ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

TRAFFIC SAFETY EVALUATION AND DEVELOPMENT OF A TRAFFIC SAFETY PREDICTION MODEL FOR THE APPROACHES OF SIGNALIZED INTERSECTION USING SURROGATE SAFETY MEASURES (THE CASE OF BOLE SUB-CITY)

A MASTERS THESIS

BY:

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to

ADDIS ABABA INSTITUTE OF TECHNOLOGY

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to

ADDIS ABABA UNIVERSITY

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June, 2024

CERTIFICATE

This is to certify that the thesis prepared by Mr. Fikadu Aschalew Behonegn entitled "Traffic Safety Evaluation and Development of a Traffic Safety Prediction Model For the Approaches of Signalized Intersection Using Surrogate Safety Measures (The Case of Bole Sub-city)" and submitted as a partial fulfillment for the Degree of Master of Science complies with the regulations of the University and meets the accepted standards with respect to originality, content, and quality.

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DECLARATION

I hereby declare that this thesis entitled "Traffic Safety Evaluation and Development of a Traffic Safety Prediction Model for the Approaches of Signalized Intersection Using Surrogate Safety Measures (The Case of Bole sub-city)" was prepared by me, with the guidance of my advisor. The work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or professional qualification.

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ABSTRACT

In developing countries like Ethiopia, particularly Addis Ababa, it has been noted that about 1,264 people have died from the year of July 2019 to June 2022 that was approximated 422 people die per year. This emphasizing that Addis Ababa city has highly affected by traffic accident with a significant loss of lives, serious injuries on individuals' well-being and property damage.

Traffic safety studies and analyses were traditionally conducted using reports on traffic crashes. The drawbacks include failure to record the accident position, incompleteness, and underreporting of crash data and additionally the drawback of the traditional approach is needed many crash data for analysis, in order to draw any conclusions and take the appropriate corrective action. Thus, the microscopic traffic simulation was chosen for the evaluation of traffic safety.

Eight signalized intersections with a combined total of 29 road approaches were selected and Simulation of Urban Mobility software were used to model the existing situation. Primary and secondary collected data are used as the input for the SUMO simulation to modify the default car-following and lane changing model with actual real data.

Surrogate safety measures (TTC) for the selected study area were derived from Sumo output. TTC has a bell-shaped distribution with some skewness and Weibull distribution function were used to model the distribution of Time to collision distribution. After calculating the Weibull shape and scale factor parameter the Weibull cumulative probability for Time to collision below 2.5second were determined for all road approaches and used as dependent variables. Traffic safety evaluation was carried based on Weibull cumulative distribution. The roads from Jacross to Gerji meberat-hayel junction have the highest cumulative probability value of 0.779, or it has 77.9% chance of occurring potential conflict, while the roads from Latica bakery to Salithmhiret intersection have the lowest cumulative probability value of 0.164, or it has 16.4% chance of occurring potential conflict.

A multiple linear regression were used to model the dependent variable, (cumulative probably for TTC below 2.5 seconds) and significant independent variables, (Traffic volume per lane and speed deviation). The coefficients of number of vehicles per lane is positive 0.00076186 indicated that for every increase of 100 vehicles per lane results the probability of the occurrence of potential conflict increased by 0.076 or 7.6% and the coefficient of speed deviation is 0.50114603 for every increase of speed deviation by 0.1 the probability of the occurrence of potential conflict increased by 0.0501 or 5.01%.

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ABBREVIATIONS AND ACRONYM

AACTMA Addis Ababa City Traffic Management Agency

AASHTO American Association of Highway and Transportation Officials

AAPCO Addis Ababa Police Commission

BR Brake Rate

CDF Cumulative Density Function

DR Deceleration Rate

DRAC Deceleration to Avoid Collision

DUA Dynamic User Assignment

DVU Driver Vehicle Unit

ERA Ethiopian Roads Administration

FHWA Federal Highway Administration

IDM Intelligent Driver Model

OSM Open Street Map

PDF Probabilistic Density Function

PET Post Encroachment Time

SG Space Gap

SSD Stopping Sight Distance

SSMs Surrogate Safety Measures

SUMO Simulation of Urban Mobility

TAZ Traffic Assignment Zone

TCT Traffic Conflict Technique

TG	Time Gap
TTC	Time to Collision

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CHAPTER 1- INTRODUCTION

1.1 Back ground of the study

Every year, nearly 1.19 million people lose their lives as a result of a traffic accident. Non-fatal injuries affect between 20 and 50 million more people, with many becoming disabled as a result of their injury. Road traffic accidents are the greatest cause of death among children and young adults aged 5 to 29. Pedestrians, cyclists, and motorcyclists account for more than half of all road traffic fatalities. Despite having around 60% of the world's vehicles, low- and middle-income countries account for 92% of all road deaths. (WHO, 2023).

Road traffic injuries cause considerable economic losses to individuals, their families, and to nations as a whole. These losses arise from the cost of treatment as well as lost productivity for those killed or disabled by their injuries, and for family members who need to take time off work or school to care for the injured. Road traffic accidents cost most countries 3% of their GDP (WHO, 2023). In addition to fatal and injuries traffic accidents and collisions can have serious effects on major interruptions to traffic flow and daily life.

According to Addis Ababa Police Commission (AAPCO) report from the year of July, 2019 to June, 2022, there were occur a total of 1,264 fatalities, additionally, the recorded number of severe injuries amounted to 5,616, furthermore, 3,174 cases of slight injuries were documented. Beyond the human toll, the report showed that 84,299 accidents resulted in property damage in Addis Ababa. This emphasizing that Addis Ababa city has highly affected by traffic accident with a significant loss of lives, serious impact on individuals' well-being and substantial economic loss.

The necessity for comprehensive safety evaluation and prediction models has become critical as the complexity of urban mobility and the number of vehicles on the road has increased. As a result, transport and road engineers continue to explore models to explain the effects of numerous factors on transportation network safety performance.

The typical method of evaluating the safety of a roadway is based on historical crash record approach. Historical crash records approach has a lot of drawback to predict crash rates (Parker and Zegeer, 1989).

To address these issues, traffic experts and researchers have resorted to modern technologies and simulation approaches to better understand and improve traffic safety. Surrogate Safety Measures (SSMs) generated from microscopic simulation tools of a roadway are one such way. SSMs are essential instruments for indirectly assessing and forecasting safety-related events and behaviors, identifying possible risks and vulnerabilities in the transportation system.

1.2. Statement of the Problem

The city of Addis Ababa, Ethiopia particularly the bole sub-city, is facing significant traffic safety challenges with an increase in traffic accidents resulting in injuries, fatalities, and property damage. Traditional approaches to predicting the potential risk of road accidents, which rely on historical traffic collision data and accident prediction models, have limitations due to the complexity of safety factors and low data quality of traffic crash records, thus

- Accidents happen rarely and occasionally, therefore the meaningful crash frequency statistics requires many years of historical crash data. In addition, the historical crash records, as reported by AAPCO, are often incomplete, with minor incidents frequently going unrecorded. This is evident in the discrepancy between the reported numbers of slightly injuries, which is lower than the number of severe injuries, which is unrealistic. As a result, the historical method's predictions may be based on incomplete data.
- The conventional traffic crash data recording system in Addis Ababa, Ethiopia, lacks the incorporation of precise location information through a coordinate system. This limitation poses a challenge when attempting to correlate safety with geometric parameters and traffic characteristics data. The absence of precise location data hinders a comprehensive understanding of the spatial dynamics of traffic accidents and restricts the ability to analyze how geometric factors and traffic characteristics contribute to road safety in specific areas.
- Analyzing conventional crash records has been a time-consuming process, due to the records have been maintained manually rather than through a computerized system. This manual approach has introduced challenges and complexities to the analysis.

As a result, this research will look into the use of surrogate safety measures developed from traffic simulations to better capture and predict safety-related events in bole sub-city, Addis Ababa. Ethiopia

1.3. Objectives of the Research

1.3.1 General Objective

The main objective of this study is to conduct a traffic safety evaluation using surrogate safety measure (Time to Collision) from the output of selected simulation tool, simulation of urban mobility, SUMO at selected locations and to develop a probabilistic model to predict the occurrence of potential collision risks for the case Bole Sub-city, Addis Ababa.

1.3.2 Specific objective

The specific objective of the research is;

1. To estimate and model the pattern of time to collision distribution from the analysis of SUMO output.
2. Evaluating the traffic safety of the lead/follow situation for 29 road approaches of selected eight signalized intersections using Time to Collision during peak hour flow.
3. Determine the most significant parameters that affect the value of TTC

1.4. Scope of the study

The research scopes are limited to the following issues: -

1. The research focuses on Bole sub-city of Addis Ababa. This sub-city has been chosen due to its distinction of having the highest recorded crash data among all sub-cities in the area. By focusing on Bole Sub-city, the research aims to focus the comprehensive and categorized crash data available, which is organized by sub-city. The selection of these specific locations within Bole sub-city allows for a targeted study that can provide detailed insights and recommendations for improving traffic safety and efficiency in one of Addis Ababa's sub-city most critical and high-risk areas.
2. The study focus is on signalized intersections and their approaches. An examination of the traffic flow, signal timing, intersection layout, and, traffic speed, speed deviation and any other elements that affect the intersections' safety are all included in this study. Through focusing on signalized intersection approach roads, the study seeks to offer a comprehensive evaluation of the variables influencing traffic accidents. By taking a targeted approach, it will be possible to

provide specific recommendations for better intersection design which will improve overall traffic safety and operation in the sub-city.

3. The focus of the research is on lead/follow conflict types at signalized intersections alone during peak traffic hours. The study aims to provide a detail evaluation of the safety risks when closely following vehicles during peak traffic hours. This focused strategy guarantees a comprehensive comprehension of the safety consequences at the busiest times of the day, enabling focused suggestions to improve the safety of signalized intersection approaches during peak traffic periods. We won't take into account off-peak hours because our main goal is to address the safety concerns that arise during peak traffic hours.
4. From those surrogate safety measures this study used time to collision TTC to evaluate and to develop a predictive probabilistic model of potential collision risks. The use of particular surrogate safety measures, with an emphasis on Time to Collision (TTC) is help to assess and create a predictive probabilistic model of possible traffic conflicts, is covered in this thesis. The study intends to measure the amount of time till a possible collision if the vehicles' current speed and trajectory are maintained by using TTC. By using TTC, a predictive model that can recognize high-risk situations and provide guidance for risk-reduction tactics can be created, improving the general safety of signalized intersection approaches in Addis Abeba's Bole sub-city.

1.5 Research question

1. What are the current traffic safety conditions at signalized intersections within Bole Sub-city?
2. What are the primary factors influencing traffic safety at signalized intersection approaches in Bole Sub-city?
3. How does the application of surrogate safety measures enhance the evaluation of traffic safety?
4. How can the findings from this research contribute to the development of effective traffic safety strategies and interventions in Bole Sub-city?

1.5. Significance of the study

Thus, the significances of the research findings are used to be for:

1. Estimating time to collision is be used to support evaluations and prediction of potential collision risk under various traffic engineering alternatives either under design stages including facilities that have not yet been built or existing traffic facility in bole sub city, Addis Ababa.
2. To validate earlier researches on accident prediction model using traffic crash data in bole sub-city, Addis Ababa.
3. The research can serve as a valuable reference and foundation for similar studies in different urban areas within Ethiopia or beyond.

1.6 Structure of Research

The structure of the report is systematized in to five chapters and an appendix part.

Chapter 1 – Introduction: deals with the background, Statement of the problem, objectives of the study, the scope and significance of the research.

Chapter 2 – Literature Review: illustrates the review of previous literatures which were executed on similar research area.

Chapter 3 – Materials and Methodology: described the methodology which was adopted to accomplish the objective of the research.

Chapter 4 – Analysis and Result: presented with the overall results of the study along with the relevant figures, tables and brief descriptions.

Chapter 5 – Conclusion and Recommendation: presents the conclusion of the entire study along with the respective suggested recommendations.

CHAPTER 2- LITREATURE REVIEW

2.1 Introduction

Most of the traditional traffic safety evaluation approaches are carried out based on recorded accident data using various types of statistical approaches, mainly before and after comparisons of observed data have several problems.

Approaches representing crash prediction models' variables are often limited to easily observable elements such as AADT, speed, and geometric aspects. They may, however, miss other essential explanatory elements, such as driver behavior and mistakes, which are often the main causes of accidents. The crash statistics are frequently questioned in terms of their completeness, quality, accessibility and so forth (Hankey et al., 1999; Stanton and Salmon, 2009).

Because of these traditional method approach constraints, certain indirect measures for assessing traffic safety are proposed by traffic engineers. (Gettman & Head, 2003) derived indirect indicators to reflect safety performance. These so-called surrogate safety measures (SSMs) are more quantitative and capable of predicting safety. They used two of the most common safety surrogate measures that are time to collision (TTC) and post-encroachment time (PET). They derived surrogate measures from existing microscopic traffic simulation models for intersections and used them to support the safety evaluation for both signalized and non-signalized intersections; (Goh et al., 2014) used another commonly-used surrogate measure—deceleration rate to avoid the crash (DRAC) along with a self-defined crash potential index to investigate the safety impacts of bus priority.

2.2. Traffic Conflicts

A conflict is defined as an observable situation in which two or more road users meet each other in time and space to the point that a collision is likely if their movements stay unchanged. The safety of a traffic facility is defined as the interms of the number expected crashes, by type, that will occur at an entity in a given time period. (Amundsen, F. and Hyden 1977)

Crash is unintentional collisions between two or more motor vehicles of the recognized categories stated in (Najm et al., 2001). It should be noted that single car crashes are not included in this definition.

The severity of the conflicts that occur is another aspect of safety. (C. Hyden, 1987) stated that the time to collision (TTC) has been considered as the key conflict severity measure, in which lower TTC indicates greater crash severity, owing to the fact that speed is not included in the measure. (G. Tiwari et al., 1995) agreed that a lower TTC suggests a higher likelihood of collision, it cannot be directly related to the severity of the crash. (J. Darzentas et al., 1980) stated that deceleration rate (DR) rather than TTC is the key measure of severity.

2.3 Traffic Conflicts Techniques

The traffic conflicts technique makes use of field observers to identify conflict situations at intersections by keeping a look out for sudden brakes and evasive actions. (Parker & Zegeer ,1989) The method's formal beginnings can be traced back to investigations conducted at General Motors (GM) Research Laboratories in the late 1960s. (Perkins, S.R.& Michigan 1967). Crash rates and the approach have been demonstrated to be somewhat correlated. However, there is still significant disagreement regarding the relationship between conflict management strategies and accident predictions. The technique is mostly criticized for adding additional uncertainty to the collecting of accurate conflict data due to the subjectivity of field observers.

Due to the subjectivity involved in determining whether a particular driving event comprises a conflict or not, field observers were a source of error when gathering conflict data. Since each observer must determine whether a given scenario constituted a conflict, various people will assess traffic conflicts differently. As a result, the data gathered by humans may not have been reliable, particularly if several observers were employed. Nevertheless, it has been demonstrated that traffic conflicts are somewhat correlated with crash frequency, and it is generally accepted that higher conflict rates are associated with lower levels of safety (Gettman et al., 2008).

However, conflict studies are still used to rank locations with respect to safety and a corresponding need for construction upgrades. (N. Katamine and I. Hamarneh, 1998.). There is a broad understanding that increased traffic conflict rates can be an indicator of decreased traffic safety. In addition to utilizing total conflict counts, conflict events can also be divided into groups according to the type of driving maneuver (events involving crossing, rear-ending, and lane-changing and diverging) using a number of different severity measures.

Numerous researches have used the quantitative measurement method, which measures conflicts using substitute safety measures, to enhance the quality of conflict data gathering (Grayson et al., 1984; Van der Horst, 1990; Kruysse, 1991). Research is being done to create data gathering systems that are more accurate and efficient, such as video sensors and computer vision algorithms (Saunier et al., 2007; Ismail et al., 2009).

In general, Traffic conflicts can offer more sources of data for evaluating safety consequences, but it is important to implement systematic investigations that limit the variation in conflict measurements. Integrating of TCTs with other surrogate safety measures, such as the micro-simulation model, may offer greater depth in understanding traffic safety issues, even though the relationship between conflicts and crashes is occasionally unclear.

2.4. Surrogate Safety Measures

Surrogate safety measures are indirectly measuring any events that can be correlated with crash rates. Because these methods use events that occur at a much greater frequency than crash rates, Surrogate safety measures are needed to address the following (H. YANG, 2012):

1. Without having to wait for a statistically significant number of crashes to occur, it is necessary able to evaluate the safety of traffic facilities.
2. Additionally, these measures can be used with micro simulated road networks to assess the safety of experimental roadway designs and/or operational strategies before they are built or employed in the field.

The following surrogate safety measures derived from microscopic simulation:

1. Time to collision (TTC) is the duration of time between two road users colliding before one of them makes an avoiding maneuver, like braking or changing lanes, or until something happens, like a pedestrian stopping or moving out of the way, that changes their present physical parameters. The idea was first presented by Hayward (1972), and it was then used in numerous researches aiming at determining the danger involved with car-following maneuvers. TTC is a projection of the present scenario into the future and is determined based on the speeds of the following and preceding users and the gap distance between them for two subsequent road users if the following user (i) conflicts with the preceding user (i-1) at time t.

Figure 1 illustrates the concept of TTC. The equation for the calculation of TTC for the case of lead follow situation is as follows:

$$TTC_i(t) = \frac{X_{i-1}(t) - X_i(t) - L_i}{V_i(t) - V_{i-1}(t)} \quad \forall V_i(t) > V_{i-1}(t)$$

Where X represents the position of the users at time t, V represents their speed and L is the length of the follower vehicle (H. YANG, 2012).

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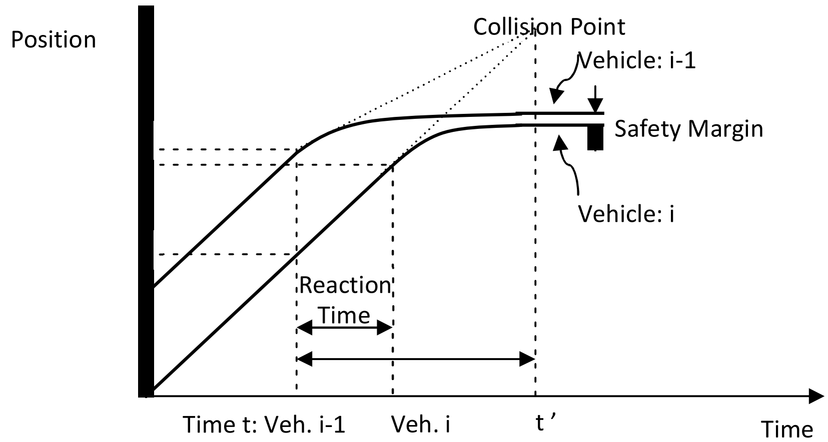


FIGURE 1: VEHICLE TRAJECTORIES AND TTC

A collision won't happen if the relative speed is zero because TTC is at infinity. When a collision course is determined, the TTC-value becomes finite and decrease as the crash distance gets closer, assuming that speed and path remain of the individual vehicle is constant. A suitable threshold or critical value TTC must be set in order to distinguish dangerous situations from those in which the driver is still safely in charge. TTC that is less than the perception reaction time should often be viewed as dangerous. For instance, common TTC selections range from 2 to 4 seconds (Minderhoud and Bovy, 2001; Hirst and Graham, 1997). The critical value's number remains a crucial validation criterion.

2. DRAC (deceleration rate to avoid a crash): It is one of the surrogate safety measures used in traffic safety analysis. DRAC quantifies the ability of a vehicle to decelerate to avoid a potential collision with another vehicle or obstacle in its path.

The deceleration rate is a critical factor in determining whether a driver can safely stop or slow down in time to avoid a crash. A higher DRAC value indicates that the vehicle can decelerate more rapidly, which is generally considered safer as it provides the driver with more time to react to potential hazards.

DRAC is often measured in meters per second squared (m/s^2) or feet per second squared (ft/s^2), representing the rate at which the vehicle's speed decreases over time. In a lead/follow scenario, where the follower vehicle is travelling at a faster rate than the leader vehicle, DRAC (deceleration to avoid a crash) is described as DRAC = 0.5*(speed difference square) /space gap. (https://sumo.dlr.de/docs/Simulation/Safety.html)

3. PET (post encroachment time): Allen et al. (1978) were the ones who initially developed the idea of Post-Encroachment Time (PET). PET was defined as the short period of time difference required for two drivers to cross a shared spatial area without necessarily colliding. More specifically, (Songchitruksa & Tarko, 2006) illustrated it as the amount of time, measured from the rear bumper of the first vehicle to the front bumper of the second vehicle as shown in Figure 2. The formula for PET is:

$$PET = t_2 - t_1$$

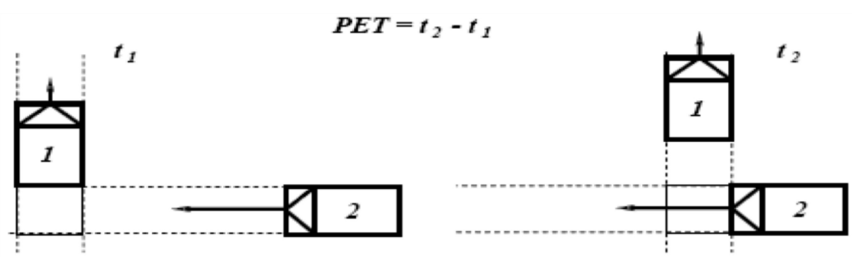


FIGURE 2: POST-ENCROACHMENT TIME (SONG CHITRUKSA AND TARKO,2006)

The idea behind PET is that Smaller PET results are thought to be associated with a higher risk of accident. According to (Kraay et al., 1985; Archer, 2004) a value of less than 1.0 or 1.5 seconds can be considered critical.

