328	4.773161
0.07	98.11131	2.481957	100.8328	4.77316
0.08	97.8661	2.470869	100.8328	4.77316
0.09	97.62086	2.459781	100.8328	4.77316
0.1	97.37562	2.448692	100.8328	4.77316
0.11	97.13036	2.437602	100.8328	4.77316

From there, we can use its logged location data and compare it with the conversion tabulation method data since both conversion method data and logged coordinate will have the same output. Below is what the comparison table look like,

Table 4.3: Sample Data of Difference between Coordinate Data from GPS Data Logger and Converted GPS Data.

GPS long [degs]	GPS lat [degs]	GPS altitude [m]	coordinates from IMU GPS		Coordinate from Conversion Method		Residuals		RMSE	
			position X [m]	position Y [m]	Length X	Length Y	X axis	Y axis	X axis	Y axis
4.773139159	100.8316529	87.80899811	-29.90836143	0.106789157	-29.87506883	0.094935298	-0.033292597	0.011853859	3.002978386	0.598767339
4.773139183	100.8316505	87.80899811	-30.16995811	0.109376185	-30.13623802	0.134258785	-0.033720092	-0.0248826	3.00305131	0.598781875
4.773139206	100.8316482	87.80899811	-30.43160629	0.111963734	-30.3976835	0.094935298	-0.033922793	0.017028436	3.003124239	0.598796393
4.773139229	100.8316458	87.80899811	-30.69328117	0.114551544	-30.65910424	0.164432759	-0.03417693	-0.049881215	3.003197173	0.598810926
4.773139252	100.8316435	87.80899811	-30.95498276	0.117139615	-30.92050087	0.134258785	-0.034481885	-0.01711917	3.003270113	0.59882537
4.773139276	100.8316411	87.80899811	-31.21671104	0.119727947	-31.18201852	0.134258785	-0.034692516	-0.014530838	3.003343057	0.598839905
4.7731393	100.8316387	87.80899811	-31.47846413	0.122461818	-31.44336754	0.134258785	-0.035096594	-0.011796967	3.003416007	0.598854444
4.773139325	100.8316364	87.80899811	-31.74024391	0.125195965	-31.70483635	0.134258785	-0.035407556	-0.00906282	3.003488962	0.598868987
4.773139349	100.831634	87.80899811	-32.00204849	0.127930388	-31.96628106	0.134258785	-0.035767426	-0.006328397	3.003561922	0.598883533
4.773139374	100.8316317	87.80899811	-32.26388168	0.130665094	-32.22798191	0.134258785	-0.035899771	-0.003593691	3.003634887	0.598898082
4.773139398	100.8316293	87.80899811	-32.52574158	0.133400068	-32.4893779	0.134258785	-0.036363683	-0.000858717	3.003707857	0.598912633
4.773139423	100.8316269	87.80899811	-32.78762436	0.13613531	-32.75102671	0.164432759	-0.036597652	-0.028297449	3.003780833	0.598927186
4.773139447	100.8316246	87.80899811	-33.04953384	0.138870835	-33.01264932	0.134258785	-0.036884518	0.00461205	3.003853814	0.598941707
4.773139472	100.8316222	87.67099762	-33.31104279	0.141602173	-33.2739755	0.164432759	-0.037067291	-0.022830586	3.003926799	0.598956261
4.773139498	100.8316199	87.67099762	-33.57257843	0.144478947	-33.53514654	0.164432759	-0.037431889	-0.019953812	3.00399979	0.598970796
4.773139524	100.8316175	87.67099762	-33.83419037	0.147356555	-33.79643273	0.164432759	-0.037757643	-0.017076204	3.004072786	0.598985337
4.77313955	100.8316151	87.67099762	-34.0958786	0.150235012	-34.05796372	0.164432759	-0.037914882	-0.014197747	3.004145788	0.598999883
4.773139577	100.8316128	87.67099762	-34.35763931	0.153260097	-34.31934	0.164432759	-0.038299309	-0.011172662	3.004218794	0.599014434
4.773139604	100.8316104	87.67099762	-34.61947632	0.156286061	-34.58082571	0.164432759	-0.038650607	-0.008146698	3.004291806	0.59902899
4.773139631	100.8316081	87.67099762	-34.88134766	0.159312427	-34.84241839	0.164432759	-0.038929269	-0.005120332	3.004364822	0.599043548
4.773139658	100.8316057	87.67099762	-35.14325333	0.162339181	-35.10411564	0.189870596	-0.039137689	-0.027531415	3.004437844	0.599058109
4.773139686	100.8316033	87.67099762	-35.40519333	0.165366337	-35.3656603	0.164432759	-0.039533029	0.000933578	3.004510871	0.599072642
4.773139713	100.831601	87.67099762	-35.66716766	0.168393895	-35.62743519	0.164432759	-0.039732471	0.003961136	3.004583903	0.599087206
4.773139741	100.8315986	87.67099762	-35.92915726	0.171567038	-35.88918414	0.164432759	-0.039973116	0.007134279	3.00465694	0.599101771
4.77313977	100.8315963	87.67099762	-36.19116211	0.174740374	-36.15078307	0.164432759	-0.040379037	0.010307615	3.004729983	0.599116336
4.773139798	100.8315939	87.67099762	-36.45318222	0.177913889	-36.41248273	0.189870596	-0.040699491	-0.011956707	3.00480303	0.599130899
4.773139827	100.8315915	87.67099762	-36.71521759	0.181087598	-36.67428095	0.189870596	-0.040936635	-0.008782998	3.004876083	0.599145462
4.773139855	100.8315892	87.67099762	-36.97728729	0.184261724	-36.93605365	0.21228178	-0.041233641	-0.028020056	3.00494914	0.599160029
4.773139884	100.8315868	87.67099762	-37.23939133	0.187436268	-37.1979225	0.189870596	-0.041468831	-0.002434328	3.005022203	0.599174568
4.773139912	100.8315844	87.67099762	-37.50152969	0.190611228	-37.45964489	0.189870596	-0.0418848	0.000740632	3.005095271	0.599189139
4.773139942	100.8315821	87.67099762	-37.76370239	0.193932116	-37.72158226	0.21228178	-0.042120128	-0.018349664	3.005168345	0.599203712
						Avarage	2.580502574	0.513684453	4.038808619	0.499919134

The blue column in table 4.3 represents the GPS data obtained from the data logger, collected at the velocity of 90 km/h; the result is then calculated. The green colour column is the result of the calculated value. Its output is then compared with the coordinate data obtained from the GPU data logger. The accuracy is then calculated by taking its RMSE value, which gives 4.038 m for the X-axis and Y-axis of 0.51368 m.