4. BR (brake rate): Brake rate refers to the rate at which a vehicle decelerates or slows down when the brakes are applied. It is a measure of the vehicle's braking performance and indicates how quickly the vehicle can come to a stop when the driver engages the brakes.

The brake rate is typically expressed in units of meters per second squared (m/s^2) or feet per second squared (ft/s^2), representing the rate of change of speed per unit of time. A higher brake rate indicates that the vehicle can decelerate faster, leading to a shorter stopping distance. The brake rate is influenced by several factors on vehicle classification, road condition, driver skill, perception reaction time and speed of the vehicle

Brake rate is an essential factor considered in traffic safety evaluations, road design, and the development of predictive models for crash risk assessment. It is crucial for drivers to be aware of their vehicle's braking performance and maintain their vehicle's brake system to ensure safe driving practices. A high brake rate is desirable for optimal traffic safety, as it allows the vehicle to stop quickly in emergency situations, reducing the risk of collisions and accidents. Automotive manufacturers continuously work to improve the braking performance of vehicles to enhance safety and comply with safety regulations. (https://sumo.dlr.de/docs/Simulation/Safety.html)

2.5 Simulation of Urban Mobility (SUMO) Simulation Package

SUMO simulation software was used in this study due to open-source documentation and from its usability and accessibility, which enable a smooth integration with the study framework.

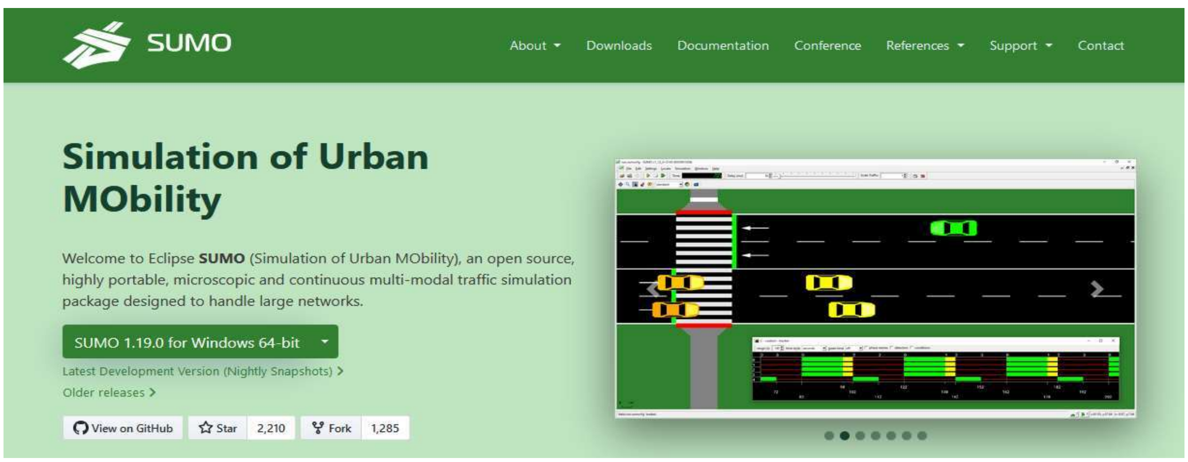


FIGURE 3: SUMO'S GRAPHICAL USER INTERFACE

SUMO is an open source microscopic and continuous traffic simulation tool that was primarily created by employees of the German Aerospace Center's Institute of Transportation Systems. It has been widely used in recent years and is open source and published under the Eclipse Public Licence V2 (López et al., 2018) Since each vehicle and its dynamics are independently depicted, the name "microscopic" is used here. Its benefits in traffic simulation include simple inputs, reasonable outputs, and ease of model modification. Additionally, its easy-to-use visual user interface is beneficial for observing the flow of traffic for vehicles during the simulation.

The inputs of SUMO's are a network file, a route file, and additional optional files. The network file, which can be constructed with the built-in program Netedit or imported directly from a digital road map like Open Street Map (OSM) or another traffic simulator like Vissim, generally comprises the road information involved in the simulation. With so many variables, users can create a simple road to evaluate the models' effectiveness before having them verified in a more complicated road setting. According to (López et al., 2018), Individual trips, flows, or routes can be thought of as components of the route file, often referred to as the traffic demand file. The package includes a number of tools that can be used to generate the route file. With the use of the tool OD2TRIPS, for instance, the conventional origin and destination (O-D) matrix, which comprises the simulation hour, the origin, the destination, and other parameters, can be converted to vehicle trips. Additional settings and other entities can be imported in the optional files. SUMO is often simple to construct or import the relevant road conditions and traffic patterns.

2.6 Car-following and lane-changing models

In this paper, two of the most common and important traffic situations are considered, namely car-following and lane-changing model. The car following situation basically involves two vehicles, the ego vehicle and the preceding vehicle. The longitudinal interaction between them are explored on the other hand using the lane-changing situation of the lateral behaviors.

2.6.1. Car-Following Model

Different microscopic models have been applied to simulate the behavior of individual vehicles. The car-following model, is used to simulate the longitudinal movements of driver-vehicle units (DVUs) in actual traffic (i.e., vehicle speed and acceleration). Figure 4 depicts a typical situation of a car following.

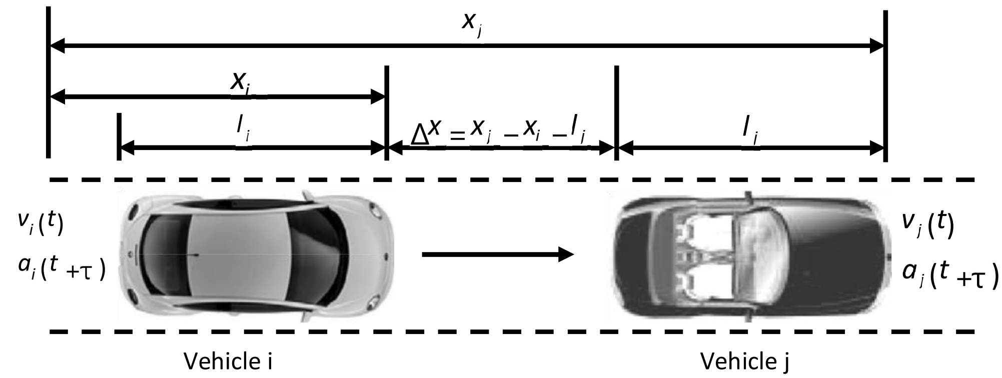


FIGURE 4: CAR-FOLLOWING SCENARIO

As shown in the above figure, a vehicle i is classified as following when it is constrained by a leading vehicle j. The constraint usually requires the following vehicle to adjust its acceleration to maintain a safe following. Different models have been developed to describe such adjustment. (Hourdos et al., 2008)

There are up to fifteen different car-following models that can be used in SUMO alone, each based on a different the argument and using a different set of parameters, such as the Krauss model by default (Krauss, 1998). Additionally, there is the widely used Intelligent Driver Model (IDM) developed by (Treiber et al., 2000) Additionally, there are several more sophisticated car-following models, like the Cooperative Adaptive Cruise Control (CACC) model and the Adaptive Cruise Control (ACC) model (Xiao et al., 2017)

2.6.2 Lane-Changing Model

In addition to the car-following model, an understanding of the lateral movements of vehicles is necessary to allow an accurate representation of traffic movement in simulation. Lateral movements are usually described using lane-changing models. These models control how vehicles merge, wave, and make lane changes in multilane situations. As far as lane-changing is concerned, a vehicle will attempt to change lanes in two typical situations: mandatory lane changes (i.e., when a lane is dropped or blocked) and discretionary lane changes (i.e., when a vehicle is impeded by a slower vehicle). (Duncan, 1998).

Figure 5 illustrates an example of a lane-changing situation in which the subject vehicle is impeded by a slower lead vehicle and desires to move into the fast lane.

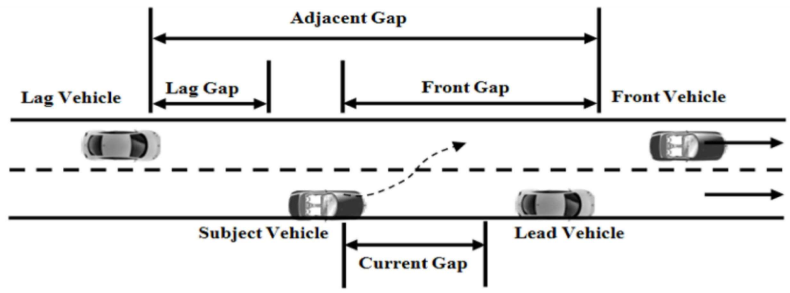


FIGURE 5: LANE-CHANGING SCENARIO

For the gap-acceptance policy, when a subject vehicle desires to change lanes it must find an acceptable gap between the lag vehicle and front vehicle in the target lane. Duncan (1997) indicated that this gap-acceptance policy is linked with the car-following model because the accepted gap is based on target headway. Target headway for a vehicle varies around the specified mean target headway and depends on many other factors such as the aggressiveness of the driver. (Quadstone, 2004).

For the lane-changing simulation, there are three models in SUMO, and the default one is LC2013 is the default lane-changing model in SUMO. It was developed by Erdmann in 2015 based on the DK2008 model developed by Krajzewicz in 2010. According to the motivations for the maneuvers, it divides the lane changes into four categories: strategic, cooperative, tactical, and regulatory. The characteristics utilized in this model to reflect the driver's readiness to change lanes in addition also include to various vehicle and traffic factors, such as vehicle acceleration and lateral space. (Erdmann, J. 2015).

2.7 Driving Data

To produce as realistic a driving condition as possible, real-world traffic data is needed for the calibration of the models under SUMO. The driving data include variables like the spot speed, speed limit, traffic volume, vehicle classification, pedestrian volume, vehicle dimension, minimum vehicle gap when they standing, minimum time headway, vehicle acceleration and deceleration capacity, relative values for vehicle lane change characteristics for each vehicle type, etc.

2.7.1 Traffic Volume studies

Traffic volume Studies are carried out to determine the number, classification, and movements of vehicles on the road at a certain location. These data can be used to determine traffic volume, to identify critical flow time, to assess the impact of large vehicles on the traffic and to determine pedestrian volume walking and crossing the road. The length of counting time period depends on the objective of the study. For instance, evaluation of traffic safety at intersection, count might be carried out during the peak flow time. (Handbook of Simplified Practice for Traffic Studies, 2002)

There are two ways to count the traffic volume: manual and automatic count method.

1. Manual counts are commonly employed to collect data with vehicle classification, turning patterns, travel direction, pedestrian movements, and vehicle occupancy
2. Automatic counts is used to predict annual traffic volumes, daily or seasonal variations and growth trends, or hourly vehicle patterns.

The count period should be used to decide which study method to use. The count period should representative of the time of day, day of the month, and month of the year. In January, for instance, counts would not be taken at a summer resort. Special events and hazardous weather conditions should be avoided throughout the count time (Sharma, 1994). There are several count periods: five minutes to a year. Peak periods are often counted for 15 minutes or 2 hours, morning and afternoon peaks for 4 hours, morning, lunchtime, and afternoon peaks for 6 hours, and daytime periods for 12 hours (Robertson, H. D., & Hummer, J. E, 1994.).

The study methods for short duration counts are used from least expensive (manual) to most expensive (automatic).

2.7.1.1 Manual Count Method

Manual count method used for small samples of data at a given location are needed, used when the effort and cost of automated equipment are not necessary and used in situations of automatic equipment is unavailable.

Usually, manual counts are conducted for a period of shorter than a day. The interval of manual count is occurring every 5, 10 or 15 minutes. Traffic counts are typically performed on Tuesdays, Wednesdays, or Thursdays since they are less likely to reveal unusually large volumes during Monday morning rush hour and Friday evening rush hour. (Handbook of Simplified Practice for Traffic Studies, 2002)

There are three major manual counting method: tally sheets, mechanical counting boards, or electronic counting boards. (Handbook of Simplified Practice for Traffic Studies, 2002)

- Tally Sheets

The easiest way to perform manual counts is to enter data onto tally sheets. The data can be recorded with tick boxes on a field form that has already been constructed. It requires a watch or stopwatch to determine the appropriate count interval.

- Mechanical Counting Boards

Mechanical count boards are made up of mounted counters that count the flow of vehicles in each direction. The counting board consist of push-button devices with three to five registers. A distinct stratum of the vehicle or pedestrian being counted is shown by each button. The number of classifications that can be counted on a particular board may be limited by the counter's limited number of buttons. A watch or stopwatch is required in order to determine the desired count interval.

- Electronic Counting Boards

Electronic counting board are easily hand-held, battery-operated electronic device that are used to gather traffic count data. Electronic counting boards are more manageable than of mechanical counting board and it is lighter, and more compact. They automatically divide the data by time interval no need of external clock or stopwatch. The data can be easily downloaded to the computer and the device also prepare summary and automatic data reduction with special function.

2.7.1.2 AUTOMATIC COUNT METHOD

Automatic count method is allowed to collect a large amount of traffic count data. Typically, automatic counts are carried out 1hr for a total of 24hr hours. The counts could extend for a week, a month, or an entire year.

In automatic count method there are generally three methods: videotape, permanent counters, and portable counters. (Handbook of Simplified Practice for Traffic Studies, 2002)

- **Videotape**

Videotape that can be used to count traffic volumes by recording traffic flow, observers can capture count data. Time intervals can be noted with the help of the digital clock in the video image. In most cases, videotaping is not a cost effective in most cases.

- **Portable counters**

Portable counters provide the same function as manual counts with the exception of automatic counting technology of pneumatic road tubes. Data collecting typically lasts longer than when using manual counts. Portable counter approach usually used for 24-hour counts.

- **Permanent counters**

Permanent counters are employed when conducting long-term counts. The counts could be conducted daily for a year or more. Long-term traffic volume and trend monitoring and evaluation may be possible with the use of the gathered data. In most cases, permanent counters are not a cost-effective option. This equipment is not available in many areas.

2.7.2 Vehicle Classification

Vehicle classification is essential component in evaluating traffic volume (and equivalent axle load). The classification of vehicle types used by ERA for traffic counts includes: cars; pick-ups and 4-wheel drive vehicles, like Land Rovers and Land Cruisers; small, medium, and big buses; trucks; heavy trucks; trucks and trailers. For reporting purposes, this breakdown is further simplified and expressed in the five classes of vehicles (vehicle codes 1 to 5).

TABLE 1: VEHICLE CLASSIFICATION (SOURCE: ERA PAVEMENT DESIGN MANUAL: - CHAPTER 2)

Vehicle code	Types of vehicles	Descriptions
1	Small cars	Passenger cars, minibuses (with up to 24 seats), taxis, pick-ups, Land Cruisers, Land Rovers, and other similar vehicles.
2	Buses	Buses of medium and large sizes with more than 24 seats
3	Medium trucks	Small and medium-sized trucks, including tankers with a load capacity of up to seven tones
4	Heavy trucks	Trucks with loads over 7 tones
5	Articulated trucks	Trucks semi-trailers, trailers, and tanker trailers

TABLE 2: ERA ROAD VEHICLE COUNT FORM

					ERA MOTORIZED and NON-MOTORIZED PEAK HOUR VEHICLE COUNT FORM						DATE	12/10/2023
PROJECT:			Adey Ababa Stadium Intersection								DAY	√
LOCATION											NIGHT	
Time	Bicycle	Motorcycle	Cars	4WD Station-Wagons	Pick-up	Mini Buses(≤ 20 Seats)	M/Bus ≤ 27 Seats	L/Buses	S/Trucks	M/Truck	H/Truck	Truck & Trailer
01:00-01:15												
01:15-01:30												
01:30-01:45												
01:45-02:00												
02:00-02:15												
02:15-02:30												
02:30-02:45												
02:45-03:00												
TOTAL	-	-	-	-	-	-	-	-	-	-	-	-

2.7.3. Spot Speed Measurement

Speed has important element that has an impact on time, safety, comfort, convenience, and economy, it is a crucial factor in transportation. To determine the speed distribution of a traffic stream at specific location, spot speed studies are employed.

Vehicle speed percentiles are produced from the data collected in spot speed studies, and these values are helpful when deciding on various aspects of speed. Numerous safeties use exists for spot speed data, such as the following (Robertson 1994):

- Assessing current traffic operations and traffic control device performance
- Establishing the components of a roadway design elements.
- Assessing roadway safety questions
- Monitoring trends in traffic speed through comprehensive, continuous speed studies
- Assessing the efficiency of traffic control devices or traffic programs, such as traffic sign and markings, modifications to traffic operations, and initiatives to enforce speed limits

Traffic counts are typically done on Tuesdays, Wednesdays, and Thursdays since they are less likely to reveal unusually large volumes during Monday morning or Friday peak hours.

Spot speed data are gathered using one of three methods (Handbook of Simplified Practice for Traffic Studies, 2002): Stopwatch method, Radar meter method, or Pneumatic road tube method

- **STOPWATCH METHOD**

The stopwatch approach is one type of measuring approach and used for a limited sample size collected over a short period of time. The stopwatch method is a rapid and low-cost technique to record speed data.

- **RADAR METER METHOD**

Radar can be fixed on a tripod, held in the hand, or installed in the vehicle. Radar meters have an effective measuring range of 200 feet to 2 miles. A single person may easily operate a radar meter, which measures speed accurately only when it is in line of sight. Two radar units can be required if there is a lot of traffic or if the sampling approach is complex.

Radar readings may be affected by different sized vehicle and the observation vehicle's detection (Currin 2001). Large vehicles, like trucks and buses, send the strongest return signal to the radar meters, making it difficult for smaller vehicles to be detected. If large vehicles are present, the observer may need to record the speeds of the vehicles that are alone. Additionally, some vehicles are equipped with radar detectors to alert them when a radar unit is operating nearby. When a detector alerts a driver, they will typically slow down; this slowing will likely affect the study results. Finally, some vehicles have radar detectors installed to alert the driver when a radar unit is operating nearby.

- **PNEUMATIC ROAD TUBE METHOD**

The pneumatic road tube method is normally used for longer data gathering times than those of the stopwatch or radar meter methods. This technique involves putting pneumatic tubes in the travel lanes and connecting them to recorders on the side of the road.

The automatic recorders are stored large volumes of data on individual vehicles or even more data on vehicle classification. The gathered data are transferred via phone modem to a centrally placed computer or downloaded from the recorder to a laptop or portable floppy disk drive in the field.

2.8 Continuous probability distribution

(Myers, 2012) Continuous probability distribution is a statistical distribution that describe the likelihoods of potential outcomes for a continuous random variable. Continuous probability distributions deal with random variables that can take on any value within a certain range, in contrast to discrete probability distributions, which deal with random variables that take on a finite or countably infinite set of distinct values.

(Myers, 2012) A probability density function (PDF), represented by the notation f(x), characterizes the

characteristics of a continuous probability distribution by indicating the probability that the random variable will fall within a given interval. In a continuous distribution, the probability of the variable taking on any given value is, in theory, zero; instead, probabilities are linked to intervals.
Key characteristics of a continuous probability distribution include:

- Probability Density Function (PDF): The PDF is a function that gives probabilities to intervals; it is represented as f(x). It needs to meet these two requirements:
  - for any x, $f(x) \geq 0$
  - The total area under the curve equals 1. Over the whole range of the PDF.
- Probability of an Interval: The area under the PDF curve for a certain interval [a,b] indicates the probability that the random variable will fall within that interval. It can be expressed mathematically as follows: $P(a \leq X \leq b) = \int_a^b f(x)dx$
- The cumulative distribution function, denoted as F(x), is used to calculate the probability that a given random variable would be less than or equal to a certain value of x. It is the PDF integral up to x:
  $F(x) = \int_{-\infty}^{x} f(x)dx$
- The random variable in a continuous probability distribution has an infinite number of possible values that fall inside a specified range.

Different probability density functions represent to different distribution types.

2.8.1 Continuous uniform distribution

(Myers, 2012) The probability is uniform within a closed interval [A, B] let's. Since his distribution has a "flat" density function.

The density function of the continuous uniform random variable X on the interval [A, B] is

$$f(x; A, B) = \begin{cases} \frac{1}{B-A}, & A \leq x \leq B, \\ 0, & \text{elsewhere.} \end{cases}$$

Density function form a rectangle with base B−A and constant height (1/(B−A)). The uniform distribution is hence sometimes referred to as the rectangle distribution.

The mean and variance of the uniform distribution are:

$$\mu = \frac{A+B}{2} \text{ and } \sigma^2 = \frac{(B-A)^2}{12}.$$

2.8.2 Normal distribution

Its graph, known as the normal curve, is a bell-shaped curve that approximately characterizes a variety of events seen in science, industry, and research. The normal distribution is also called the Gaussian distribution. (Myers, 2012)

The mathematical equation for the probability distribution depends on the two parameters σ and μ, standard deviation and mean, respectively.

The probability or density of the normal random variable X is with mean μ and standard deviation σ

$$n(x;\mu,\sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2\sigma^2}(x-\mu)^2}, \quad -\infty < x < \infty$$

The curve is symmetric about a vertical axis passing through the mean μ

2.8.3 Gamma and Exponential distribution

The density function of the continuous random variable X has a gamma distribution with parameters α and β. (Myers, 2012)

$$f(x;\alpha,\beta) = \begin{cases} \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta}, & x > 0, \\ 0, & \text{elsewhere} \end{cases}$$

Where gamma function is defined by

$$\Gamma(\alpha) = \int_0^\infty x^{\alpha-1} e^{-x}\, dx, \qquad \text{for } \alpha > 0.$$

and β > 0.

The exponential distribution is the special gamma distribution for which α = 1.

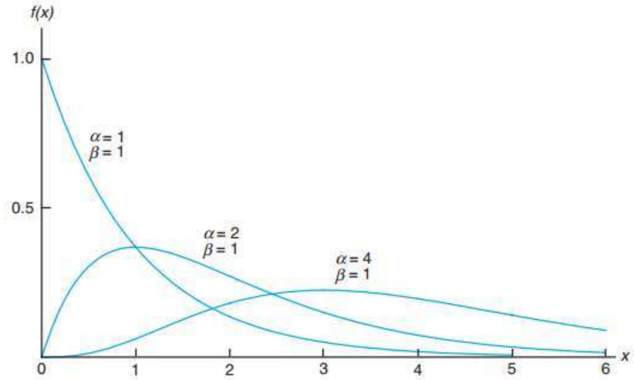


Figure 6: Gamma Distribution

The mean and variance of the gamma distribution are $\mu = \alpha\beta$ and $\sigma^2 = \alpha\beta^2$

2.8.3 Weibull distribution

The continuous random variable X is represented by Weibull distribution with parameters α and β then the density function is given by: (Myers, 2012)

$$f(x;\alpha,\beta) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} e^{-(x/\beta)^{\alpha}}$$

Where $x>0$, $\alpha > 0$ and $\beta > 0$

The Weibull distribution reduces to the exponential distribution if we let $\beta = 1$. If $\beta > 1$, the curves become somewhat to a bell-shaped and resemble to the normal curve but have some skewness. (Myers, 2012)

The mean and standard deviation of the Weibull distribution are:

$$\mu = \beta\Gamma\left(1+\frac{1}{\alpha}\right)$$

$$\sigma = \beta\sqrt{\Gamma\left(1+\frac{2}{\alpha}\right) - \left[\Gamma\left(1+\frac{1}{\alpha}\right)\right]^2}$$

. Where Γ represent the gamma function.

The cumulative distribution function for the Weibull distribution is provided by

$$F(x;\alpha,\beta) = 1 - e^{-(x/\beta)^{\alpha}}$$

where $x>0$, $\alpha > 0$ and $\beta > 0$

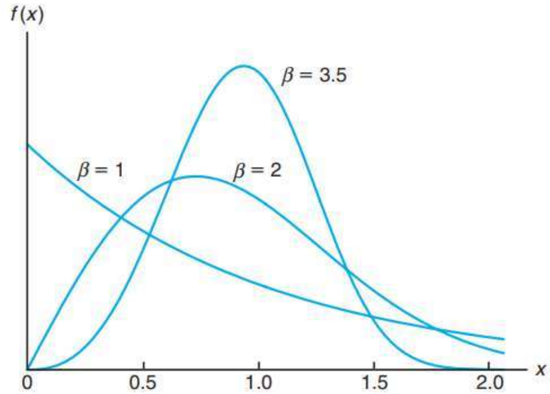


Figure 7: Weibull distribution for α=1

2.9. Development of a Traffic Safety Prediction Model using Surrogate safety Measures

Developing a traffic safety prediction model using Surrogate Safety Measures (SSMs) from the simulation model without historical crash data involves a method that relies solely on surrogate indicators to predict potential safety outcomes. Without historical accident data, developing a traffic safety prediction model from the simulation model to forecast probable safety outcomes. The model incorporates two variables that are independent variables and dependent variables.

Independent variables are parameters that are the factor contributing to conflicts and obtained from data collection of the necessary road geometry, traffic control data, traffic flow data, and other variables for the traffic simulation analysis. It is used to simulate various traffic scenarios within the study region, set up and run the simulation model.

Dependent variables are parameters that are influenced by independent variables and obtained from simulation outputs. Surrogate Safety Measures (SSMs) are outputs of the traffic safety simulation, and then identify and pick appropriate surrogate safety measures (SSMs). The following SSMs are frequently used in traffic simulation analyses: time-to-collision (TTC), post-encroachment time (PET), deceleration rate to avoid crash (DRAC), and others. This step generates a dataset of SSM values for different locations within the study area at peak hour periods.

Using statistical approaches used to develop a probability model for the occurrence of potential conflict risk based on the surrogate safety measure dataset obtained from the traffic safety simulation and the independent variables that contribute to potential conflict risk. From the review the independent variables that are causing conflicts, such as the type of vehicle, length of the vehicle, composition of the vehicle, number of vehicles, maximum speed, speed limit, acceleration, deceleration, distance headway, time headway, initial position, turning position, and starting position is used under the simulation. The goal of the model is to predict the likelihood of potential safety events or crash risks under various conditions.

2.10 Review of Related Research

(Astarita et al., 2019) Conducted different traffic micro-simulation models for evaluating intersection safety is examined in this review, with particular focused on how well these models work while evaluating three urban scenarios: roundabouts, traffic light-regulated intersections, and unregulated intersections. The study intends to assess how well simulation findings may be used to analyze surrogate safety measures for road safety research. It does this by utilizing three microscopic traffic simulation models in combination with the FHWA tool SSAM. The results showed that similar outcomes are generated by several simulation models, categorizing circumstances as "potentially" risky. Specifically, the study emphasizes how efficient the SSAM methodology is at minimizing conflict locations and finding the best solutions in intersection planning, emphasizing the importance of proper modeling and calibration in order to arrive at a general optimal solution. Insightful information for well-informed planning and design decisions at intersections.

(Mohanty et al., 2021) The focus of the study, which was conducted out in India, is to quantify Post Encroachment Time (PET) in order to determine its predictive value for determining the severity of crashes at median openings. The study computes PET by using different traffic volume levels at median opening areas, offering a critical safe ratio for improved traffic safety assessments. Important variables like the speed to PET ratio and the minimum stopping sight distance (SSD) are used to calculate this ratio.

(Xiao, 2020) The study conducted microscopic heterogeneous traffic simulation using SUMO, with a particular emphasis on the impact of self-driving vehicles on traffic efficiency and safety. To evaluate the overall safety and effectiveness of traffic, the assessment uses a variety of surrogate safety measures, including the time to collision and the number of lane changes. Additionally, the results showed that between traffic safety and efficiency increases when the rate at which self-driving vehicles are increased.

(Papadoulis et al., 2019) Based on the simulated CAV data, a hierarchical spatial Bayesian negative binomial regression model is developed in order to forecast the conflict reduction for any given market penetration rate and gain a thorough understanding of the underlying factors behind traffic conflicts in a traffic microsimulation environment. The findings show that speed variance between lanes has a considerable impact on the generation of simulated conflicts in addition to CAV market penetration rate. The safety benefit diminishes as speed variation rises. These findings highlight the significance of speed homogeneity between lanes in a motorway and the elevated risk in the locations where motorways merge and diverge.

(Ariza, 2011) Before conflicts can be used to forecast crash frequencies for arterials, clearly more study has to be done. It can be seen that arterial conflicts are not as strong as those at intersections because the conflict-based crash prediction models for intersections do better. Enhancing agent vehicle motions when cruising is the next stage for simulation-based crash-prediction models to enhance the formation of arterial conflicts. Public transportation might potentially be included in the simulation to see if it can also forecast crashes in the event of simulated collisions involving transit vehicles. Conflict-based models offer a substitute for volume-based models and give an instrument for assessing projects that are being proposed. Road safety will become a larger priority as traffic volume grows and the ratio of fatalities from collisions increases.

(Gettman et al., 2008) Although, in direct comparison, volume-based prediction models provided better correlation to field data (crash records) than simulated conflicts, the SSAM approach demonstrated significant correlations with actual crash data, consistent with the range of correlations reported in several studies with traditional (primarily volume-based) crash prediction models.
Even though variations sometimes involved sacrificing one safety feature for the improvement of another, SSAM also showed the ability to discern safety differences between various intersection design elements under the same traffic loads.
Furthermore, traffic control policies that have not yet been implemented in the field and traffic facilities that have not yet been built can both be analyzed using SSAM. As a result, the SSM technique shows potential, but the validation results are not conclusive.

CHAPTER 3- MATERIAL AND METHODOLOGY OF THE STUDY

3.1 Introduction

The major aim of this research is to evaluate the safety of selected locations and develop a probabilistic model that predict the risk of potential conflict from surrogate safety measures, TTC along road approaches of signalized intersection at bole sub city in Addis Ababa.

Hence, the study was primarily executed for modeling the cumulative effect of geometric and traffic characteristics data on the occurrences of traffic collision. Moreover, the research was executed by employing eight signalized intersections of the bole sub city, Addis Ababa.

The entire methodology was adopted for accomplishing the objective of the study that is includes selection of the study area, primary and secondary data collection, calibrations of car following and lane changing model in simulation of urban mobility using real site data, traffic safety simulation using SUMO package, traffic safety evaluation and development of probabilistic model for the occurrence of potential conflicts using excel statistical analysis method , and finally evaluating the model for its goodness of fit.

3.2 Research Flow Diagram

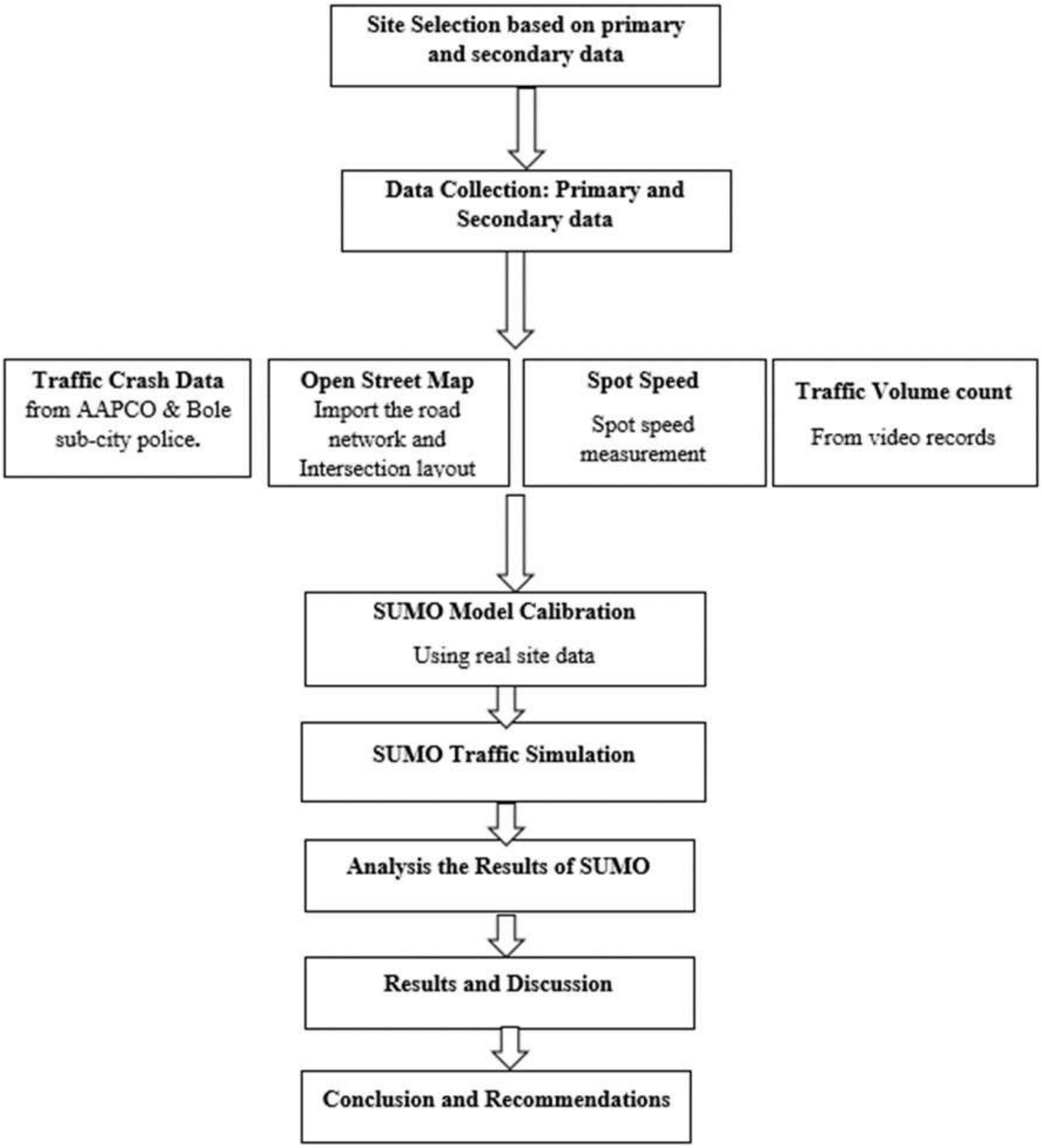


FIGURE 8 : METHODOLOGY OF THE RESEARCH

3.2 Study Area

3.2.1. Sampling Method and Procedure

The selection technique applied to this study was nonprobability sampling (also known as non-random sampling) for the purpose of most relevant to the research objectives. From different non-probability sampling approach, purposeful sampling approach was chosen in order to meet the objective of the research.

3.2.2. Study Area Selection Criteria

3.2.2.1. Selection Criteria of Sub-city of Addis, Ababa

The study area scope is limited to sub-city level due to the fact that the availability of detail traffic crash data records of Addis Ababa city categorized on the sub-city level. The selection criteria of sub-city of Addis Ababa as follows:

- Frequency and severity of crash along the sub-cities of Addis & Availability of recorded crash data for the sake of selection of specific study area within the sub-city.
- Incorporate a variety of geometric elements such as number of lanes from one to four lane per direction, and a variety of traffic volume within the sub-city that helps to derive good predictive probabilistic model for the occurrence of the potential risk using TTC.

AAPCO traffic accident report from July 2019 to June 2022 below on table 3 showed that, from eleven sub-cities of Addis Ababa, Bole sub-city is the leading sub-city that encounters with high traffic accident in the city of Addis and in addition the sub-city incorporates a wide range of roads in terms of road geometric feature and traffic characteristics data. Therefore, based on the above reason this study conducted on Bole-sub city, Addis Ababa.

TABLE 3: AAPCO THREE YEAR FATAL, SEVERE, AND SLIGHT AND PROPERTY DAMAGE CRASH DATA REPORT ALONG THE SUB-CITY OF ADDIS ABABA.

Sub-city	Crash Data from July 2019 - June 2022				Severity Index	Rank
	Fatal Injuries	Severe Injuries	Slight Injuries	Property Damage		
Bole	**225**	**1,023**	**295**	**18,380**	**4489**	**1**
Kirkos	97	486	286	11946	2229	6
Lemi Kura	39	192	67	2857	838	11
Yeka	128	439	152	9601	2109	7
Gulele	65	190	187	3549	1082	10
Arada	69	622	185	7113	2396	5
Addis Ketema	108	443	140	3466	2009	8
Lideta	68	345	302	5214	1677	9
kolfe Keranio	131	538	342	5666	2611	4
Nifas Silk Lafto	165	777	926	11405	4082	2
Akaki Kality	169	558	292	5102	2811	3
Total	1,264	5,613	3,174	84,299	**26,333**	

3.2.2.2. Selection Criteria of Intersection Approach

Roads at the intersection's approaches were selected than mid-block road segment on the basis of four main criteria:

- ✓ Intersections involve with a history of high crash frequency or a high concentration of accidents than of Mid-block road segments.
- ✓ Intersections often involve multiple conflicting movements, such as left-turns, right-turns, and through movements, increasing the potential for conflict.
- ✓ Intersections often accommodate different types of road users, including pedestrians and cyclists.
- ✓ Intersections with high traffic volumes typically have a higher potential for conflicts. Studying busy intersections can provide valuable insights for traffic safety.

3.2.2.3. Selection Criteria for types of Intersection within Bole Sub-city

Signalized intersections Approaches of Bole sub-cities were selected on the basis of three main criteria. Those are: -

- ✓ The majority of intersections in the bole sub-city are regulated by traffic signals in compared to uncontrolled or stop sign-controlled intersections.

- ✓ Signalized intersections dominate over other types of intersections in terms of their occurrence of high crash frequency in the Bole sub-city.
- ✓ Due to time and financial constraints, it only focuses on one type's intersections type due to the characteristics of intersections varies based on intersection type.

3.2.2.4. Selection Criteria of specific study locations within signalized intersections of bole sub-city

The selection criteria for the specific site includes:

- ✓ Based on traffic crash severity index of the study area. As the predictive model must draw from a variety of cases and data, the study area should include relatively high, medium, and low severity indexes.
- ✓ The chosen sites require a range of geometric characteristics, like varying lane numbers and a gradient difference.
- ✓ The chosen site should integrate a diverse range of traffic characteristics, including varying traffic volumes and spot speeds.
- ✓ Accessibility for measuring spot speed and traffic volume.

3.2.3. Sample Size

According to the publication of (RIPCORD, 2005), it is highly recommended to select a minimum of three to five types of road segment or intersections for preparing relevant safety prediction model.

On the Bole sub-city mainly fifteen signalized intersections are found

- ✓ 24 Intersection
- ✓ All mart Intersection
- ✓ Gerji mebrat Intersection
- ✓ Jacross Intersection
- ✓ Denbez Intersection
- ✓ Kokeb Intersection
- ✓ Bole-snap plaza Intersection
- ✓ Bole Brass Intersection
- ✓ Bole sunshine intersection

- ✓ Bole Japan Intersection
- ✓ Atlas Intersection
- ✓ Bestga Intersection
- ✓ 17 health center Intersection
- ✓ Adey abeba stadium Intersection
- ✓ Salitmhiret signalized Intersection

The study was chosen eight signalized intersection at Bole sub-city from fifteen signalized intersection found on Bole-sub-city based on the above-mentioned criteria and by considering the discussion with Bole sub-city police department on which the sub-city police department identified high potential risk of collision location for different intersection type and road segment based on frequency of crash rate.

The selected intersections of the study were:

1. Adey Ababa stadium Intersection.
2. Atlas Intersection
3. Gerji Meberat-hayel Intersection
4. Jacross Intersection
5. Bole-Japan Intersection
6. Kokeb Building Intersection
7. Bole-snap plaza Intersection
8. Salitemhiret signal Intersection

3.2.4. Selected Intersections Descriptions

1. Adey Ababa stadium Intersection.

The Adey Ababa Stadium signalized intersections in the Bole sub-city, connecting the routes from the Atlas, Ednamol, and Emperial sides, as well as the 22 Golagol side. The approach road lanes vary from two to three in each direction; the road's grade varies from -5% to 2.26%; the lane width varies from 3.0 to 3.37m, during peak hours spot speeds range from 17.14 km/h to 30.33 km/h; and peak-hour flows range from 407 km/h to 1298 km/h along the intersection's approaches.

FIGURE 9: TOPOGRAPHIC & THREE-DIMENSIONAL VIEW OF ADEY ABABA INTERSECTION

2. Atlas Intersection.

Atlas signalized intersections found on Bole sub-city with four leg intersection that connects the roads from St. Urael, Bole-Rwanda, Ednamol and 22 Zerihun side. For each leg, there are three lanes in each direction of the approach, the grade varies between -7.19% and 2.77%, the lane width is between 3.2 and 3.5m, the spot speed during peak hours is between 19.36 and 41.9 km/h, and the traffic volume is between 955 and 1258 vehicles per hour during peak hours along the road approach of the intersection.

FIGURE 10: TOPOGRAPHIC & THREE-DIMENSIONAL VIEW OF ATLAS INTERSECTION

3. Gergi Meberat-Hayel Intersection.

Gerji Meberat Hayel intersections found on Bole sub-city with three leg intersection that connects the roads from All Mart/Anbessa Garaj, Jacross and Gerji side. The approach road lane is range from two to four per direction, the grade varies from -3.92% to 3.38%; the spot speed variation is between 19.32 and 34.97 km/h; and the peak hour volume variation is between 448 and 2096 km/h along the road approach of the intersection.

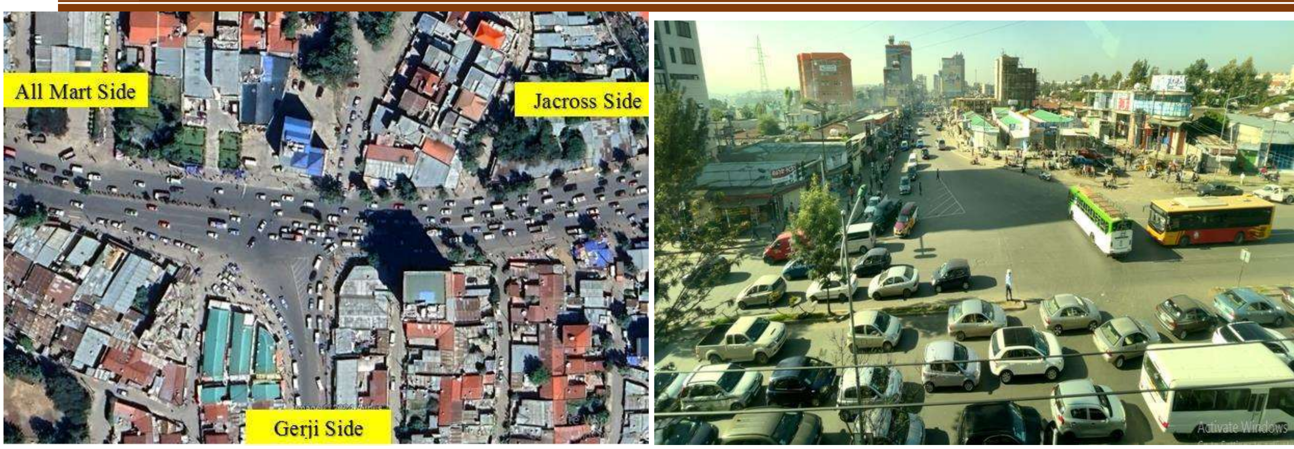


FIGURE 11: TOPOGRAPHIC & THREE-DIMENSIONAL VIEW OF GERJI MEBERAT HAYEL INTERSECTION

4. Jacross Intersection.

Jacross intersections found on Bole sub-city with three leg intersection that connects the roads from Goro, Gerji meberat hayel and Salithmhiret side. The approach road lane is three per direction for all leg, the grade varies from -5.84% to 2.84%, the lane width varies from 3m to 3.25m, the spot speed during peak hour is between 28.34Km/h and 33.59Km/h, and the peak hour volume is between 458veh/h and 2058veh/h along the road approach of the intersection.