4.1.2 GPS Data Comparison at Different Forward Speed

The next step is to compare these geographical data's consistency since this data is measured by the moving vehicle with three different speeds each time it runs the test. This result can also be used as validation tools for the statement that GPS accuracy will not be affected by the logging vehicle's speed. Vehicle speed during the GPS logging process is 90 kmh^{-1}, 100 kmh^{-1}, and 120 kmh^{-1}.

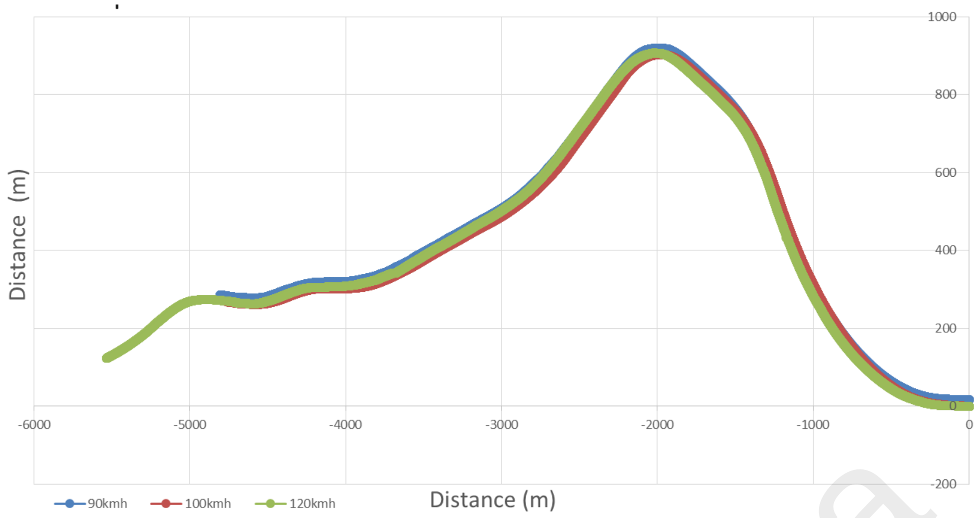


Figure 4.1: Comparison of x and y Coordinates at Different Forward Velocities

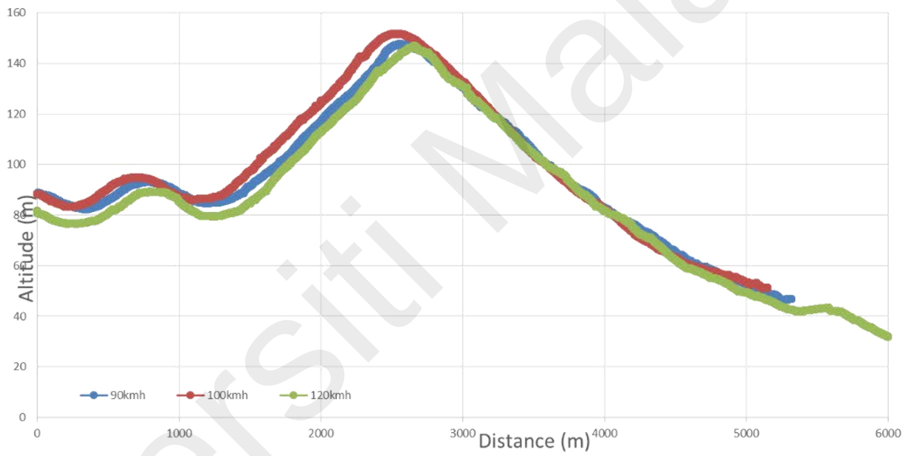


Figure 4.2: Comparison of Altitude at Different Forward Velocities

Based on the above figures, it is safe to say that the measurement data taken using the onboard IMU data logger are consistent. For the three different speed recorded, the road profile, represented by the x and y planer are very close. While the altitude profile shows slight variations, this result can still be considered reasonable since all graphs are close together.

4.1.3 GPS Data Comparison at Different Forward Speed

The following process is to conduct a cross-comparison among different sources of GPS data. As mentioned in the previous section, the IMU data logger's empirical data is compared with two other sources: LiDAR and Google Data. The result of this comparison is presented in Figures 4.3 and 4.4.

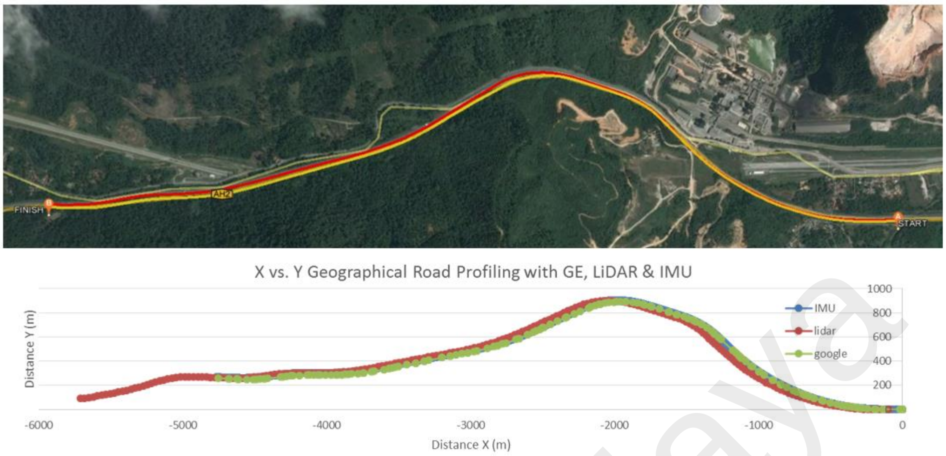


Figure 4.3: Comparison of x and y Coordinate Road Profiles Based on Different Sources of Road Data

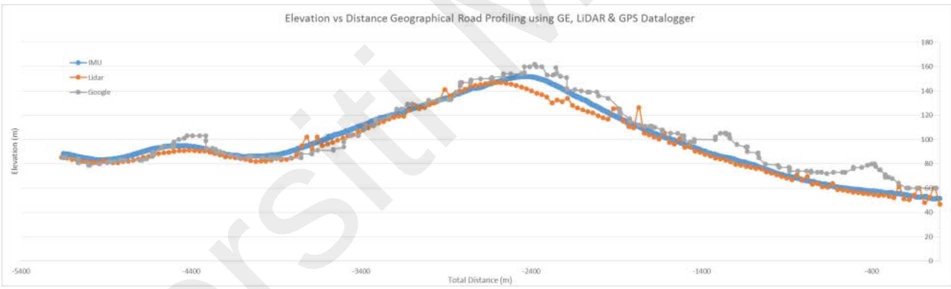


Figure 4.4: Comparison of Elevations Based on Different Sources of Road Data

Referring to figure 4.3, we can see that the LiDAR-based road profile and GE-Based road profile are very close to the reference road profile based on the IMU Data Logger. It also has a similar shape to the raw GPS data shown in the coloured figure. For the elevation data, shown in figure 4.4, taking the IMU data logger as the reference source, the LiDAR elevation profile shows more accuracy than the Google data. However, this irregularity or fluctuation of the elevation data can be easily overcome with the spline function smoothing in the simulation software.