FIGURE 12: TOPOGRAPHIC & THREE-DIMENSIONAL VIEW OF JACROSS INTERSECTION

5. Bole-Japan Intersection

Bole Japan Intersection found on Bole sub-city with four leg intersection that connects the roads from Bole-Rwanda, Bole Millennium Hall, Atlas and Bole Cargo side. The approach road lane is ranges from one to four per direction, the grade varies from -4.33% to 4.77%; the lane width varies from 3.39 to 3.9 m, during peak hours, the spot speed varies from 22.14 to 44.38 km/h; and the peak hour traffic varies from 289 to 2814 vehicles along the road approach of the intersection.

FIGURE 13: TOPOGRAPHIC & THREE-DIMENSIONAL VIEW OF BOLE JAPAN INTERSECTION

6. Kokeb Building Intersection

Kokeb building Intersection found on Bole sub-city with four leg intersection that connects the roads from Lem-Hotel, 24 Taxi-Tera, Megenagna and Anbessa Garaj side. The approach road lane is ranges from two to three in number per direction, approach grades varies in between -2.15% and 2.14%, lane widths varies between 3.25 and 3.4 m, peak hour spot speeds is between 21.34 and 45.25 km/h, and peak hour flow is between 326 and 1460 veh/h along the intersection's approaches.

FIGURE 14: TOPOGRAPHIC & THREE-DIMENSIONAL VIEW OF KOKEB BUILDING INTERSECTION

7. Bole-Snap Plaza Intersection

Bole-Snap Plaza Intersection found on Bole sub-city with three leg intersection that connects the roads from Bole Japan Side, Sunshine building side and Bole-Dildiy side. The approach road lanes are ranges from two to four in number per direction, the grades ranges from -3.24% to 1.39%, spot speed during peak hour ranges from 23.2Km/hr to 45.85Km/hr and the peak hour volume ranges from 311veh/h to 2379veh/h along the approach roads of the intersection.

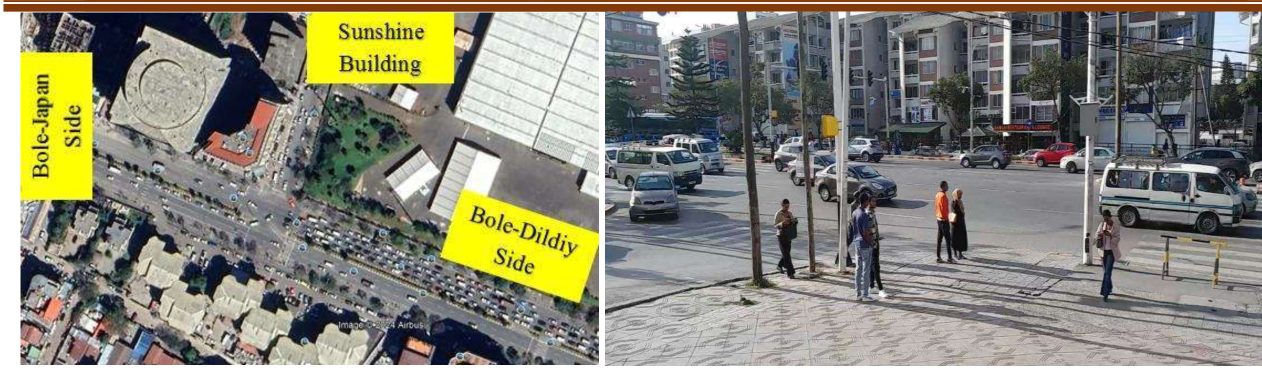


FIGURE 15: TOPOGRAPHIC & THREE-DIMENSIONAL VIEW OF BOLE-SNAP PLAZA INTERSECTION

8. Salitmehiret signal Intersection

Salitmehiret Intersection found on Bole sub-city with four leg intersection that connects the roads from Jacross, Figa, Salitmehiret and latica Bakery side. The approach road lane is ranges from two to three in number per direction, the grades ranges from -6.02% to 2.3%, spot speed during peak hour ranges from 23.12Km/hr to 42.54Km/hr and the peak hour volume ranges from 148veh/h to 1552veh/h along the approach roads of the intersection.

FIGURE 16: TOPOGRAPHIC & THREE-DIMENSIONAL VIEW OF SALITMHIRET INTERSECTION

3.3 Data Source and Data Collection

This study were used primary and secondary data sources. The actual traffic flow characteristics data, road geometric parameter, and traffic characteristics data were collected using primary data sources using field survey, while secondary data were obtained from the Addis Ababa police commission, which summarized traffic accident data for all Addis sub-cities and the Bole sub-city police department, which provided three years of traffic accident data from January 2020 to January 2023.

Since the quality of the data affects the accuracy of the safety prediction model, care was taken when gathering the necessary data. According to (Tulu et al., 2015) the construction of the safety prediction model is significantly influenced by the quality of the data that was gathered for a specific study.

3.3.1. Crash Data

The necessity of the crash data is used to select the study area. Data were acquired from the AAPOC and the bole sub-city police department. The most recent 3 to 5 years of Crash data are typically used and are generally sufficient. The period of time required to find high potential conflict area according Cheng and Washington's study in 2005 demonstrated that a duration of three years is typically used.

Keeping in mind the aforementioned justifications, a three-year period of accident data (January 2020–January 2023) from Bole sub-city police department stations were obtained for this study. They provided information regarding fatal, severe injury, minor injury, and property damage (PD) related to crashes. On the other hand, from AAPOC has collected summarized accident data from July, 2019 to June 2022 for all sub-cities in Addis Ababa.

According to the Bole police department data, a total of 2303 Traffic accidents were reported at all of the intersections of the chosen road networks throughout a three-year period. There were 6 accidents that resulted in death, while 66, 19, and 2,212 correspondingly resulted in serious injury, slight injury, and property damage respectively.

TABLE 4: TRAFFIC CRASH DATA OF SELECTED SIGNALIZED INTERSECTIONS FROM JANUARY 2020 TO JANUARY 2023(FROM BOLE SUB-CITY POLICE DEPARTMENT)

No	List of Locations	Fatal	severe Injury	slightly Injury	property Damage	Severity Index
1	Adey Ababa stadium Intersection.	0	17	3	338	54
2	Atlas Intersection	1	15	4	397	54
3	Gerji Meberat-hayel Intersection	0	12	7	497	43
4	Jacross Intersection	4	10	3	513	53
5	Bole-Japan Intersection	0	4	1	187	13
6	Kokeb Building Intersection	1	3	0	74	14
7	Bole-snap plaza Intersection	0	1	0	168	3
8	Salithmhiret signal Intersection	0	4	1	38	13
Total		6	66	19	2,212	**247**

N.B The report's findings regarding the fatality rate indicated that there was under reporting since the fatal crash report prepared by AAPCO, rather than the respective sub-city police department.

3.3.2. Driving Data

3.3.2.1. Traffic Volume studies

Traffic volume is one of the most important factors in collision data analysis. This is because there are no conflicts when there is no traffic, whereas there are more conflicts when there are more vehicles on the road. According to studies (Vogt, 1999; Greibe, 2003; Pei et al., 2011; Chiou et al., 2014; Meng and Qu, 2012b), AADT of the road networks significantly affects crash frequency. The most frequently employed and significant parameter that has to be included in any traffic safety prediction model according to numerous researchers, is traffic volume (Kalokota and Seneviratne, 1994; Golob and Recker 2004; Mustakim et al., 2005; Hauer& Jamei,1992; Hong et al., 2005).

As a result, this research included the traffic volume parameter among with the typical explanatory variables that were supposed to explain the occurrences of frequent number of conflicts along the selected intersections.

Traffic count is done using the video survey method. At a total of 8 intersection, two hours traffic counts were conducted in each approaches of the intersection on the day of representative weekdays, from Tuesday to Thursday:

1. Adey Ababa intersection traffic count were collected on Thursday October 12, 2023 from 7:00AM – 9:00AM.
2. Atlas intersection traffic count were collected on Tuesday October 17, 2023 from 7:00AM – 9:00AM.
3. Gerji Meberat Hayel intersection traffic count were collected on Tuesday October 03, 2023 from 7:00AM – 9:00AM.
4. Jacross Intersection traffic count were collected on Tuesday October 10, 2023 from 7:00AM – 9:00AM.
5. Bole Japan Intersection traffic count were collected on Wednesday October 18, 2023 from 7:00AM – 9:00AM.

6. Kokeb building intersection traffic count were collected on Thursday October 12, 2023 from 7:00AM – 9:00AM.
7. Bole Snap plaza intersection traffic count were collected on Thursday October 19, 2023 from 7:00AM – 9:00AM.
8. Salithmihret intersection traffic count were collected on Wednesday October 11, 2023 from 7:00AM – 9:00AM.

The following table 5 showed a converted peak hour volume from 2 hour traffic count for Adey Ababa Stadium.

TABLE 5: SAMPLE OF PEAK HOUR VOLUME FOR ADEY ABABA STADIUM

ERA MOTORIZED and NON-MOTORIZED PEAK HOUR VEHICLE COUNT FORM — DATE 12/10/2023

PROJECT: Adey Ababa Stadium Intersection — DAY √

LOCATION — NIGHT

Roads	Bicycle	Motorcycle	Cars	4WD Station-Wagons	Mini Buses(≤ 20 Seats)	M/Bus ≤ 27 Seats	L/Buses	Pickups	S/Trucks	M/Truck	H/Truck	Truck & Trailer
Emperial – Addis Hiwot Hospital	4	8	516	68	36	0	0	56	0	0	0	0
Emperial – 22 Golagol	4	8	204	8	24	0	0	12	0	4	0	0
Emperial – Ednamall	8	8	268	12	28	4	0	16	0	0	4	0
Emperial – Emperial	0	0	0	0	4	0	0	4	0	0	0	0
Addis Hiwot Hospital – Emperial	8	8	212	52	12	0	0	24	0	4	0	0
Addis Hiwot Hospital -Ednamall	0	8	32	4	0	0	0	0	0	0	0	0
Addis Hiwot- 22 Golagol	0	0	32	12	0	0	0	8	0	0	0	0
Ednamall – 22 Golagol	4	0	120	0	108	0	0	12	0	0	0	0
Ednamall-Addis Hiowt	0	0	4	0	0	0	0	0	0	0	0	0
Ednamall-Emperial	0	0	252	12	36	0	0	20	8	4	4	0
22 golagol – Ednamall	16	4	212	20	68	0	0	40	0	0	0	0
22 golagol – Addis Hiwot	4	0	68	0	4	0	0	4	4	4	0	0
22 golagol-Emperial	0	0	44	0	4	0	0	4	0	0	0	0
TOTAL	48	44	1,964	188	324	4	-	200	12	16	8	-

TABLE 6: SUMMARY OF TRAFFIC COUNT FOR ALL INTERSECTION

ERA MOTORIZED and NON-MOTORIZED PEAK HOUR VEHICLE COUNT FORM												
Intersections	Bicycle	Motorcycle	Cars	4WD Station-Wagons	Mini Buses(≤ 20 Seats)	M/Bus ≤ 27 Seats	L/Buses	Pickups	S/Trucks	M/Truck	H/Truck	Truck & Trailer
Adey Ababa Intersection	48	44	1964	188	324	4	0	200	12	16	8	0
Atlas Intersection	36	92	3240	424	384	32	0	320	36	12	0	0
Gerji Meberat Hayel Intersection	8	0	2448	148	400	60	108	372	16	20	8	0
Jacross Intersection	28	64	2236	212	376	48	116	396	28	12	24	4
Bole Japan Intersection	16	48	3820	548	704	44	60	388	24	4	4	0
Kokeb Building Intersection	20	88	2032	196	352	12	8	436	16	16	0	0
Bole Snap Plaza Intersection	8	40	3108	388	748	4	48	364	28	12	0	4
Salitmhiret Signal Intersection	24	20	1780	108	324	28	20	252	24	12	0	0
TOTAL	188	396	20,628	2,212	3,612	232	360	2,728	184	104	44	8

3.3.2.2. Spot Speed Measurement

Spot speed and related studies are used to determine a traffic stream's lateral and longitudinal speed, maximum speed, speed limit, acceleration and deceleration of a vehicle. Vehicle speed percentiles are important for numerous decisions involving speed. The parameter that is most frequently and widely used to construct the appropriate safety prediction model is the 85th percentile speed due to assumption of 85% of vehicles are traveling at a pace they consider safe. In addition, the studies of the following researchers— (Kalokota and Seneviratne, 1994; Golob and Recker 2004; Mustakim et al., 2005; Hauer& Jamei,1992; Hong et al., 2005). —found that spot speed is important explanatory variables for safety prediction model.

Spot speed measurement is carried out using stopwatch method by taking 20vehicles for each direction and approach. By taking constant distance 54m and then record the time that takes the vehicle entering and leaving the section using stopwatch. The analysis was used 85th percentile speed.

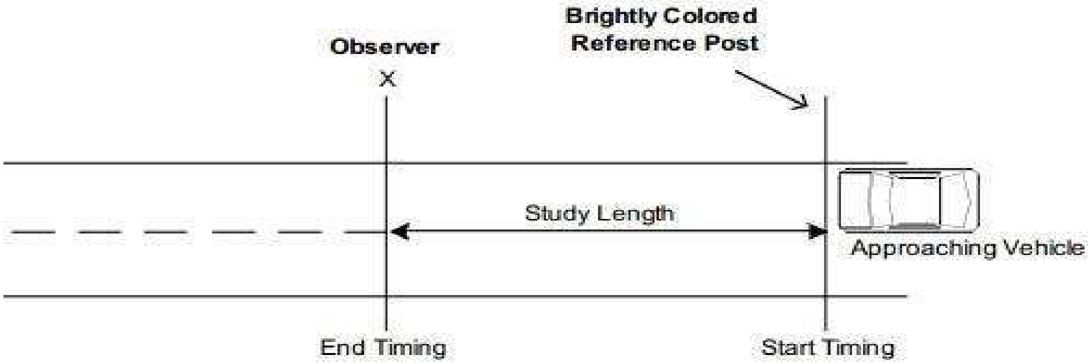


FIGURE 17: STOPWATCH SPOT SPEED STUDY LAYOUT.

(Source: Handbook of simplified practice for traffic studies, (2002).

TABLE 7: SAMPLES OF SPOT SPEED MEASUREMENT AT ATLAS INTERSECTION FOR THE APPROACH ROAD FROM JUNCTION TO ST. URAEL ROAD

SR.No	Time(s)	Length(m)	Speed(m/s)	Speed(Km/h)	Frequency Distribution	Cumulative Frequency
1	7.08	54	7.63	27.46	5.00%	5.00%
2	6.58	54	8.21	29.54	5.00%	10.00%
3	6.4	54	8.44	30.38	5.00%	15.00%
4	6.24	54	8.65	31.15	5.00%	20.00%
5	6.06	54	8.91	32.08	5.00%	25.00%
6	6.03	54	8.96	32.24	5.00%	30.00%
7	6.02	54	8.97	32.29	5.00%	35.00%
8	5.77	54	9.36	33.69	5.00%	40.00%
9	5.66	54	9.54	34.35	5.00%	45.00%
10	5.44	54	9.93	35.74	5.00%	50.00%
11	5.37	54	10.06	36.20	5.00%	55.00%
12	5.32	54	10.15	36.54	5.00%	60.00%
13	5.23	54	10.33	37.17	5.00%	65.00%
14	5.15	54	10.49	37.75	5.00%	70.00%
15	5.14	54	10.51	37.82	5.00%	75.00%
16	4.96	54	10.89	39.19	5.00%	80.00%
17	4.86	54	**11.11**	**40.00**	5.00%	**85.00%**
18	4.43	54	12.19	43.88	5.00%	90.00%
19	4.37	54	12.36	44.49	5.00%	95.00%
20	4.29	54	12.59	45.31	5.00%	100.00%

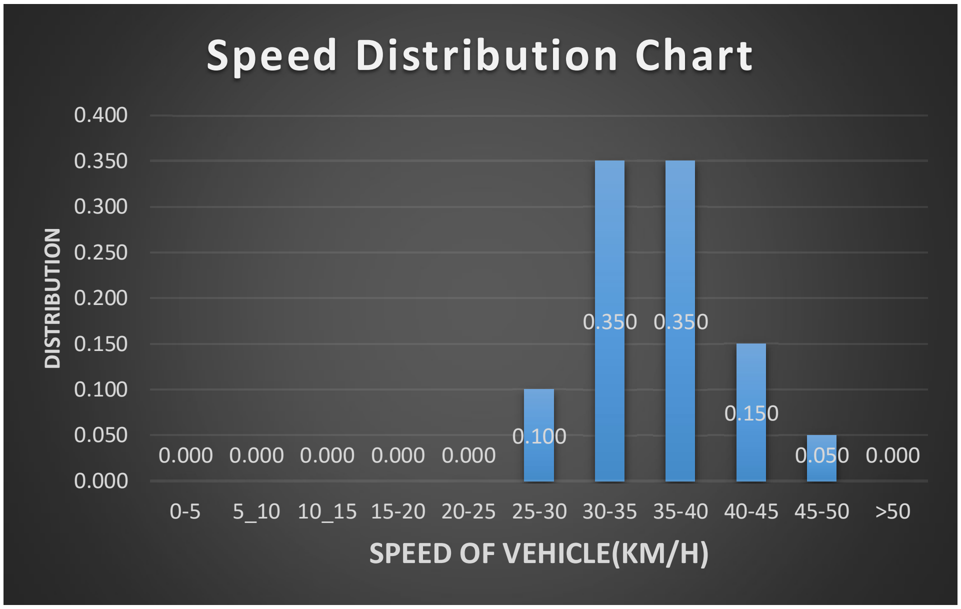


FIGURE 18: SAMPLE OF SPOT SPEED DISTRIBUTION CHART FOR THE APPROACH ROAD OF ATLAS JUNCTION TO ST.URAEL

3.3.2.3. Traffic signal time measurement

We have chosen to use the stopwatch method in collecting data for traffic signal time for each phases of signalized intersections of the study area.

3.3.2.4. Additional parameters

Additional parameters are needed for the input of traffic simulation beyond traffic volume and spot speeds parameters values. Measurement were carried out using observations, field measuring, vehicle's specification and video record analysis for car following and lane changing parameter for each vehicle type of each study area.

For instance, the following are the car following and lane changing parameter and values for vehicle type car for the salithmhiret signalized intersection:

- vType id means the identification of the type of vehicle to be used for this vehicle. (vType id="car")
- length means the vehicle's length in m (length="4.80")
- minGap means minimum Gap when standing after leader vehicle(m) (minGap="1.83")
- maxSpeed means the vehicle's (technical) maximum velocity (in m/s) (maxSpeed="33.33")

- speedFactor means the ratio of the vehicles actual speed with speed limit per lane. (speedFactor="0.563”).
- actionStepLength means the duration of time that the vehicle uses its decision-making logic either for lane-changing or acceleration. (actionStepLength="1")
- vClass means the vehicle class that recognized by Sumo for the purpose of using default values if three is gap in the definitions of parameter and for the purpose of determining access restrictions for lanes and edges. vClass=("passenger").
- Impatience means willingness of vehicles to obstruct high priority vehicles. When the value is one or more, the driver will use it to prevent a collision, even if it means forcing another car to brake as hard as it can. When the setting is 0, the driver will only make decisions that won't cause other vehicles to slow down. Between these extremes, intermediate values interpolate smoothly. (impatience="0.25")
- guiShape means a vehicle shape for drawing. (guiShape="passenger")
- width means the vehicle's width in m. (width="1.88")
- height means the vehicle's height in m(height="1.60")
- color means the vehicle type's color(color="red")
- lcStrategic means the eagerness for performing strategic lane changing. Higher values result in earlier lane-changing. The value ranges from 0 to positive infinity. Small vehicle are higher lcStrategic value compared to heavy vehicles due to the eagerness of lane changing before the end of their lanes. (lcStrategic="2.0")
- lcCooperative means the willingness for performing cooperative lane changing for the use of another vehicle. The values range from 0 to 1. Lower values result in reduced cooperation. Small vehicle are higher lcCooperative value than heavy vehicles. (lcCooperative="1.0").
- lcSpeedGain means the eagerness for performing lane changing to gain speed. Higher values result in more lane-changing. The values range from 0 to positive infinity. (lcSpeedGain="2.0")
- lcKeepRight the eagerness for following the obligation to keep right. Higher values result in earlier lane-changing. (lcKeepRight ="2.0"). The value ranges from 0 to infinity.
- lcAssertive means willingness to accept lower front and rear gaps on the target lane. The value ranges from 0 to positive real. Higher value result for the vehicle accepts lower gap. (lcAssertive="2.0”)

- accel means the acceleration ability of vehicles in m/s^2. It is not the vehicle's maximum acceleration possibility but rather the maximum acceleration a driver choice. (accel="2.2")
- decel means the deceleration ability of vehicles where a driver choice in m/s^2 (decel="4.2")
- emergencyDecel means the maximal physically possible deceleration for the vehicle in m/s^2. (emergencyDecel="8.0").
- apparentDecel means the deceleration value that will assumed by another configured vehicle (apparentDecel="8.0")
- collisionMinGapFactor is the parameter introduced for the purpose of reducing the gap below minGap to characterize the real situation otherwise during simulation the vehicle never reduce the gap below minGap.
- tau means the driver's desired minimum time headway in second. (tau="2.02")

Pedestrian Definition: A person can either walk or ride through the network. A person element contains child components that define its plan's phases. The phases consist of a linked series of walk, ride, and stop components. Every individual's stage has to include at least a single stage in its plan. The following are person attribute parameter.