4.2 Risk Assessment Parameter Validation

Once the GPS data Validation process has been conducted, the same data sources will then be used to construct the road profile at the selected highway stretch name, N5 Route 1 and N5 Route 2. The road profile result of the N5 Route 1 has already been discussed in the previous subsection, where the x and y coordinates of the road profile closely resemble the actual road profile, as shown in Figure 4.3. Hence the risk assessment simulation process can be carried out for that particular road section. While the location of N5 Route 2 will be discussed in the next paragraph.

Figure 4.5: x and y Coordinate Comparison with Raw GPS Data

Figure 4.5 shown the coordinate comparison result of the N5 Route 1 obtained in this location. The result indicates that the Google database's road profile is similar to the raw GPS data, represented by the coloured image in figure 4.5. Since it has been established in the previous section that all three GPS data sources can be used as a result shown in the last paragraph are coherent with each other. Hence, any one of the data sources can be used in the absence of the other. Therefore, we can say that the GE Base road profile use in deriving the N5 Route 2 road could represent the actual road profile, and it is good to be used as in the road safety simulation.

From the visual comparison presented in Figures 4.3 and 4.5, both road stretches show similarity in their road shape. The road stretch and curvature seem to be represented correctly in the x and y coordinates shown by the mapped graph at the bottom of each figure. The x and y coordinate of each road segment is then keyed in the simulation software, which is then mapped in a similar shape as the input data as shown in figure 4.6 and 4.7 below,

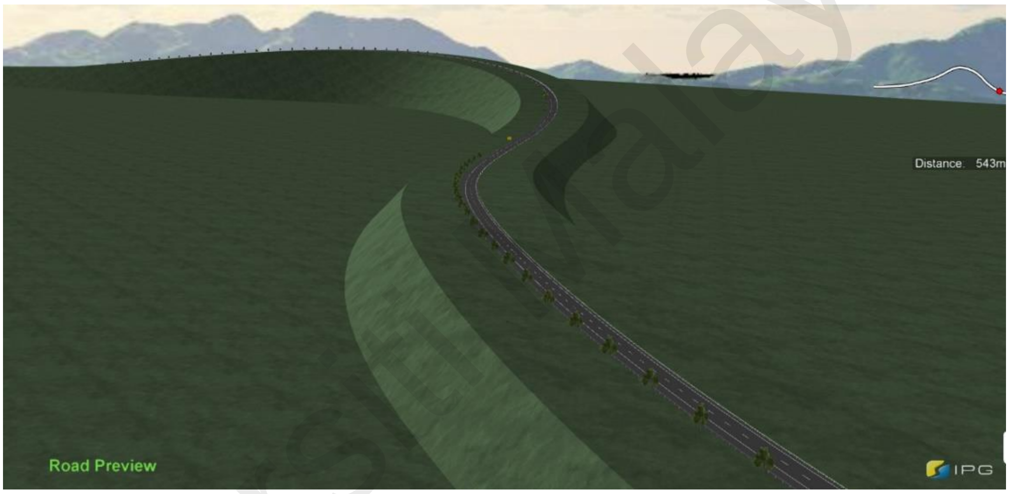


Figure 4.6: N5 Route 1 Overview in the Simulation Software

Figure 4.7: N5 Route 2 Overview in the Simulation Software

Besides visual validation as conducted in the previous paragraph, we compare its total distance from both data and the simulation road. The length of the recorded data for the N5 Route 1 stretch is 5.2 km, where the size of the same stretch after it is mapped on the simulation is 5.0 km. As we can see from the result, based on the smoothing factor set up, the difference is not significant and can still be accepted. The result showed a promising result as the actual and simulation road's total distance has only had 200 meters different.

4.2.1 Road Environment

The ready-to-use virtual road will have road profile and road furniture such as barrier and signage present in the simulation. This process is conducted using the google street view's image and google earth's length measurement function. As a result, basic road furniture is installed to resemble the environment and ambient of the actual road profile.

Figure 4.8: Virtual Road Overview of N5 Route 1 (Above) and N5 Route 2 (Below)

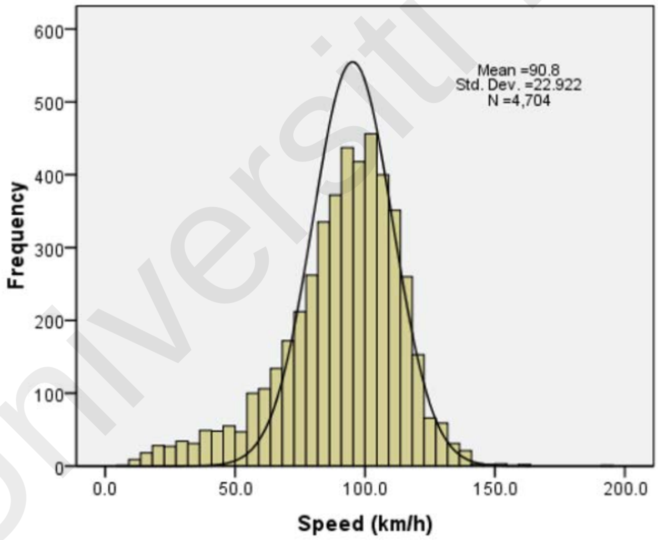
Figure 4.9: Comparison View Between Virtual Road and the Actual Road of N5 Route 1.

Figure 4.10: Comparison View Between Virtual Road and the Actual Road of N5 Route 2.

Figure 4.8, figure 4.9, and figure 4.10, we can see that the virtual road can resemble the actual road in terms of its profile and appearances. This appearance aspect will not affect the vehicle's dynamic response, but it will help understand or identify the fail location during the simulation. Visible road landmark is correctly copied into the simulation, including road signage, light pole, road barrier, and road marking.

4.2.2 Traffic Characteristic

The traffic characteristic is used to determine the measured road stretch's actual vehicle behaviour; this will better understand how the traffic behaves. This is done by collecting several data on the predetermined period, from 10.00 am to 01.00 pm, three hours' worth of data. The data that will be used from this data collection is the speed of the vehicle.