- vType id means the identification of the type of vehicle to be used for this vehicle. (vType id="pedestrian")
- jmDriveAfterRedTime: if the value is lower than the specified threshold during the red phase, people will go through a red light. If the setting is 0 People will always walk at yellow but attempt to stop at red measured in seconds. (jmDriveAfterRedTime="1.5")
- Impatience: willing to cross the road at an unprioritized crossing when cars need to stop (impatience="0.33")
- personsPerHour: number of persons per hour, equally distributed. (personsPerHour="1212")
- begin: first-person departure time measured in seconds. (begin="0")
- end: end of departure interval measured in seconds(end="3600")
- width: The person's width measured in m. (width="0.48")
- length: The person's length measured in m. (length="0.215")
- mingap: The minimum gap after leader. (minGap="0.25")
- desiredMaxSpeed: The person's desired maximum velocity [m/s] (desiredMaxSpeed="1.39")
- speedFactor: The persons expected multiplier for desiredMaxSpeed (speedFactor ="0.50")

- vClass="pedestrian"

3.3.3. Geometric Design Data

In order to identify potential safety hazards and the conflict patterns, safety analysis of intersections requires examining the design factors and how they interact. It typically consists of the prominent factors that are thought to play a significant role in causing a number of traffic conflicts at intersections, such as the type of intersection, the number of lanes, the lane width, the intersection skew, the turning radii, the channelization, visibility, clear zones, the super elevation, the pavement markings and signage, the traffic control devices, the pedestrian and bicycle facilities, the turning treatments, the curb design, and the intersection sight distance.

Primary data collection for the geometric elements were carried out for the study area such as number of lanes, lane width, walkway width, existence of median, median width. Elevation of nodes and slopes of the approach road were extracted from google earth pro. The roadway infrastructure of the network can be imported directly into SUMO from a digital road map, Open Street Map (OSM). The collected infrastructure data enables us to edit and modify the network and layout of the intersection

3.4 Calibration of Models

There are many different ways to calibrate the driving models based on existing models in SUMO, including adding new parameters, modifying the principles behind the models, and setting more reasonable values for current parameters. Out of consideration for the workload and convenience, setting more reasonable values for current parameters would be chosen.

(Pourabdollah et al ,2017) IDM are taken more parameters into consideration than of the default lane changing model of SUMO, Krauss model, and LC2013 are the default model of lane-changing model. IDM and LC2013 are chosen as the basis for the car-following and the lane-changing model. Table 8 contains a list of some of their parameters and the definitions.

TABLE 8: SOME PARAMETERS OF IDM AND LC2013 (HTTP://SUMO.SOURCEFORGE.NET/USERDOC/DEFINITION_OF_VEHICLES_VEHICLE_TYPES,_AND_ROUTES.HTML)

Model	Parameter	Definition
IDM	minGap	Minimum Gap when standing (m)
	accel	the acceleration ability (m/s^2)
	decel	the deceleration ability (in m/s^2)
	emergencyDecel	The maximum deceleration ability in case of emergency (in m/s^2)
	tau	the driver's desired (minimum) time headway
LC2013	lcStrategic	the eagerness for performing strategic lane changing
	lcCooperative	the willingness for performing cooperative lane changing
	lcSpeedGain	the eagerness for performing lane changing to gain speed
	lcAssertive	Willingness to accept lower front and rear gaps on the target lane

Parameter setting for IDM for car following model

Setting up the previously specified IDM parameters for each type of vehicle separately in SUMO. It should modify them to represent the conditions of the actual study area. The driver's minimum time headway, acceleration, deceleration, and emergency deceleration are among the characteristics that can be adjusted in IDM. The parameter is based on the correspondence of the vehicle type.

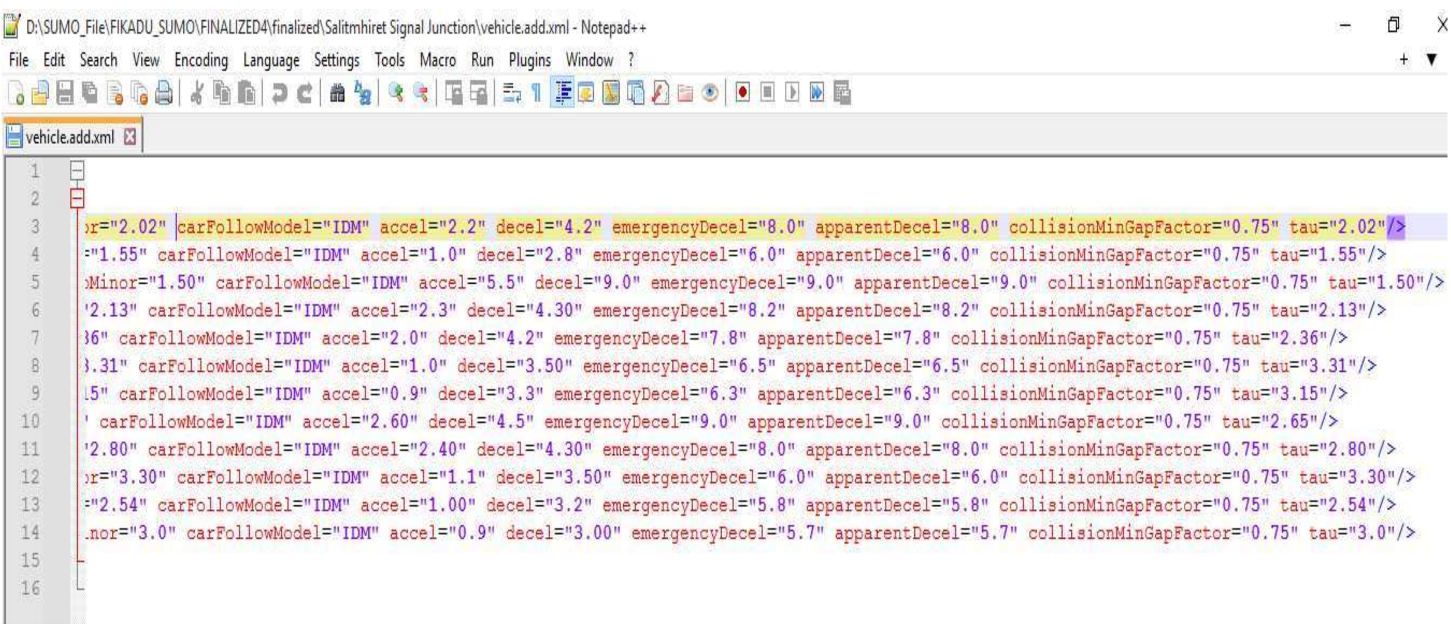


FIGURE 19: MODIFICATION OF CAR FOLLOWING MODEL

Parameter setting for LC2013

After setting up car following model, to create a more realistic lane-changing situation. The parameters of LC2013, such as lcStrategic, lcCooperative, lcSpeedGain, lcKeepRight and lcAssertive, should be changed based on the information gathered from the study area.

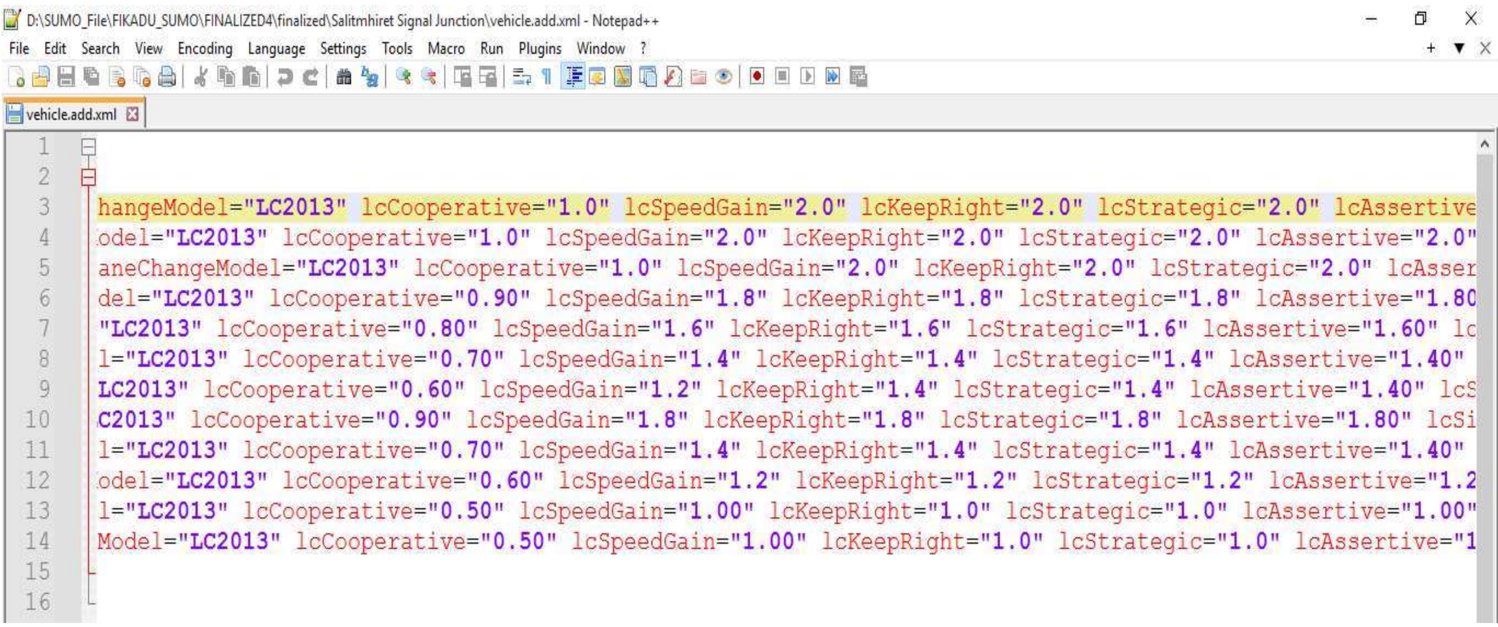


FIGURE 20: MODIFICATION OF LANE CHANGING MODEL

3.5 Simulation of Urban Mobility

3.5.1 Introduction

(*Eclipse SUMO*, 2021) SUMO, or "Simulation of Urban Mobility," is a continuous, microscopic, open-source traffic simulation program made to cope with big networks. It includes a wide range of tools for creating scenarios and enables multimodal simulation with pedestrians. It is mainly developed by German Aerospace Center's Institute of Transportation Systems.

3.5.2 SUMO Network File

(*Sumo*, 2021) SUMO network describe traffic related maps, roads and intersections that the simulated vehicles run along or cross. SUMO network is a directed graph. In SUMO-context Nodes, which are sometimes referred to as "junctions", stand in for intersections and "edges" are stands for streets or roads. Recall that edges only go in one direction. The SUMO network specifically has the following data:

- Each street (edge) as a group of lanes, with each lane's position, shape, and speed limit included,
- Intersections that refer to traffic light logics

- Intersections, including the laws governing their right of way,
- Nodes between lanes at intersections.

Non-sumo network imported with netconvert from a variety of non-Sumo network formats. For instance, after downloading open street map then can be imported using netconvert.

The road network stored in "Adey_Ababa_Stadium.osm.xml" is imported by the command to netconvert, which also stores the SUMO-network created from this data in "Adey_Ababa_Stadium.net.xml":

netconvert --osm-files Adey_Ababa_Stadium.osm.xml -o Adey_Ababa_Stadium.net.xml

3.5.3 Creating and modifying network using netedit

(*Sumo*, 2021) Netedit is a visual network editor. It may be used to completely redesign networks as well as build new ones from the ground up. On top of netconvert, netedit can do well. Because Netedit offers unlimited undo and redo options, editing errors can be quickly corrected. Depending on the edit mode that is active, a left-click is typically used to issue editing commands. The sumo-gui user interface is closely follow the netedit.

3.5.4 Including Elevation Data

You can import elevation data from the following sources.

- directly from the input of the network
- by using extra data from supplementary files
- using Netedit's move mode to move geometry points and junctions along the z-axis.
- by using the netgenerate option --perturb-z to create an abstract network with z-level noise.

3.5.5 Definition of Vehicles, Vehicle Types, and Routes

(*Sumo*, 2021) A variety of applications can be used to define the vehicular demand for SUMO. Netedit can also be used to graphically develop and edit traffic demand. XML definitions are eventually produced by all of the application. Of course, there are other options as well, such manually defining the demand file or using a text editor for editing the generated files.

It's necessary to understand that a SUMO vehicle is composed of up of three parts:

- a vehicle type that describes the physical features of the vehicle,
- A route that the vehicle will take
- As well as the vehicle itself.

3.5.6 Importing O/D Matrices

(*Sumo*, 2021) O/D (origin/destination) matrices are used by od2trips to compute trip tables. Od2trips operates under the assumption that the matrix and/or matrices are coded as the number of vehicles that travel during a specified time frame from one district or traffic assignment zone (TAZ) to another. Od2trips needs a mapping of TAZ to edges because the generated trips have to begin and end at edges.

3.5.7 Describing the TAZ

A traffic assignment zone, also known as a traffic analysis zone or TAZ for short, is identified by lists of source and destination edges and its id, an arbitrary identifier.

```
<tazs>
   <taz id="<TAZ_ID>" edges="<EDGE_ID> <EDGE_ID> ..."/>
   ... additional traffic assignment zones......
</tazs>
```

3.5.8 Trips Generation

(SUMO, 2021) Od2trips imports O/D matrices, splits them into single vehicle trips in sumo, and generates a collection of trips for a particular network (the traffic analysis zones specified in netedit, TAZ-files) and the OD matrices created from traffic counts. The resulting trips are recorded in an XML file that may be used by duarouter (option -o, od_file.odtrips.xml). The begin (option -b, default 0) and end (option -e, default 3600) times are used to distribute the trips equally throughout the allotted period.

3.5.9 Route Generation

(*Sumo*, 2021) duarouter achieves dynamic user assignment (DUA). It imports various demand definitions and compute shortest path that may be used by sumo. This is facilitated by the tool duaiterate.py, which converges to an equilibrium state.

The primary output of the duarouter is rou.xml file name which is the main output of duarouter. There will also be a rou.alt.xml generated, which will have the same name prefix as the rou.xml file.

Each vehicle's route distribution is stored in this route alternative file. A route distribution file can be loaded into sumo or used in dynamic user assignment (DUA).

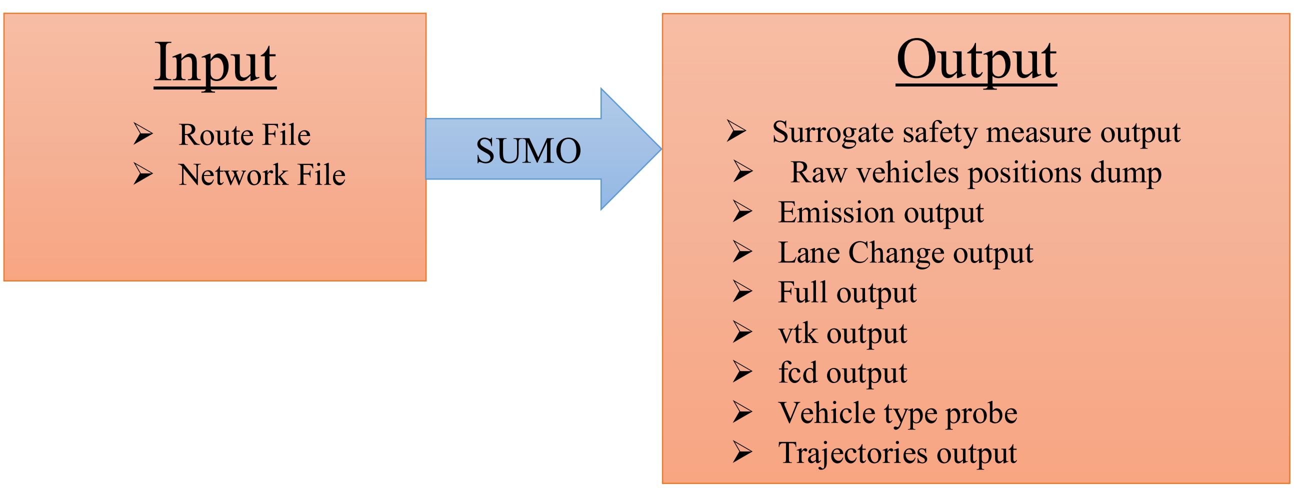
The route file is generated from vehicle trip file, pedestrian trip file, network file and addition file such as vehicle definition, pedestrian definition and bus stop file using duarouter.

3.5.10 Simulation

(*Sumo*, 2021) Sumo-gui simulates a defined scenario using network file and route file. After the model has been adjusted, a simulation is modeled for eight selected study area of existing conditions to evaluate the current traffic safety performance and to develop a probabilistic model of the occurrence of potential conflict risk

3.5.11 Simulation output

(*Sumo*, 2021) SUMO is possible to generate a wide variety of measures. All adhere to the standard file writing guidelines when writing the values, they have gathered into files or socket connections. By default, each is disabled and needs to be activated separately. Command line parameters can be used to trigger some of the available outputs, such as the raw vehicle position dump, trip information, vehicle routes information, and simulation state statistics; additional files have to be created for the remaining outputs.



- The traffic safety is evaluated using the number of surrogate safety measures. In this thesis, TTC are the criteria used to identify potential risk of conflicts.

3.6 Development of Traffic Safety prediction Model

The objective of the study is to develop predictive model for the probabilistic occurrence of potential conflict using TTC surrogate safety measure as dependent variable and independent variables of geometric and traffic characteristics elements that are high potential of contributing conflicts.

To develop the relationship between dependent variables the cumulative probability for the occurrence of potential conflict and the independent variables (spot speed, speed deviation traffic count, number of lanes, lane width and grade of the approach road) were adopting.

TTC probabilistic distribution is more represented by Weibull distribution. The Weibull distribution have two parameter α and β.

The parameter α and β were used to determine the probability of the occurrence of potential conflict.

In this thesis, only lead/follow conflict types are considered for the purpose of taking similar geometric elements for one conflict point between two vehicles that are on the same direction, but crossing or merging conflict type has different geometric components for a single conflict point because they are coming from separate directions.

CHAPTER 4- RESULTS AND DESCUSSION

4.1 Analysis of SUMO simulation

Step 1: Importing networks from external open street map

1. From the SUMO programs, launch OSM Web Wizard to get an online open street map. Search and download the study area map, and the output file is a sumo network file(.net.xml). As an alternative, perform a straight Google search for OSM, download the study area and the output file is non-SUMO network file (.osm), which we need to convert to a SUMO network file.

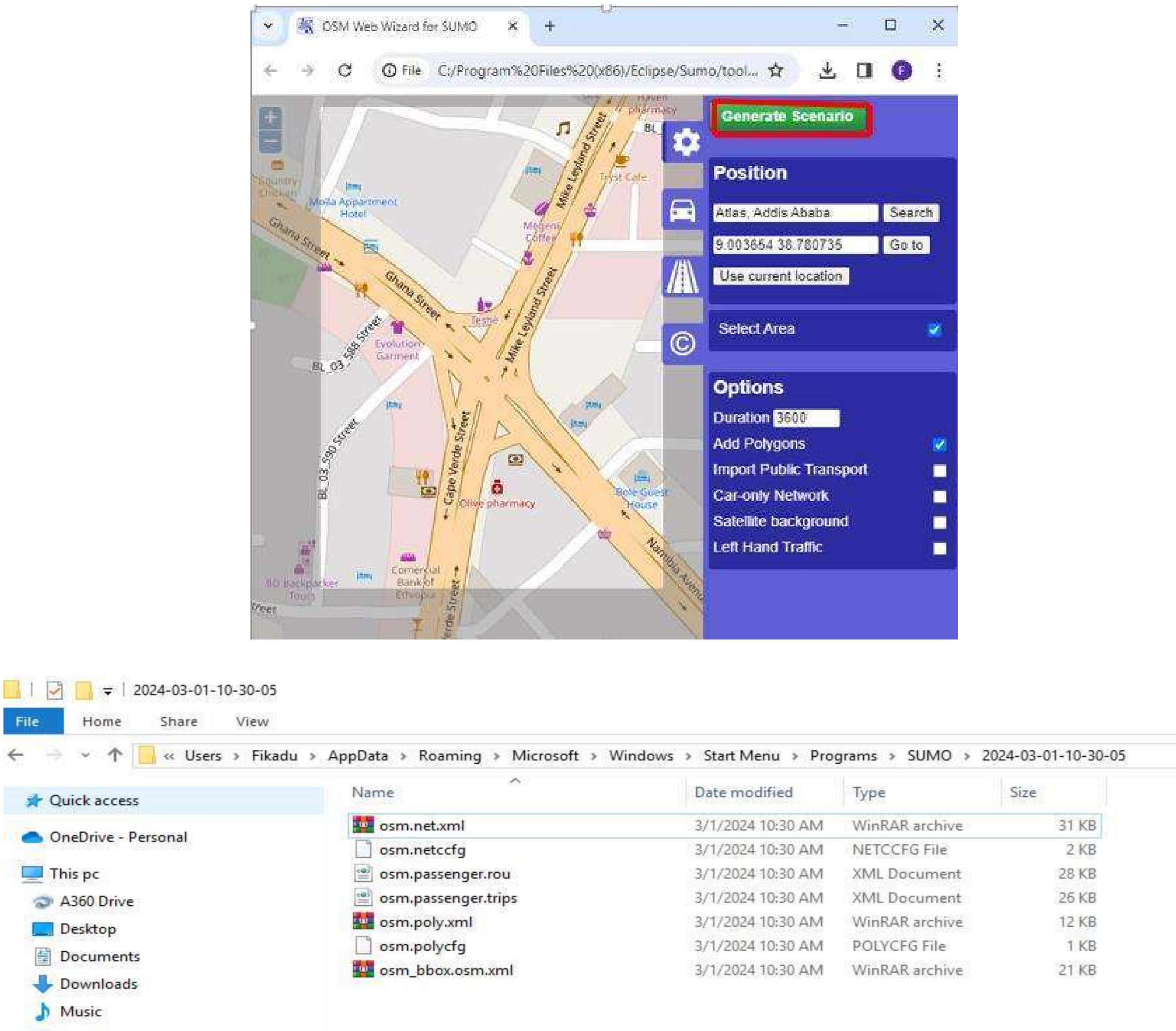


FIGURE 21: OPEN STREET MAP FOR ATLAS INTERSECTION USING OSM WEB WIZARD

2. If we are choosing the second alternative we need to Convert OSM to SUMO networks using netconvert

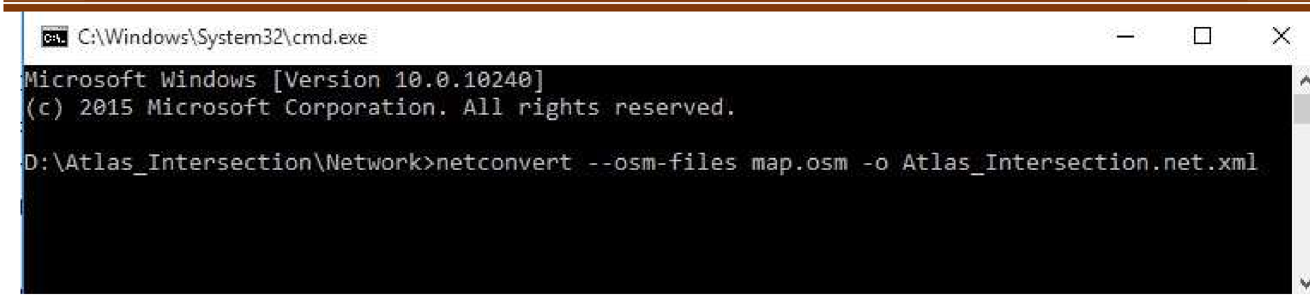


FIGURE 22: NETWORK CONVERSION OF NON-SUMO NETWORK IN TO SUMO NETWORK FILE

3. Modifying the sumo Network using netedit

The approach road and intersection parameters, such as the number of lanes, lane width, position of pedestrian crossing, speed limit of each lane, vehicle restriction per lane, walkway width, bus stop position, intersection type selection, sequence, and timing of the traffic signal, are modified using the primary data that are collected on the site.

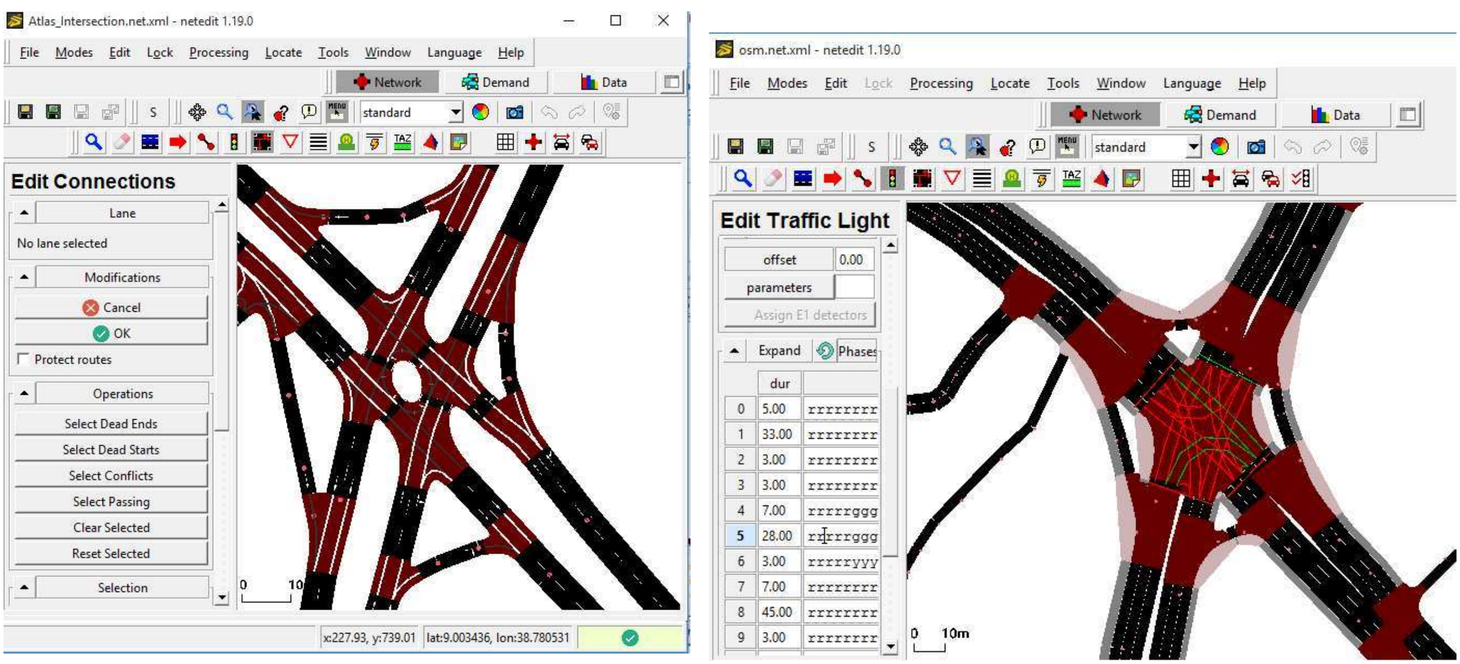


FIGURE 23: BEFORE AND AFTER NETWORK MODIFICATION OF ATLAS INTERSECTION

4. Inserting elevation data on the junctions and geometric point using Netedit's.

N.B Geometric points are those point that are present on the edge (the road segment) and serve as internal control points to keep the edge's shape during edge movement. If a junction connects two edges, it can be transformed into a geometric point.

- Collecting geometric point and junction coordinates. The coordinate reference of the netedit set the leftmost point's x-coordinate to zero and the bottommost point's y-coordinate to zero. Thus, the coordinate has be converted to UTM Zone 37N Adindan reference.

TABLE 9: COORDINATES OF NODES FOR ATLAS INTERSECTION

Sr.No	Easting	Northing	Sr.No	Easting	Northing	Sr.No	Easting	Northing
1	475152.298	995805.283	31	475752.518	994953.063	61	475640.338	994945.703
2	475157.318	995849.413	32	475799.438	995018.903	62	475752.518	994953.063
3	475366.538	995429.893	33	475967.048	995038.493	63	475781.318	995152.913
4	475348.218	995426.603	34	475837.218	994979.333	64	475820.418	995152.943
5	475414.238	995342.193	35	475966.718	994983.943	65	475790.338	995201.743
6	475525.438	995424.863	36	475902.248	994890.123	66	475738.878	995220.903
7	475443.978	995282.573	37	475850.408	994843.343	67	475803.978	995228.833
8	475362.238	995160.703	38	475894.528	994916.123	68	475816.508	995222.383
9	475468.358	995261.253	39	475960.648	994934.533	69	475884.898	995210.913
10	475457.818	995137.733	40	475937.528	994851.883	70	475828.018	995248.143
11	475513.528	995228.853	41	475891.368	994819.913	71	475986.268	995272.303
12	475516.208	995239.763	42	475980.628	994806.383	72	475836.298	995296.983
13	475561.088	995366.933	43	475988.678	994814.683	73	475849.128	995294.923
14	475628.778	995170.793	44	476063.338	994720.303	74	475932.978	995311.403
15	475665.958	995280.313	45	476035.658	994688.873	75	475850.938	995369.803
16	475637.518	995165.593	46	476103.348	994697.503	76	475819.488	995375.743
17	475738.878	995220.903	47	476155.368	994762.773	77	475846.478	995429.133
18	475683.268	995120.393	48	476111.448	994675.163	78	475858.418	995432.493
19	475629.088	995087.313	49	476257.948	994580.883	79	475913.908	995450.963
20	475709.128	995098.473	50	476339.708	994685.813	80	475825.608	995509.033
21	475640.338	994945.703	51	476357.258	994513.853	81	475740.028	995428.853
22	475708.838	995113.783	52	476411.908	994646.793	82	475801.968	995558.613
23	475751.878	995119.973	53	476390.178	994468.723	83	475811.258	995569.123
24	475738.178	995077.753	54	476408.878	994479.963			
25	475719.928	995037.183	55	475598.588	994299.593			
26	475733.488	995035.273	56	475610.648	994292.873			
27	475760.088	995045.063	57	475698.278	994825.653			
28	475764.158	995061.903	58	475722.378	994809.613			
29	475758.918	995106.593	59	475703.178	994946.833			
30	475797.978	995004.693	60	475719.088	994938.263			

- Display the coordinate on google earth.

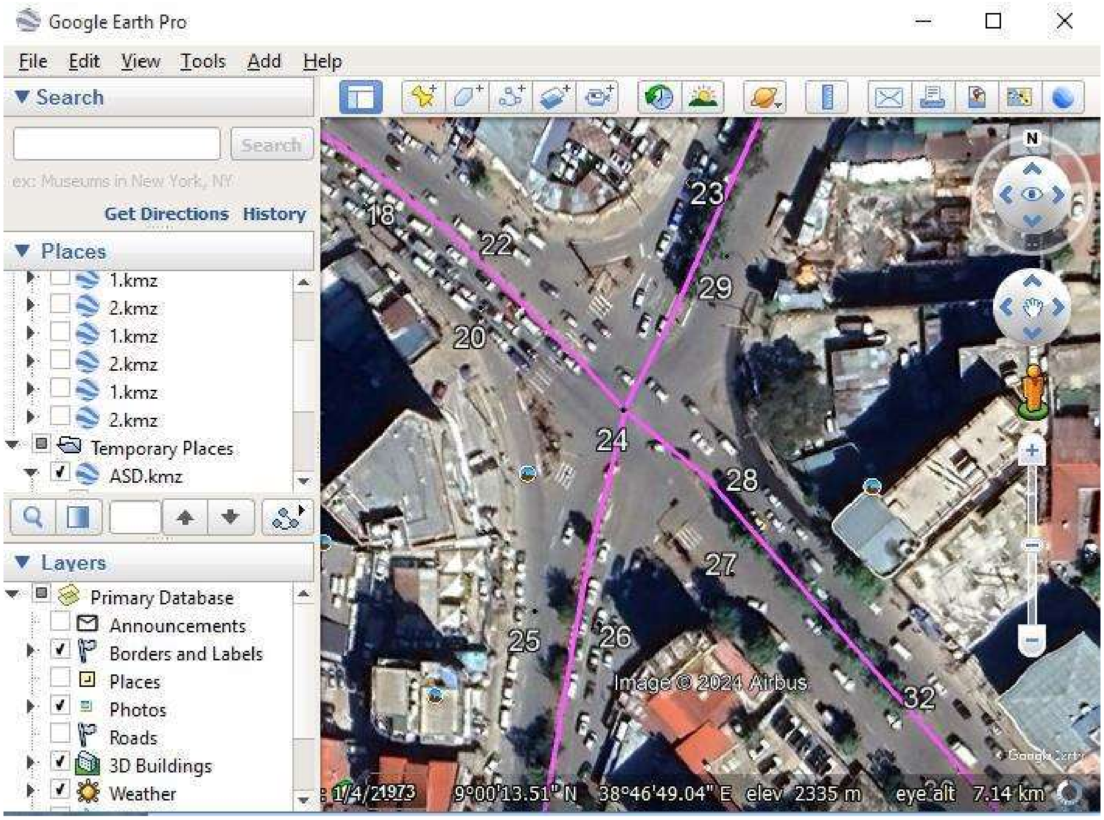


FIGURE 24: DISPLAY JUNCTION AND GEOMETRIC POINTS ON GOOGLE EARTH

- Extract elevation from google earth and inserting in to SUMO network using netedit

For instance, the main Atlas intersection is shown in the above figure at Point No. 24, and the elevation on Google Earth indicates that it is 2335 m. Manually inserting elevation on the junction position and inserting elevation for the geometric point on the edge shape.

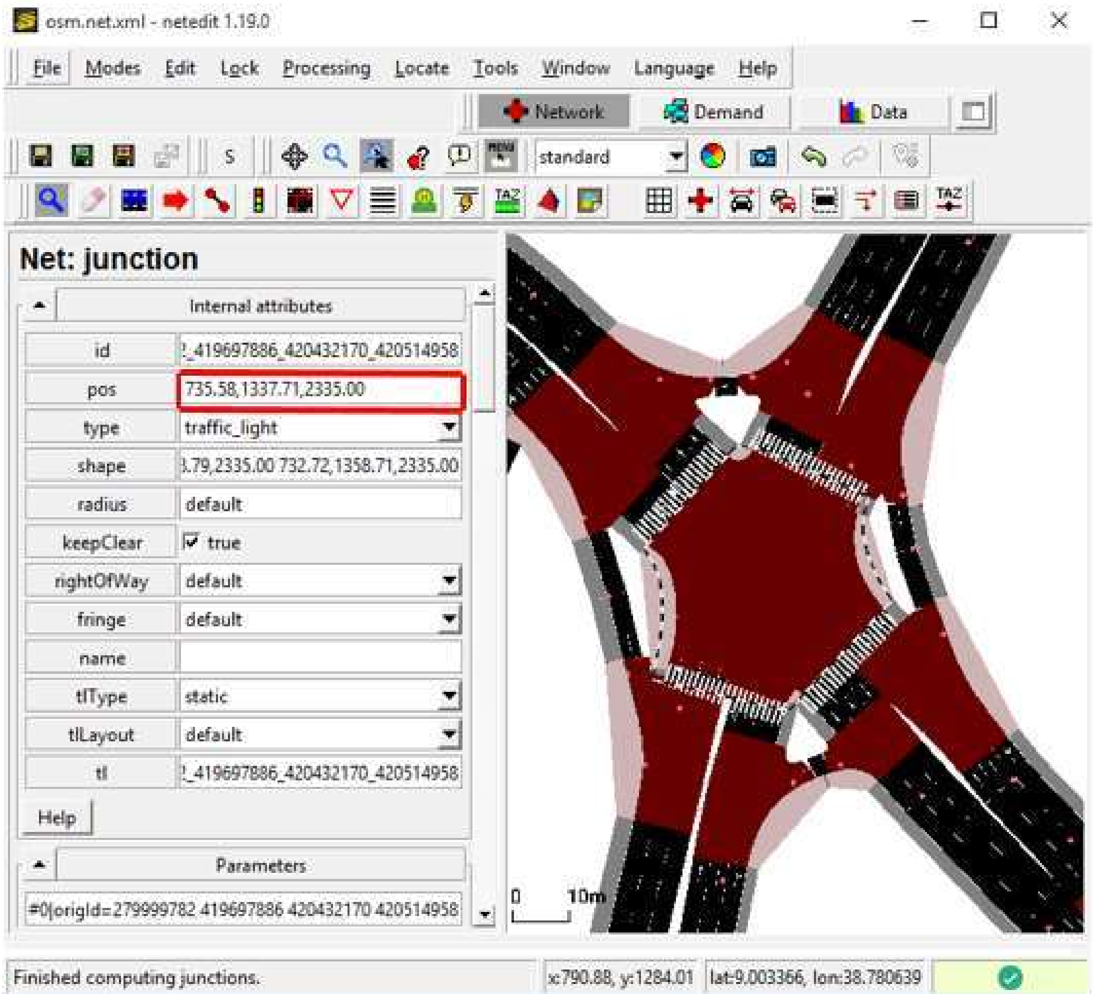


FIGURE 25: ADDING Z-COORDINATE FOR ATLAS INTERSECTION

Step 2: Trip File Generation

Single trip file is generated from O/D-matrices and traffic assignment zone (TAZ) using od2trips. The trip file is generated separately for the vehicular and pedestrian trip due to different movement.

- Vehicular trip file

1. **Traffic Assignment Zone (TAZ)**: TAZ are a closed polygon and composed of a list of edges associated with to specific weights for the inputs (Sources) and outputs (Sinks). TAZ is composed of edges that represent some section that are either flow origin or flow destination location.

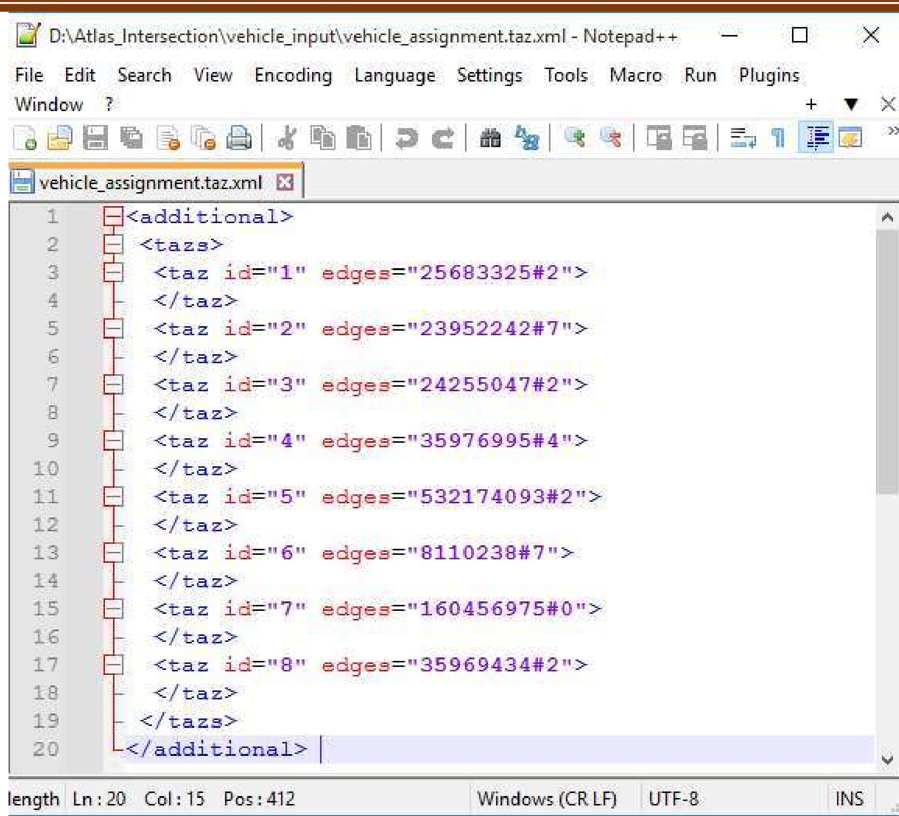


FIGURE 26: TRAFFIC ASSIGNMENT ZONE

2. O-D matrices

O-D matrix represent the names of the origin and destination districts. Every matrix explains a specific time frame. The number of vehicles that travel within the specified time period from the corresponding origin district to the corresponding destination district is represented by the values contained in the matrix.

There are different format types to create O-D matrices such as: -

- tazRelation format: For each specific vehicle type, the demand per OD pair is defined in time slices
- PTV formats
- V format
- O-format
- Amitran format

TazRelation format is utilized due to each specific vehicle type demand represented by a single file by stating the vehicle type in time slices.