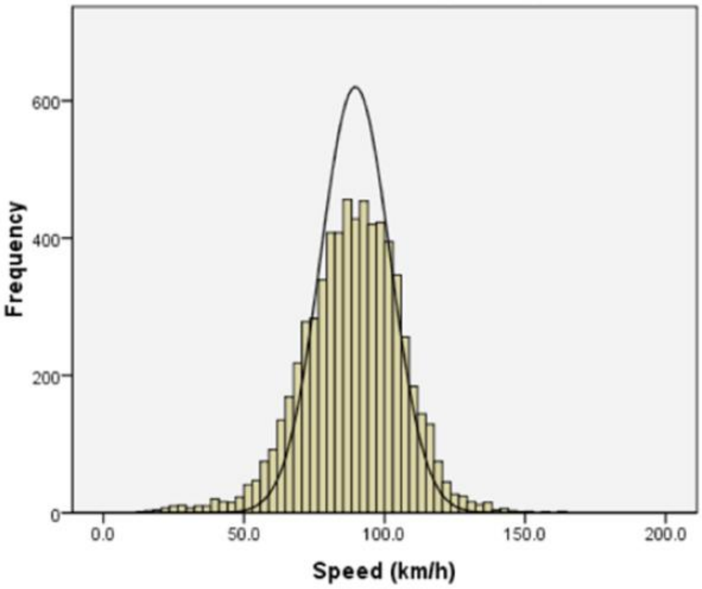


Speed (km/h)

N	Valid	4704
	Missing	1274
Mean		90.801
Std. Deviation		22.9223
Minimum		8.1
Maximum		192.8
Percentiles	85	112.100

Figure 4.11: Vehicle Speed Characteristic of N5 Route 1

Referring to figure 4.11, the N5 Route 1 location, the mean speed recorded by the device is 90.8 km/h, while the 85^{th} percentile speed is 112.1 km/h, and the highest speed logged is 192.8 km/h. A similar output for N5 Route 2 shown in the diagram below,



Speed (km/h)

N	Valid	6498
	Missing	648
Mean		88.609
Std. Deviation		17.6293
Minimum		14.6
Maximum		163.7
Percentiles	85	105.600

Figure 4.12: Vehicle Speed Characteristic of N5 Route 2

Figure 4.12 above reported that the mean speed for all vehicle on the N5 Route 2 is 88 km/h, with 105 km/h as its 85th percentile speed, the maximum speed recorded is about 163.7 km/h. All these data are then used as the simulation's speed parameter, which is then used as a road safety risk assessment on the particular road stretch. These results will be discussed in the final subchapter.

4.2.3 Traffic Characteristic

The vehicle model used in this project is based on the Toyota Camry 2.0. This car was chosen because it is listed as one of the default cars available on the CarMaker database; this vehicle also widely available locally. Using the processes described in the previous chapter, it is found that the vehicle's CG location has been determined to be: y = 1.569 m (longitudinal), x = 0.785 m (lateral), and h = 0.367 m (height above ground). Comparing it directly with the CG recorded on the simulation car, we then obtain the following comparison data,

Table 4.4: Comparison of Distance between Actual and Simulation Road

COG location of the test vehicle			COG Location of the Simulation Vehicle		
x	y	h	x	y	h
0.785 m	1.569 m	0.367 m	0 m	2.262 m	0.571 m

The above table shows a slight shift in the test vehicle's COG location compared to the determined simulation vehicle. This subtle change may cause the suspension system's age degradation that may cause an imbalance in the vehicle. The difference in the longitudinal COG location y may occur because of the engine's different weights in the simulation environment with actual engine weight. Regardless, these differences in COG location may not affect the overall result since the DAQ will still sit on the vehicle's COG.

4.2.4 Vehicle Simulation Validation Result

Simulation validation is done by comparing the vehicle response data obtained from the experimental with the simulation data. The vehicle response data that will be reached is the vehicle’s lateral acceleration. Another source of data that can be used as a comparison with the simulation is vehicle response acceleration. When the test vehicle is running on the predetermined road stretch that is used in the simulation, it should give a similar response to the vehicle simulation. During the simulation, the vehicle travel at speed around the initial speed parameter set, with a deviation of a plus-minus 4km/h.

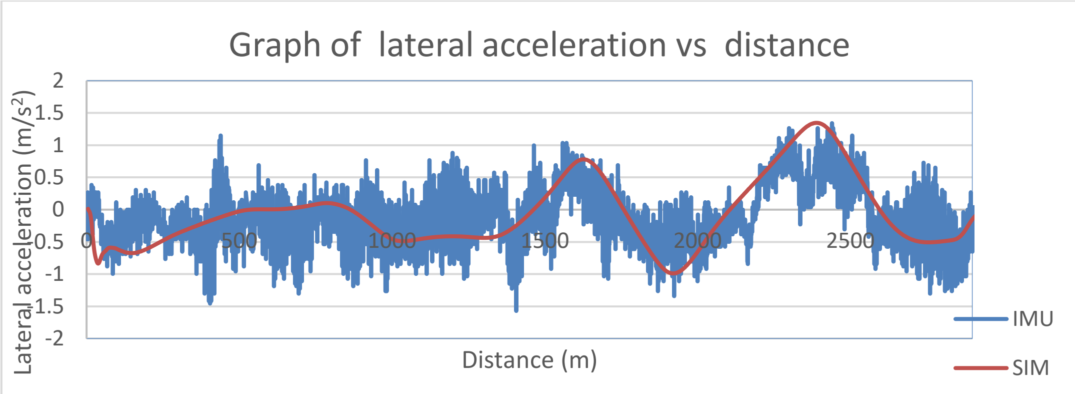


Figure 4.13: Graph Comparison of the Lateral Acceleration Obtain Between IMU and Simulation

The above diagram compares the test vehicle and simulation vehicle's lateral acceleration, presented with the blue and orange lines. The graph observation shows a similar trend present on the graph, especially in the km 1.5 to km 2.9 from the initial point. The vehicle simulation response is also still in the test vehicle response range, indicating an acceptable error. The small magnitude difference is present because the test vehicle has more hart time to maintain its constant speed and trajectory at the desired speed than the simulation vehicle, which may cause a slight fluctuation of magnitude. The DAQ placement can also contribute to the irregularity of the experimental data. This is because the test vehicle's vibration may have picked up by the DAQ sensor since it is located inside the hand rest box. The vehicle's age can also contribute to the vibration picked up by the DAQ since the model used in this experiment is considered aged. In contrast, the simulation vehicle model is run perfectly without considering parts degradation into the simulation.

4.3 Risk Assessment Application and Analysis

After the experimental test run and validation, the subsequence stage is to execute these virtual processes into the application. Following the flowchart shown in the previous chapter, the analysis will analyze the vehicle response obtained from the vehicle movement's simulation data and visual or obvious abnormality. This simulation intends to replicate the actual various driving scenarios relevant to the selected road sections in the virtual driving environment to achieve this thesis's primary objective, which is to assess the safety risk on the pre-collision stage, trough on the development of the road profile.