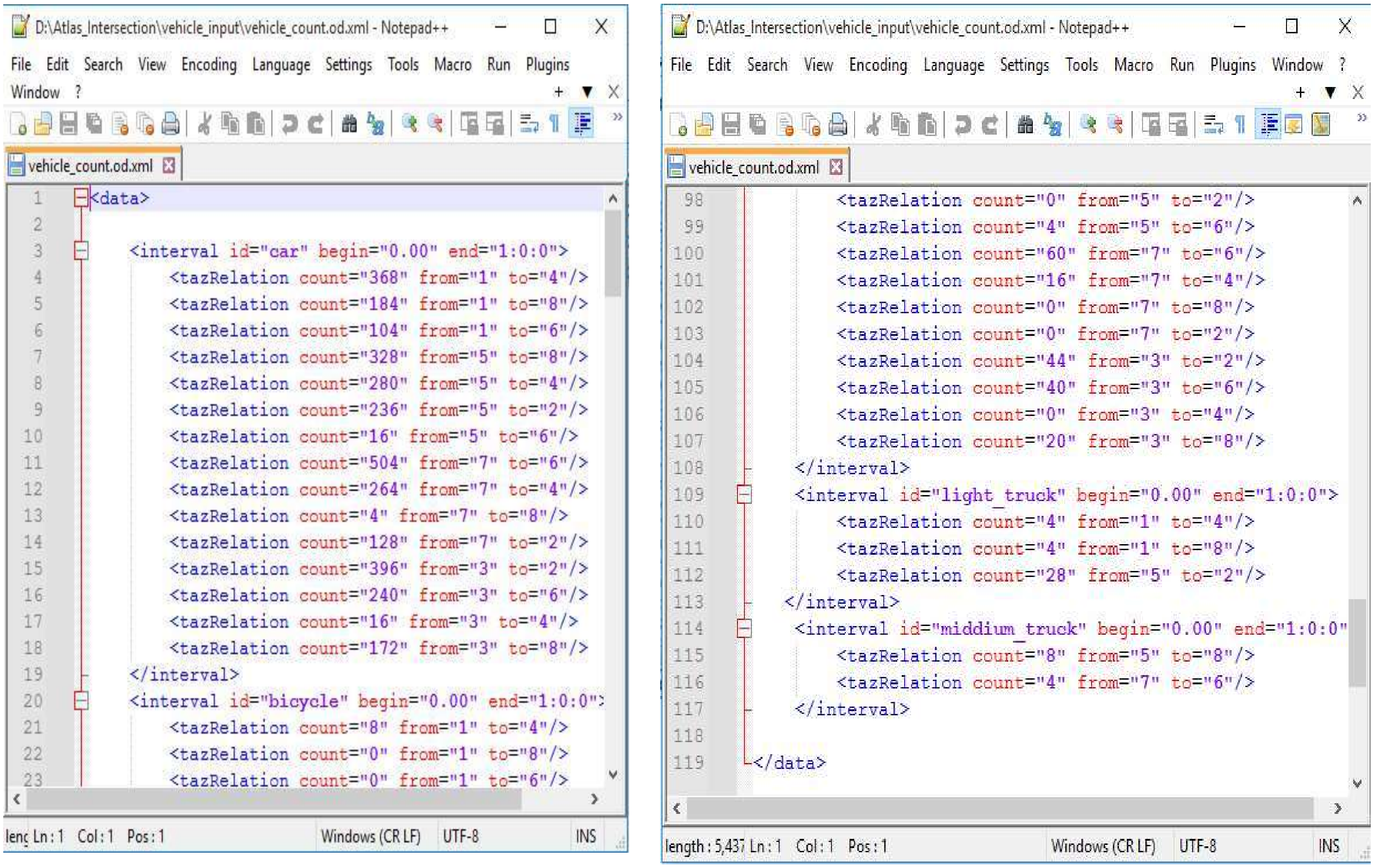


FIGURE 27: O-D MATRICS USING TAZRELATION FORMAT OF ATLAS INTERSECTION

3. Trip file Generation

Trip file is generated by integrating the TAZ and O-D matrices using od2trips

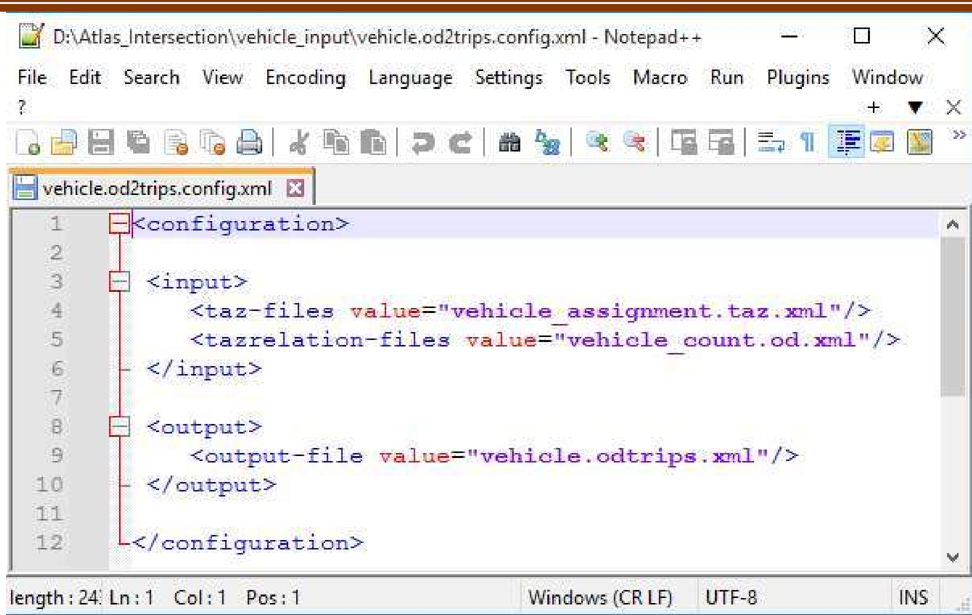


FIGURE 28: CONFIGURATION FILE TO GENERATE VEHICULAR TRIP FILE FROM TAZ AND O-D MATRICES USING OD2TRIPS

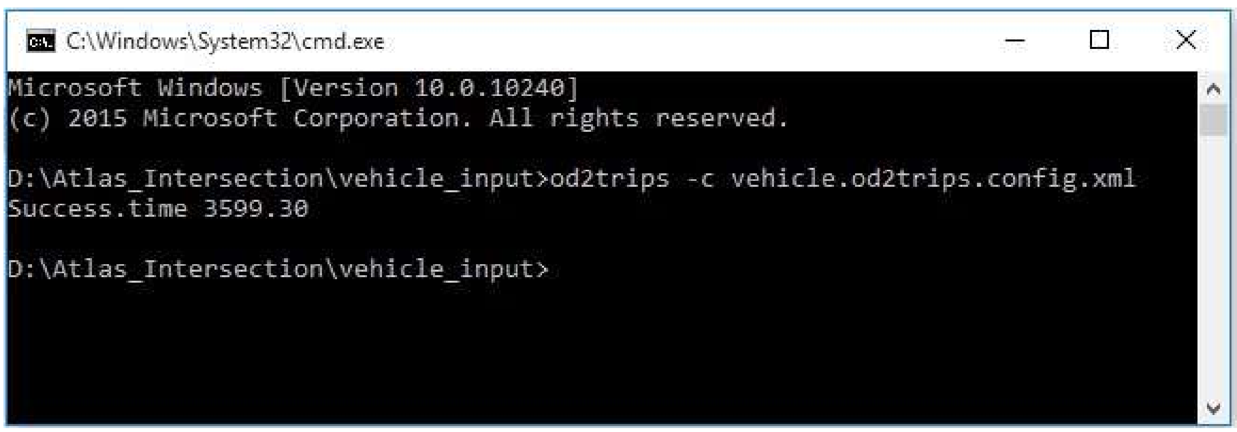


FIGURE 29: COMMAND TO GENERATE TRIP FILE USING OD2TRIPS

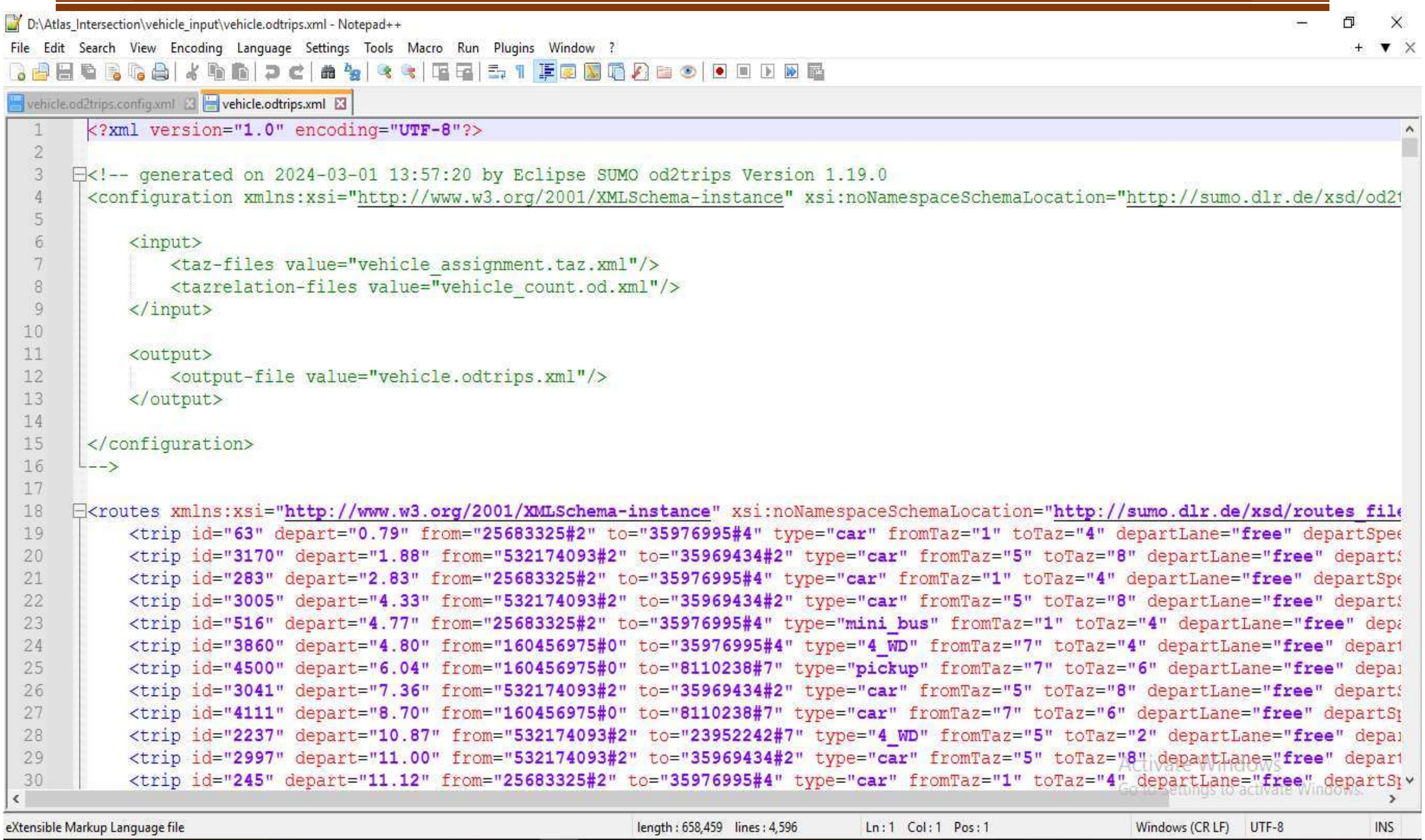


FIGURE 30: GENERATED VEHICULAR TRIP FILE

4. Add prefix value on the generated trip file

We have to add a prefix value to the trip id since, as you can see on the above figure, it does not describe the type of vehicle that is difficult to analyze the output file.

Using python add prefix for each vehicle.

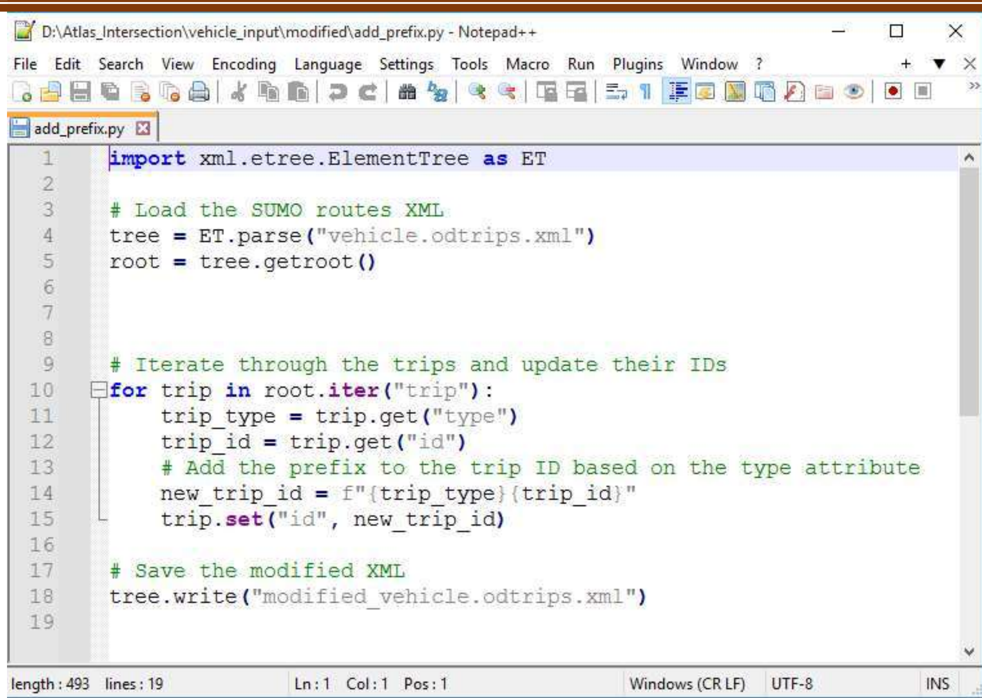


FIGURE 31: PYTHON CODE TO ADD PREFIX VALUE ON GENERATED TRIP FILE

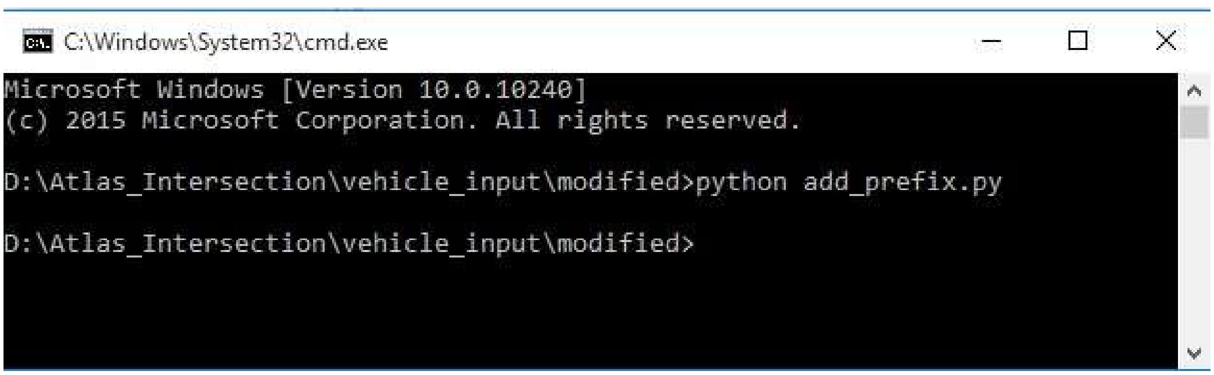


FIGURE 32: COMMAND TO GENERAT MODIFIED TRIP FILE USING PYTHON

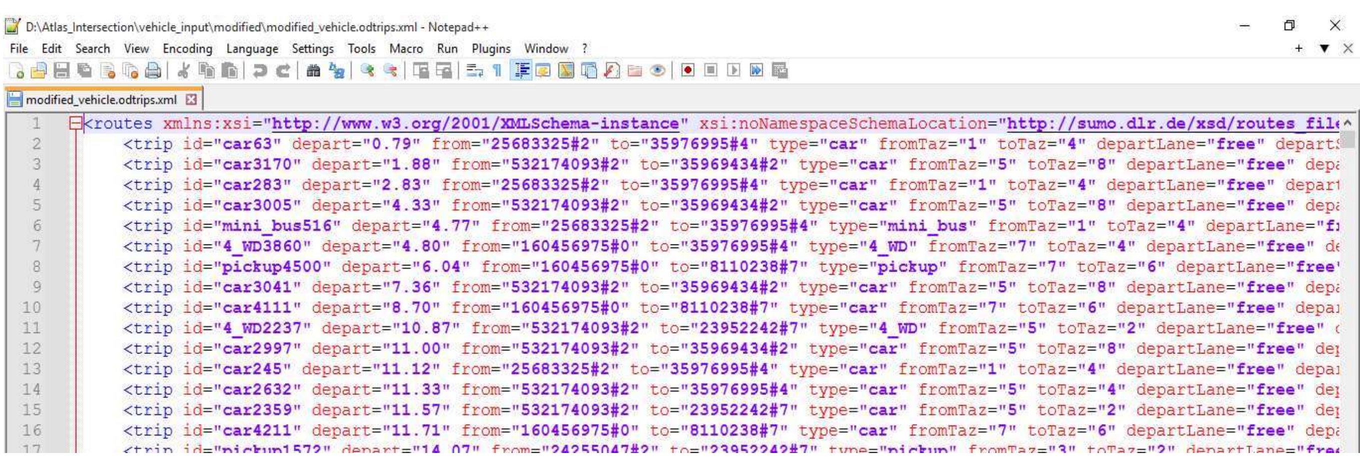


FIGURE 33: SAMPLES OF MODIFIED TRIP FILE

- Pedestrian Trip File

Pedestrian trip file is generated from O/D-matrices and traffic assignment zone (TAZ) using od2trips.

1. Traffic Assignment Zone and O-D matrices

N.B The O-D matrices is on the O-format due to simplicity and due to the assumption that all pedestrian type unique characteristics.

pedestrian_assignment.taz.xml

```xml
<additional>
 <tazs>
  <taz id="9" edges="532174093#8">
  </taz>
  <taz id="10" edges="8110238#1">
  </taz>
  <taz id="11" edges="25683325#8">
  </taz>
  <taz id="12" edges="23952242#0">
  </taz>
  <taz id="13" edges="160456975#5">
  </taz>
  <taz id="14" edges="35969434#0">
  </taz>
  <taz id="15" edges="200591485#2">
  </taz>
  <taz id="16" edges="35976990#1">
  </taz>
 </tazs>
</additional>
```

pedestrian_count.od.xml

```
$OR;D2
* FROM-Time To-Time
0.00 1.00
* Factor
1.00
* some
* additional
* comments
   10 9 160
   11 12 224
   14 13 292
   16 15 152
```

FIGURE 34: TAZ & O-D MATRIX RESPECTIVELY FOR THE PEDESTRIAN FLOW

pedestrian.od2trips.config.xml

```xml
<configuration>

    <input>
        <taz-files value="pedestrian_assignment.taz.xml"/>
        <od-matrix-files value="pedestrian_count.od.xml"/>
    </input>

    <output>
        <output-file value="pedestrian_trip.xml"/>
        <pedestrians value="true"/>
    </output>

    <processing>
        <prefix value="person"/>
    </processing>

</configuration>
```

FIGURE 35: CONFIGURATION FILE TO GENERATE PEDESTRIAN TRIP FILE FROM TAZ AND O-D MATRICES USING OD2TRIPS

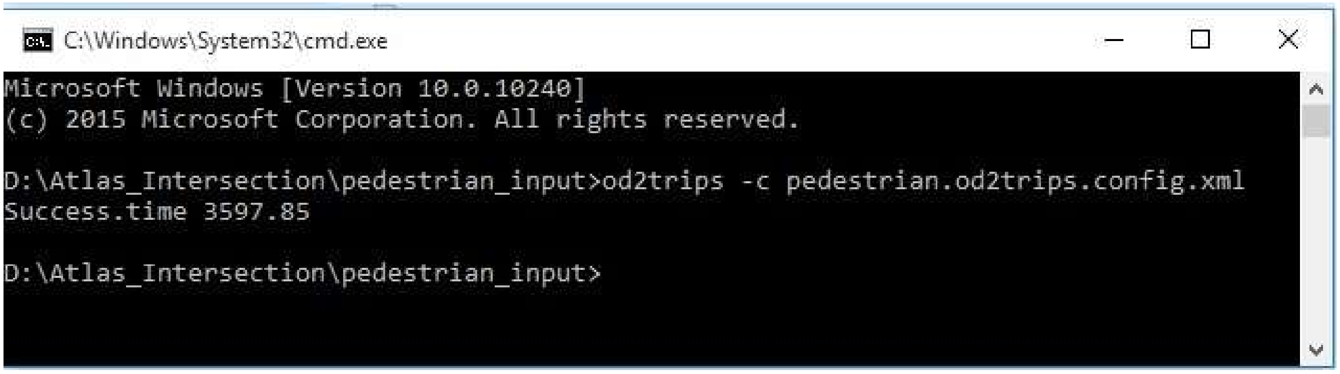


FIGURE 36: COMMAND TO GENERAT PEDESTRIAN TRIP FILE USING OD2TRIPS

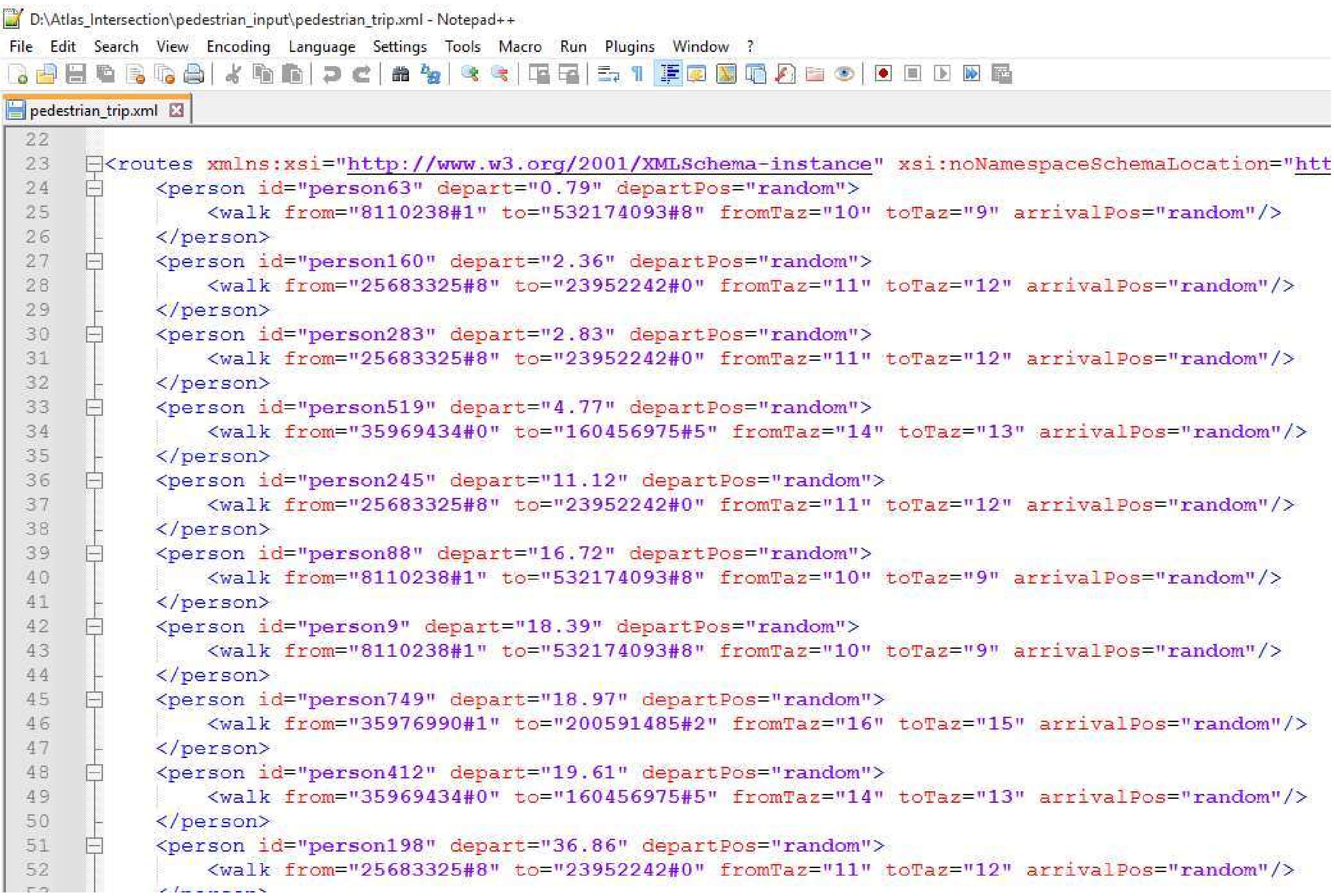


FIGURE 37: GENERATED PEDESTRIAN TRIP FILE

Step 3: Route File Generation

The route file is generated from vehicle trip file, pedestrian trip file, network file and addition file such as vehicle definition, pedestrian definition and bus stop file using duarouter.