4.3.1 Risk Assessment Application

The safety assessment starts with determining the simulation's input variable, which consists of vehicle classification, road surface coefficient of friction, and driving speed. Some of the input variable results were discussed in the previous subchapter, vehicle type, and driving speed. In detail, these various parameters can be breakdowned and presented in the following component table;

Table 4.5: Overall Component Breakdown of the Various Parameters in The Simulation

Location	Vehicle classification	Road surface coefficient of friction	Vehicle or driving speed
NSE N5 Route 1 – Changkat Jering; NSE Rawang; ELITE Nilai; NSE N5 Route 2 – Sungai Perak	Car (sedan model); Truck (3-axle Single Unit Truck (SUT))	0.3 (represent wet condition); 0.7 (represent dry condition)	For car: Speed limit (typical 110 kmh^{-1}); 85 percentile (values depend on location); Maximum (values depend on location) For SUT:

			Speed limit (typical 90 kmh^{-1}); 120 kmh^{-1}

The three variables are considered in the virtual vehicle simulation work because a typical driving event is a combination of vehicle, road, and driver (behaviour). The vehicle classification will represent the dynamic performance and vehicle weight or load in the load-carrying vehicle. In shipment carrying a vehicle, two different GVWs are considered, which are 20 and 40 ton, these two GVW representing the condition of normal loading and overloading, respectively. Meanwhile, the road surface coefficient of friction represents the road conditions during driving. Specifically, a coefficient of friction of 0.3 can be associated with poor road conditions, possibly due to the wet weather scenario, while contrariwise, the 0.7 coefficients of friction related to the ideal dry weather scenario. Moreover, driving speed is related to the vehicle and indirectly associated with drivers' overall driving characteristics or behaviour.

As mentioned in the above table, the simulation involving the car parameters, which is speed, is location-dependent. Hence the speed characteristic for each location is different; it is represented in the following table;

Table 4.6 Speed Parameter of Location One and Two

No	Location	Speed Limit	85% percentile	High speed	Maximum Speed
1	NSE N5 Route 1	110 km/h	130 km/h	140 km/h	192 km/h
2	NSE N5 Route 2	110 km/h	105 km/h	140 km/h	163 km/h

The simulations were conducted on both road sections with the various combinations of the three-simulation variable, which then came up with 33 virtual driving simulation results. Moreover, for each case, the simulation is run until the completion of the entire road sections or until the vehicle loses control, resulting in the simulation not proceeding further.

4.3.2 Visual Analysis Result

A total of 33 simulation results are presented in simulation outcomes, such as the vehicle being in control or out of control and vehicle responses. This simulation outcome is then summarized in the following table;

Table 4.7: Simulation Outcome Based on the Parameter

Location	Vehicle classification	Road coefficient of friction	Vehicle speed	Outcome
NSE KKangsar	car	0.3	110	[a]
			112 (85 %)	
			140	
			192 (max)	1[b]
		0.7	110	
			112 (85 %)	
			140	
			192 (max)	
	SUT (20 ton)	0.3	90	
			120	
		0.7	90	
			120	2[c]
	SUT (40 ton)	0.3	90	

			120	
		0.7	90	
			120	2[c]
NSE Menora	car	0.3	105 (85 %)	
			110	
			140	1[d]
			163 (max)	1
		0.7	105 (85 %)	
			110	
			140	
			163 (max)	
	SUT (20 ton)	0.3	90	
			120	1
		0.7	90	
			120	2[e]
	SUT (40 ton)	0.3	90	1
			120	1
		0.7	90	
			120	1
Outcome indices: 1 = out of control, 2 = out of control momentarily, but completed simulation				

Additional special notes on Table 6 are stated here:

- [a]entry with no index stated in the Outcome column refers to the vehicle being in control, and the entire road is completed with no issue.

- [b]special note: both uphill issue and sliding out of the lane, the road not completed.

• [c]special note: almost unable to overcome uphill section, no lateral issue; for this location, the outcome is not binary; all cases suffer from a drop in speed when overcoming uphill section but to varying severity.

• [d]special note: additional trial simulation (not stated here) shows that vehicle is in control at the coefficient of friction larger than 0.3.

• [e]special note: vehicle goes out-of-lane momentarily, however, managed to be saved by IPG Driver's corrective manoeuvres, road completed.

Table 4.7 represents the simulation outcome based on the test vehicle model's observation through simulation video when it runs across each road section. The out of control situation is where the vehicle cannot maintain its trajectory even with the driver's model's help to correct it by entering adjacent lane or event multiple lanes, either with understeering or over-steering. However, in some simulation results, the vehicle simulation is managed to complete the test run but with momentary or slight lane departure on the same area within the road segment. This phenomenon will still be recognized since this can directly or indirectly become a safety concern if another vehicle is present in the adjacent lane.

Figure 4.14: Understeering Behavior of the Car, N5 Route 2

Figure 4.15: Oversteering Behavior of the SUT, N5 Route 2

The above figure is the case where the test vehicle is experiencing an out of control situation. The above condition only occurs in unfavourable conditions in the maximum speed and minimum friction coefficient.

From the two figures, we can see that understeering out of control happens on the car presented in figure 4.14 while oversteering out of control identic with SUT shown in figure 4.15. This is relevant to the actual passenger car behaviour since it is designed to behave as slightly understeering at the limit of driving.

4.3.3 Simulation Analysis Result

This subsection will discuss the simulation data in the two road segments mention before. This data will explain the nature of the accident and the early indication of the out of control occurrence in the simulation. The analysis parameter will include lateral acceleration and longitudinal speed; all these parameters are plotted against the meter distance.

4.3.3.1 N5 Route 2

Route 2 has the highest number of out-of-control occurrences among the two locations, as indicated in table 4.7. As previously mentioned, the out-of-control happens to the car it tends to be understeer, while the SUT is otherwise.

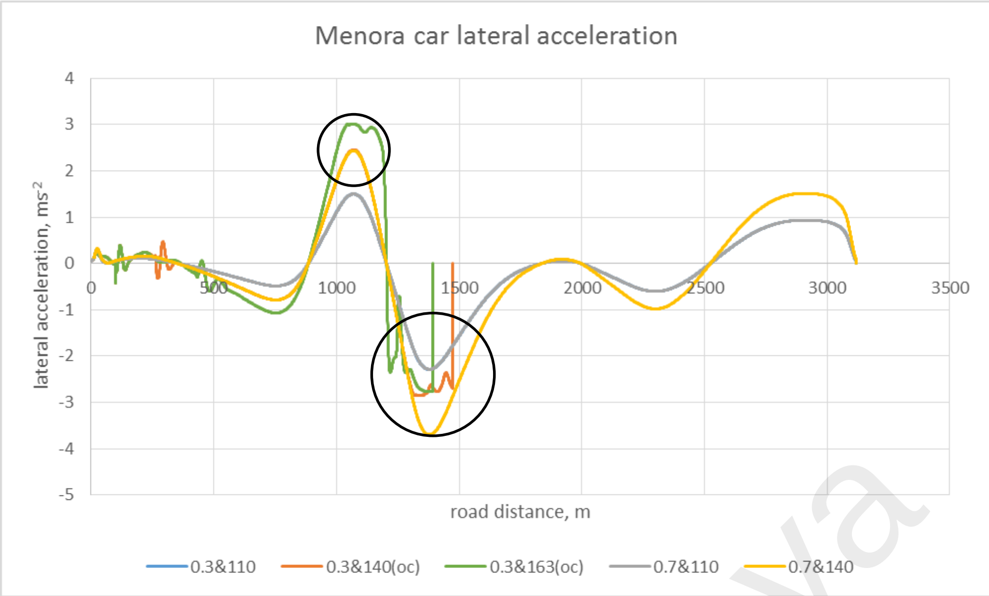


Figure 4.16 Selected Lateral Acceleration Responses, Car, N5 Route 2

The above figure provides a clear indication of the occurrence of the out of control situation. This indication is an abnormal or erratic vehicle response, much more apparent than the typical driving situation. Hence this erratic behaviour can be used as an indicator to forecast the accident. The accident-prone location of the N5 Route 2 consists of several tight turns. The combination of over speed limit and low coefficients of friction may cause out of control.

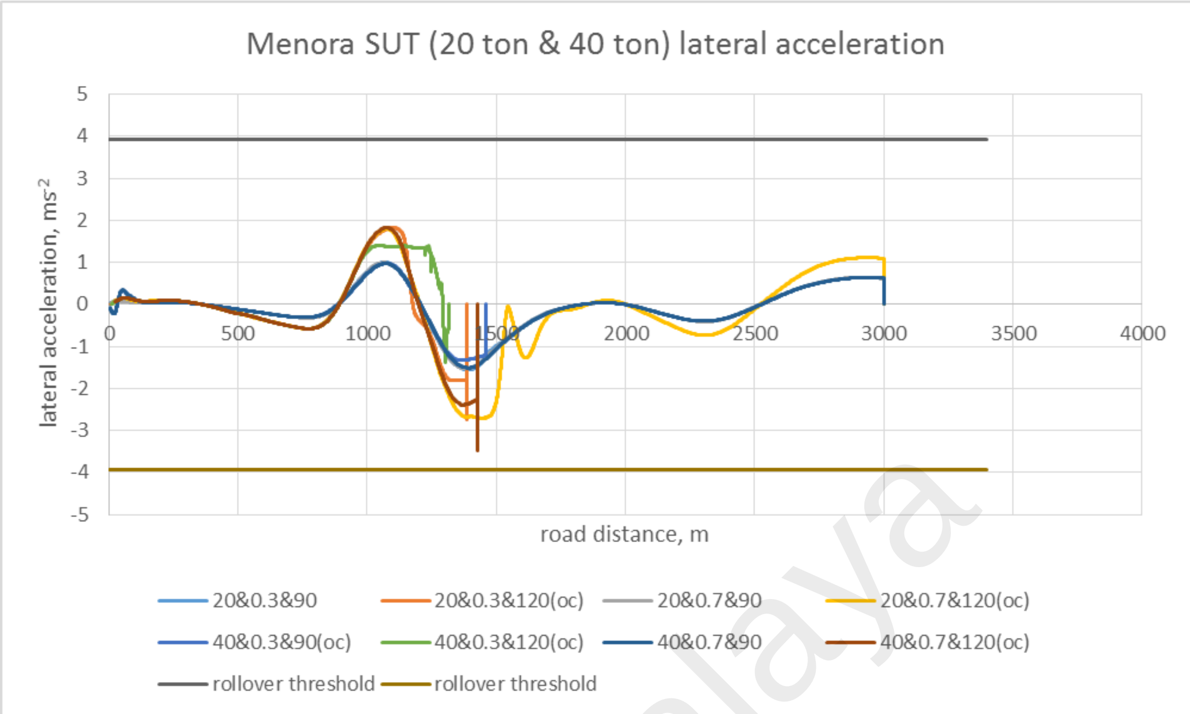


Figure 4.17 Selected Lateral Acceleration Responses, SUT, N5 Route 2 with Rollover Threshold

The SUT lateral acceleration response presented in the above figure indicates that SUT travel above the speed limit will experience an out of control except for the SUT below the speed limit but with an overloading vehicle condition. The grey and brown color represents the typical rollover incident threshold for the truck based on the previously mentioned literature. However, we can see from figure 4.17, the out of control situation happen far before the indicated threshold, which means that this safety risk assessment used in this thesis can be used as a clear indicator in deriving a flexible rollover threshold base on the road segment itself.

4.3.3.2 N5 Route 1

Looking from N5 Route 1, the problem that occurs is mainly represented in the longitudinal dynamic data. This is because the N5 Route 1 accident-prone location happens in the road segment's uphill section. The simulation result shown that both vehicle and SUT are suffering a speed drop phenomenon while overcoming the uphill section. This can be seen from the figures 4.18 below,

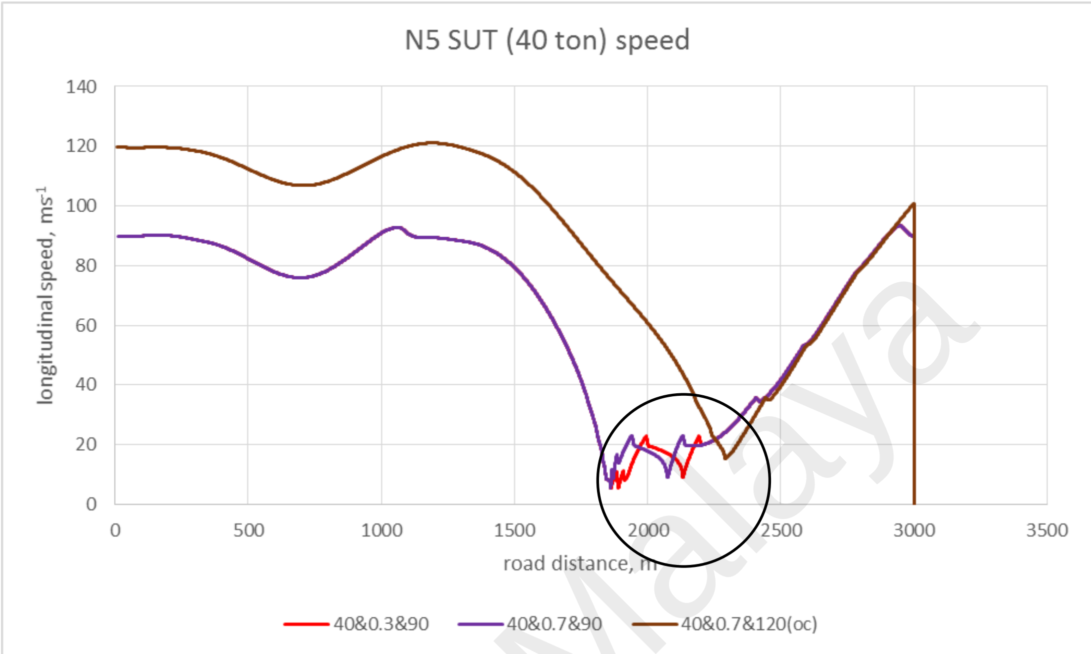


Figure 4.18 Selected Longitudinal Speed Responses, SUT, N5 Route 1

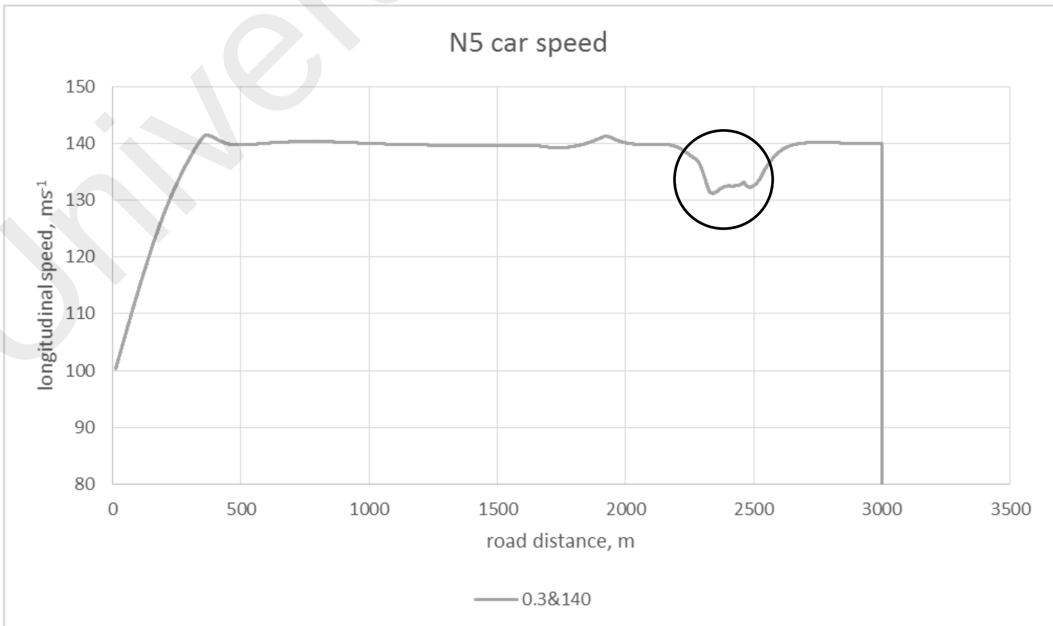


Figure 4.19: An Example of Drop-in Longitudinal Speed Involving a Car, N5 Route 1

By comparing figures 4.18 with 4.19, we can see that the speed drop of the SUT is much more severe compared to the speed drop of the tested car. This difference of SUT speed drop may cause by the much greater mass or GVW, especially in heavy load SUT. This is also supported by the comparison between the coefficient of friction of the road surface, in both coefficient different under the same weight and speed, the SUT has shown a similar drop-in rate, this concludes that the loss of speed doesn't affect by the road coefficient of friction but more due to the GVW of the SUT.

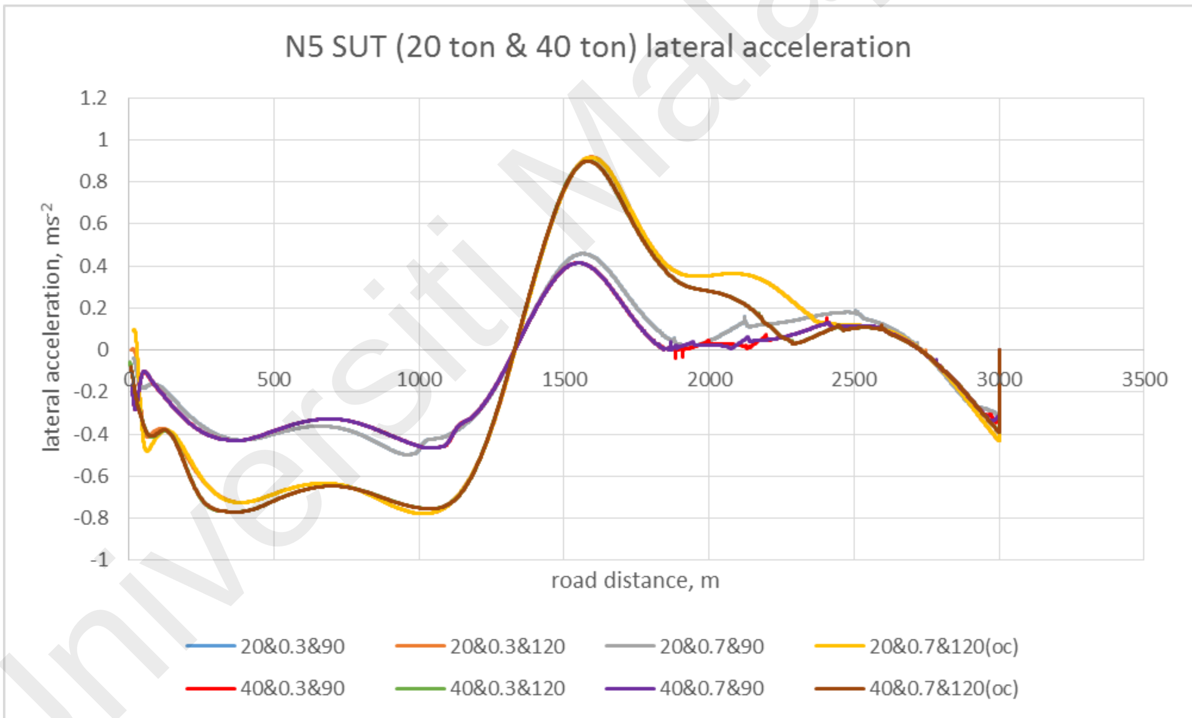


Figure 4.20: Lateral Acceleration Responses, SUT, N5 Route 1

Figure 4.18 presenting no significant change in the lateral acceleration of the SUT, for both 20 and 40 ton, all simulated SUT manage to complete all the run despite the speed drop occurrences. It is also safe to say that the only road safety breach indicator is from the longitudinal dynamic data, which shows a massive speed gap between SUT and car due to the different speed reduction.

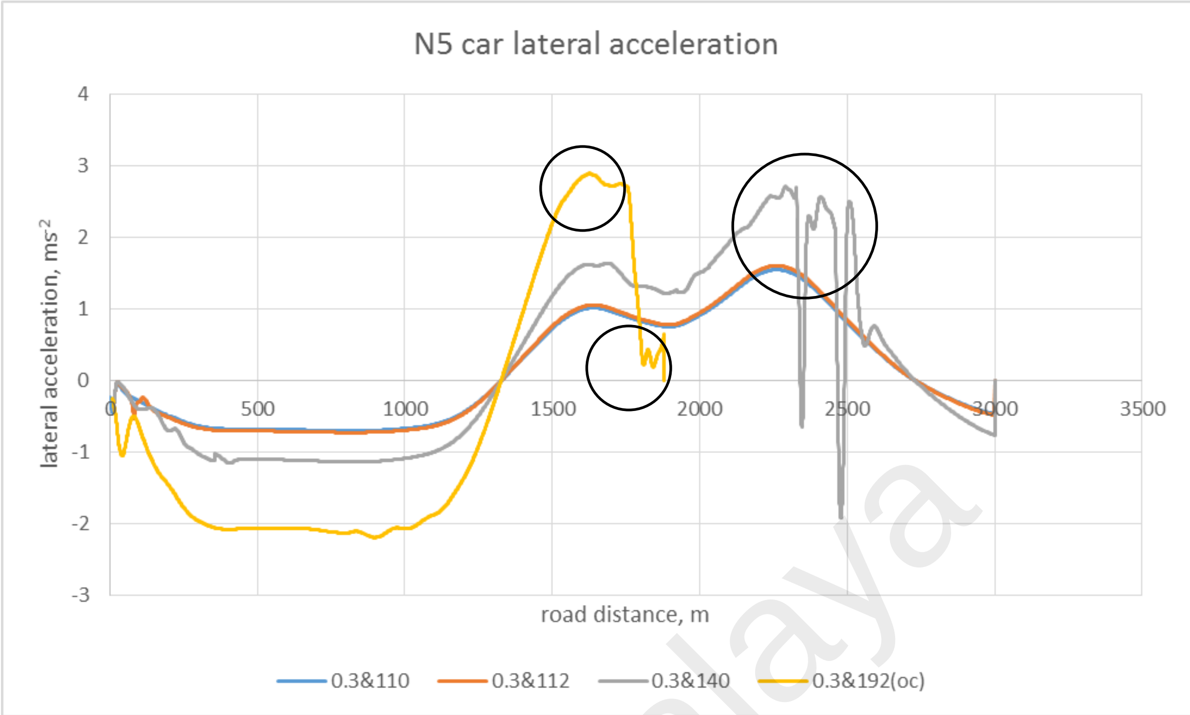


Figure 4.21: Selected Lateral Acceleration Responses, Car, N5 Route 1

Similar vehicle response also occurs in the car simulation, shown in figure 4.21, with only one combination of the variable that causes out-of-control situations. The significant out of control occurrence is in the maximum recorded speed and low coefficients of friction, as shown by the yellow lines. Looking closely at the above figure, we can see a slight disturbance in the grey line, which is car simulation with 0.3 coefficients of friction and 140 km/h speed. The simulation video of this particular simulation shown it manages to complete its run; however, after inspecting its simulation data, we can see that it is almost failing at km 2.4, indicated by the disturbance mention before. The vehicle is virtually failing to maintain its direction but able to gain control of it. This vehicle response analysis was able to identify an impending or almost happen out of control situation.

Based on the above discussion, the dangerous scenario in the particular road segment is where a much faster vehicle such as a car travels on the vehicle's fast lane. While it is confronted with two heavy vehicles in which the other heavy vehicle is trying to overtake the other vehicle, the much faster and lighter car may not have been able to stop in time, which then makes a rear-end collision. This scenario is then illustrated in the figure below,

Figure 4.22: Screenshots of Overtaking Simulation with Mixed Vehicle Classifications at N5 Route 1

Moreover, the figure below shows the actual scenario that happens on the road segment,

Figure 4.23: An Actual Overtaking Scenario at N5 Route 1 Involving Different Vehicle Classifications.

This scenario is represented in the dynamic simulation result indicating what kind of road accident may occur in the particular road section. This result is also confirmed by the type of accident that previously happened in the location selection criteria: rear end collations and more than one vehicle.

4.4 Chapter 4 Summary

Its conversion is then compared with other sources of data such as LiDAR and Google database. The elevation profile will also be compared to have comprehensive validation. The empirical data collection of the previous chapter's GPS data is used as comparison data for validation purposes. The elevation profile will also be compared to have comprehensive validation. For the GPS data to be used in the simulation software, its format needs to be adjusted. This adjustment is by converting the GPS form of data into the Cartesian coordinate data by implanting the law of cosine formulation to find the shortest distance in the great circle in the X and Y-direction.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

To conclude this thesis, the previous chapter's result showed promising satisfaction of the objectives drawn. The designed road safety assessment through simulation manages to give a positive outcome as intended. However, there always room for improvement, which will discuss in this chapter along with the detailed conclusion beforehand.

5.1 Conclusion

As an essential asset in this project, the virtual road has carried several points to be concluded. Firstly, based on the carried out work, this virtual road's validation has been successfully conducted. Moreover, the comparison between three different virtual road data sources can conclude that the virtual x and y or planar road profile derive from the IMU is sufficiently close to the actual road profile. However, in the absence of this and LiDAR data, GE data can be a valuable source of the geographic coordinate system, despite its elevation error. In this safety risk assessment simulation, this elevation error is relatively small since reasonable accuracy can still be achieved with the polynomial curve-fitting process preloaded in the simulation software. The method of converting the geographical data into the familiar file format for the simulation software is also successful. This is shown by the validation process that comes up with a small percentage of error, discuss in the previous chapter.

The conclusion can be drawn from this thesis's primary objective in developing methods to assess road safety. Vehicle response data such as lateral acceleration can be used as a suitable indicator in determining the potential fail point of the particular road section by indicating its erratic response. This and together with a visual inspection of the simulation will allow us to pinpoint the out of control and event impending loss of control to be identified. The two-location discussed indicate that lateral out of control or slight lane departure present at both locations. This is shown that most accidents occur on the highway will involve more with the out of control situation. Where in the hilly road segment, the longitudinal speed reduction becomes its leading cause of the accident. Since this can create a vast speed gap between the lane and may cause rear-end collision.

Overall, the developed pre-collision safety risk assessment using the multi-body simulation technique has been carried out successfully. It is shown that this technique can be an efficient approach, especially in the road characteristic and conditions and vehicle characteristics. Implementing this technique in a new or planned road segment, resulting in pre-collision mitigation, can be carried out without waiting for the accident to happen first. This technique is also helpful in indicating the fail point after the accident.

5.2 Recommendation

One recommendation can be addressed in increasing the road simulation validation process's value or strength by utilizing heavy-duty and robust vehicle tests. The vehicle test can contain several extra data such as vehicle torque, speedometer speed, steering angle, wheel displacement, pitch and roll angle measurement, and many more. The next recommendation is on the simulation side. The closeness of the vehicle simulation movement with the actual vehicle movement can be increased by implementing a virtual simulation rig, which can control the virtual vehicle to duplicate the real test run's driving style. This can also enhance the safety-risk assessment technique by implanting the driver distraction factor on the risk assessment.

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