1. Network file, vehicle trip file and pedestrian trip file were generated on step 1 and step 2.
2. Additional file is used to load additional entities such as infrastructure related things and demand related entities.
   - Bus Stops are infrastructure related things that vehicles (referred to as "busses") can be programmed to stop at designated locations for a pre-given time.

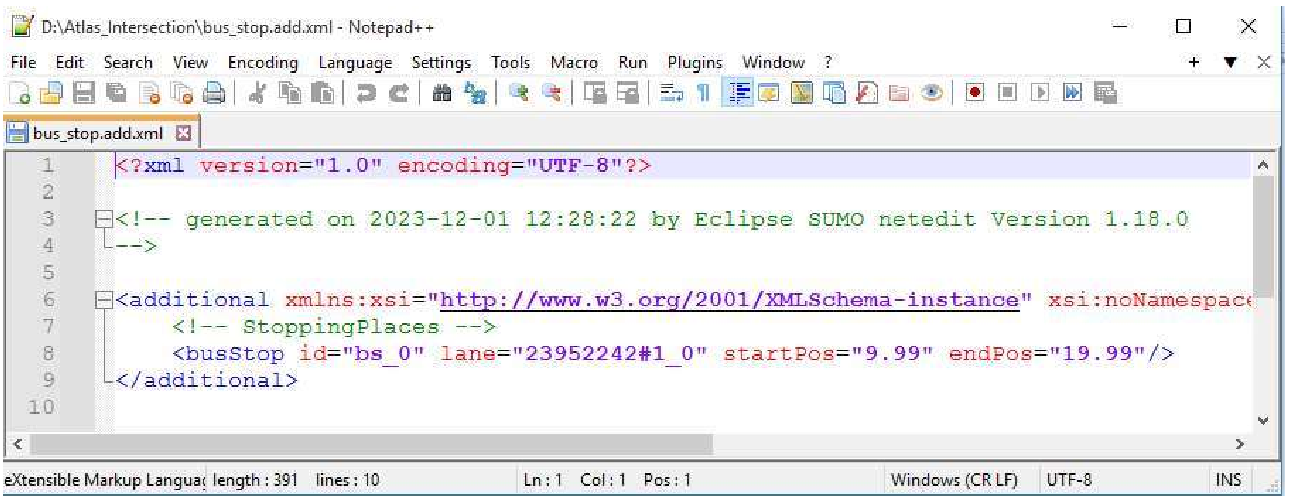


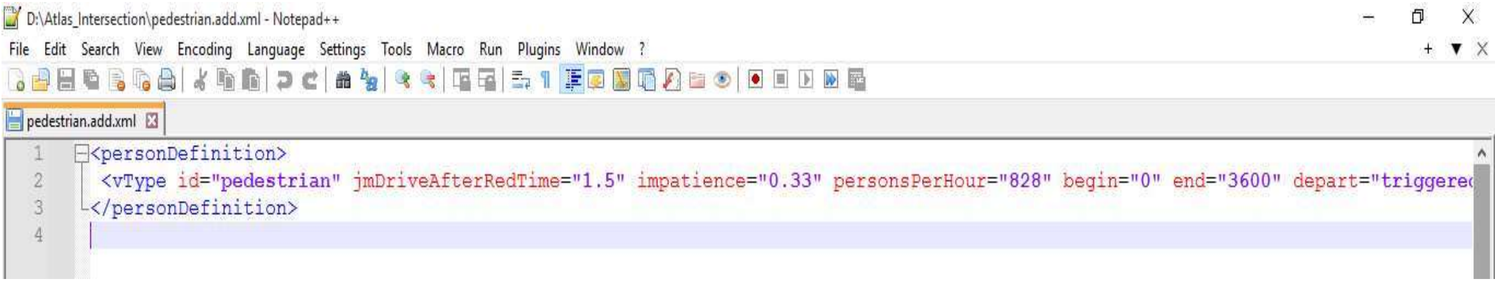
FIGURE 38: BUS STOP ADDITIONAL FILE FOR THE INPUT OF ROUTE FILE

- Vehicle type definition is under demand related parameter on which define a vehicle with a route that belongs to each vehicle type. It defines the "purely physical" parameters of the vehicle, including its length, color, or maximum speed, as well as the parameters of the car-following model that is being utilized and the lane-changing parameter.

```
<additional>
  <routes>
    <vType id="car" length="4.80" minGap="1.83" maxSpeed="33.33" speedFactor="0.615" actionStepLength="
    <vType id="bicycle" length="1.60" minGap="1.00" maxSpeed="13.89" speedFactor="0.615" actionStepLeng
    <vType id="motorcycle" length="2.20" minGap="1.3" maxSpeed="33.33" speedFactor="0.615" actionStepLe
    <vType id="4_WD" length="4.7" minGap="1.85" maxSpeed="33.33" speedFactor="0.615" actionStepLength="
    <vType id="mini_bus" length="4.7" minGap="1.58" maxSpeed="33.33" speedFactor="0.615" actionStepLeng
    <vType id="middium_bus" length="8.1" minGap="1.56" maxSpeed="33.33" speedFactor="0.615" actionStepI
    <vType id="large_bus" length="12" minGap="2.69" maxSpeed="33.33" speedFactor="0.615" actionStepLeng
    <vType id="pickup" length="5.5" minGap="1.95" maxSpeed="33.33" speedFactor="0.615" actionStepLength
    <vType id="light_truck" length="5.5" minGap="1.7" maxSpeed="33.33" speedFactor="0.615" actionStepLe
    <vType id="middium_truck" length="7.1" minGap="2.3" maxSpeed="33.33" speedFactor="0.615" actionStep
    <vType id="heavy_truck" length="9" minGap="2.75" maxSpeed="27.77" speedFactor="0.615" actionStepLen
    <vType id="truck_trailer" length="16.2" minGap="3" maxSpeed="22.22" speedFactor="0.615" actionStepI
  </routes>
</additional>
```

FIGURE 39: VEHICLE TYPE DEFINITION FOR THE INPUT OF ROUTE FILE

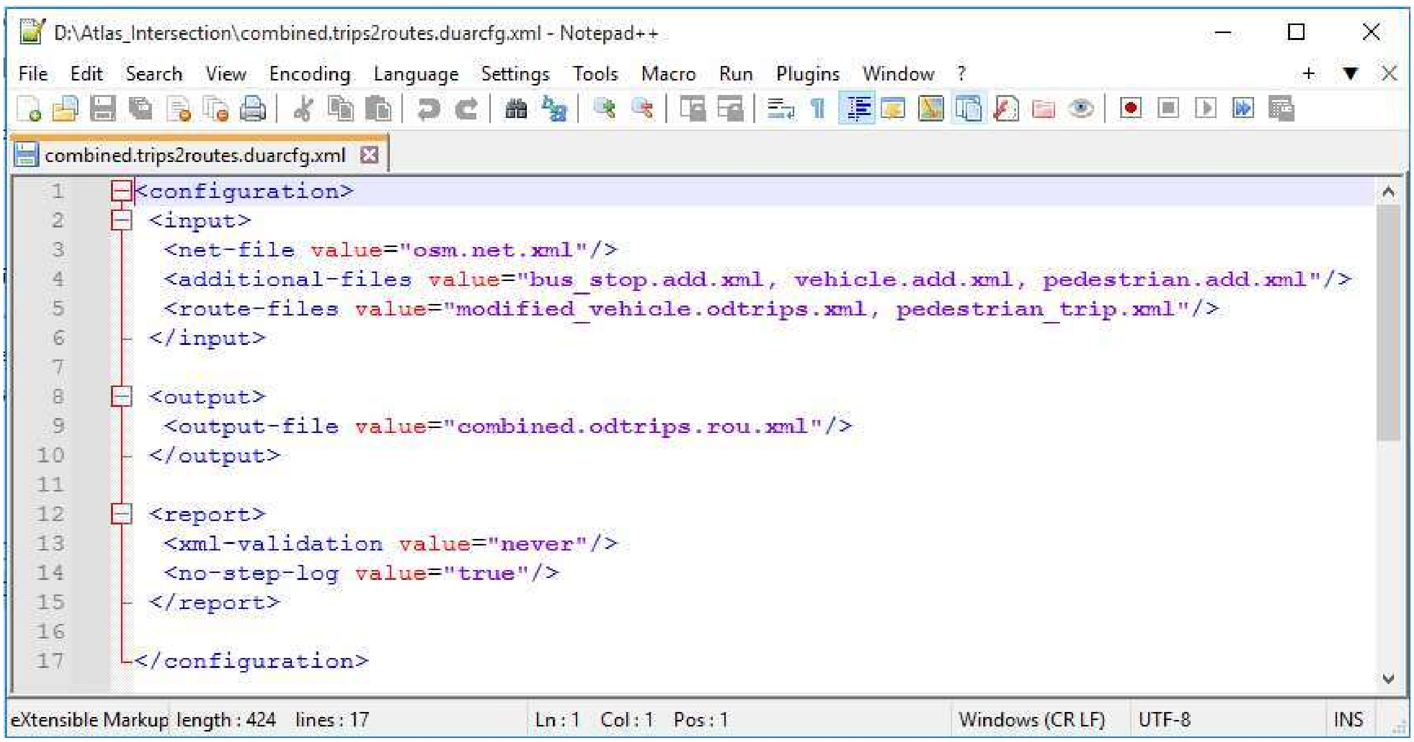
- Person definition: A person can either walk or using vehicles through the network



```
<personDefinition>
 <vType id="pedestrian" jmDriveAfterRedTime="1.5" impatience="0.33" personsPerHour="828" begin="0" end="3600" depart="triggere
</personDefinition>
```

FIGURE 40: SAMPLES OF PEDESTRIAN DEFINITION

3. Route file are generated using duarouter as outputs and network, trip, and additional files are used as inputs.



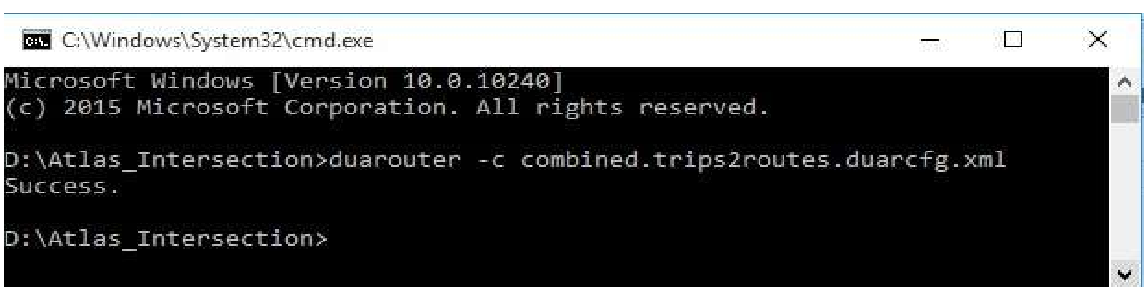
```
<configuration>
  <input>
    <net-file value="osm.net.xml"/>
    <additional-files value="bus_stop.add.xml, vehicle.add.xml, pedestrian.add.xml"/>
    <route-files value="modified_vehicle.odtrips.xml, pedestrian_trip.xml"/>
  </input>

  <output>
    <output-file value="combined.odtrips.rou.xml"/>
  </output>

  <report>
    <xml-validation value="never"/>
    <no-step-log value="true"/>
  </report>

</configuration>
```

FIGURE 41: CONFIGURATION FILE FOR ROUTE FILE GENERATION

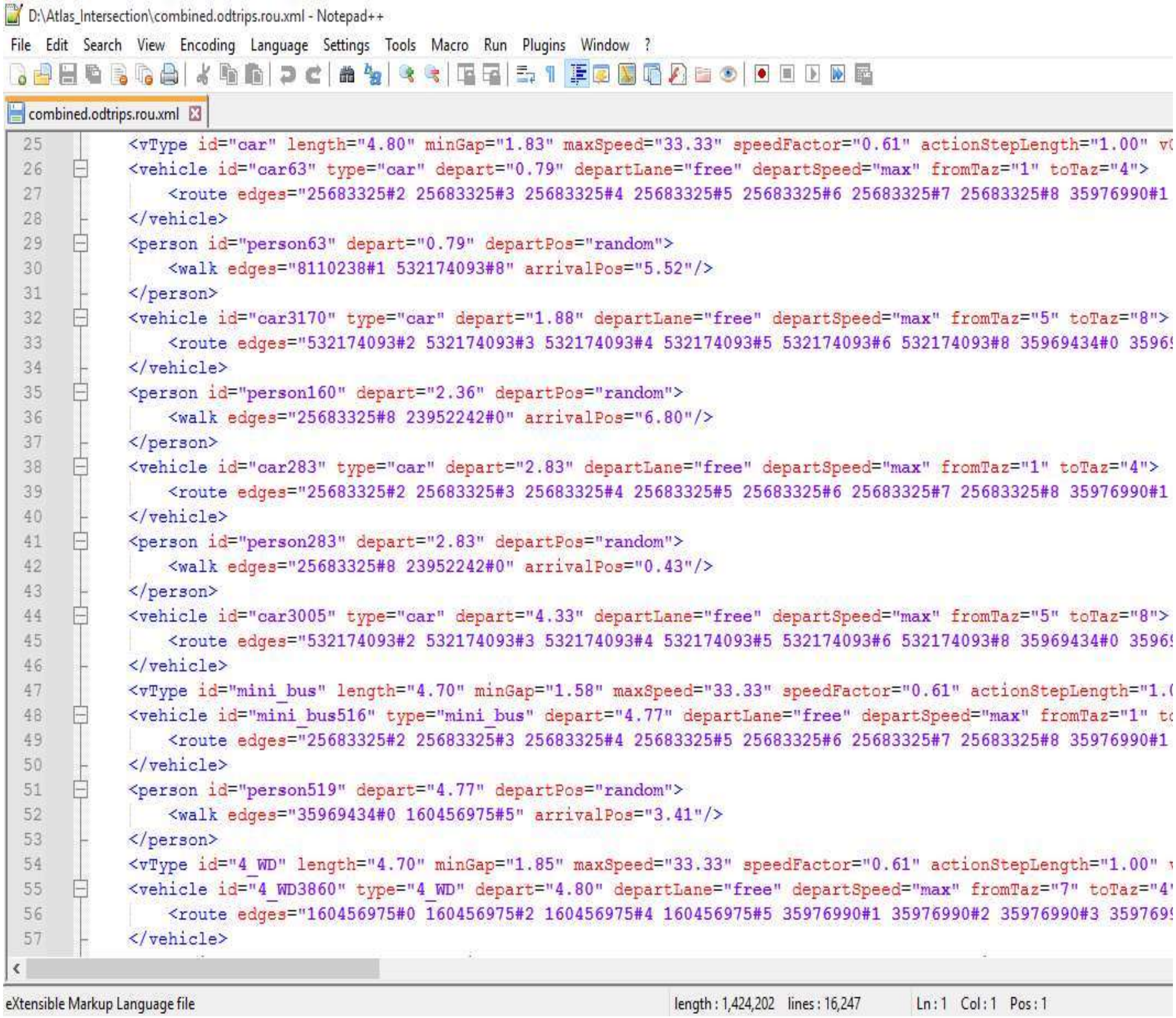


```
Microsoft Windows [Version 10.0.10240]
(c) 2015 Microsoft Corporation. All rights reserved.

D:\Atlas_Intersection>duarouter -c combined.trips2routes.duarcfg.xml
Success.

D:\Atlas_Intersection>
```

FIGURE 42: COMMAND TO GENERATE ROUTE FILE USING DUAROUTER




```
<vType id="car" length="4.80" minGap="1.83" maxSpeed="33.33" speedFactor="0.61" actionStepLength="1.00" v
<vehicle id="car63" type="car" depart="0.79" departLane="free" departSpeed="max" fromTaz="1" toTaz="4">
    <route edges="25683325#2 25683325#3 25683325#4 25683325#5 25683325#6 25683325#7 25683325#8 35976990#1
</vehicle>
<person id="person63" depart="0.79" departPos="random">
    <walk edges="8110238#1 532174093#8" arrivalPos="5.52"/>
</person>
<vehicle id="car3170" type="car" depart="1.88" departLane="free" departSpeed="max" fromTaz="5" toTaz="8">
    <route edges="532174093#2 532174093#3 532174093#4 532174093#5 532174093#6 532174093#8 35969434#0 3596
</vehicle>
<person id="person160" depart="2.36" departPos="random">
    <walk edges="25683325#8 23952242#0" arrivalPos="6.80"/>
</person>
<vehicle id="car283" type="car" depart="2.83" departLane="free" departSpeed="max" fromTaz="1" toTaz="4">
    <route edges="25683325#2 25683325#3 25683325#4 25683325#5 25683325#6 25683325#7 25683325#8 35976990#1
</vehicle>
<person id="person283" depart="2.83" departPos="random">
    <walk edges="25683325#8 23952242#0" arrivalPos="0.43"/>
</person>
<vehicle id="car3005" type="car" depart="4.33" departLane="free" departSpeed="max" fromTaz="5" toTaz="8">
    <route edges="532174093#2 532174093#3 532174093#4 532174093#5 532174093#6 532174093#8 35969434#0 3596
</vehicle>
<vType id="mini_bus" length="4.70" minGap="1.58" maxSpeed="33.33" speedFactor="0.61" actionStepLength="1.
<vehicle id="mini_bus516" type="mini_bus" depart="4.77" departLane="free" departSpeed="max" fromTaz="1" t
    <route edges="25683325#2 25683325#3 25683325#4 25683325#5 25683325#6 25683325#7 25683325#8 35976990#1
</vehicle>
<person id="person519" depart="4.77" departPos="random">
    <walk edges="35969434#0 160456975#5" arrivalPos="3.41"/>
</person>
<vType id="4_WD" length="4.70" minGap="1.85" maxSpeed="33.33" speedFactor="0.61" actionStepLength="1.00"
<vehicle id="4_WD3860" type="4_WD" depart="4.80" departLane="free" departSpeed="max" fromTaz="7" toTaz="4"
    <route edges="160456975#0 160456975#2 160456975#4 160456975#5 35976990#1 35976990#2 35976990#3 359769
</vehicle>
```


FIGURE 43: GENERATED ROUTE FILE USING DUAROUTER

Step 4: SUMO simulation

Sumo-gui simulates a defined scenario using generated network file and route file. The SSM device needs to be equipped to a vehicle and the SSM device threshold value has to be set in the configuration file to records any conflicts between the vehicle and other vehicle and to log the corresponding surrogate safety measures values.

To attach SSM device, the standard device-equipment technique can be applied <device name>=ssm

SSM device are created the output file for each vehicle. To allow each vehicle to write the output into the same file, we can provide the option --device.ssm. file.

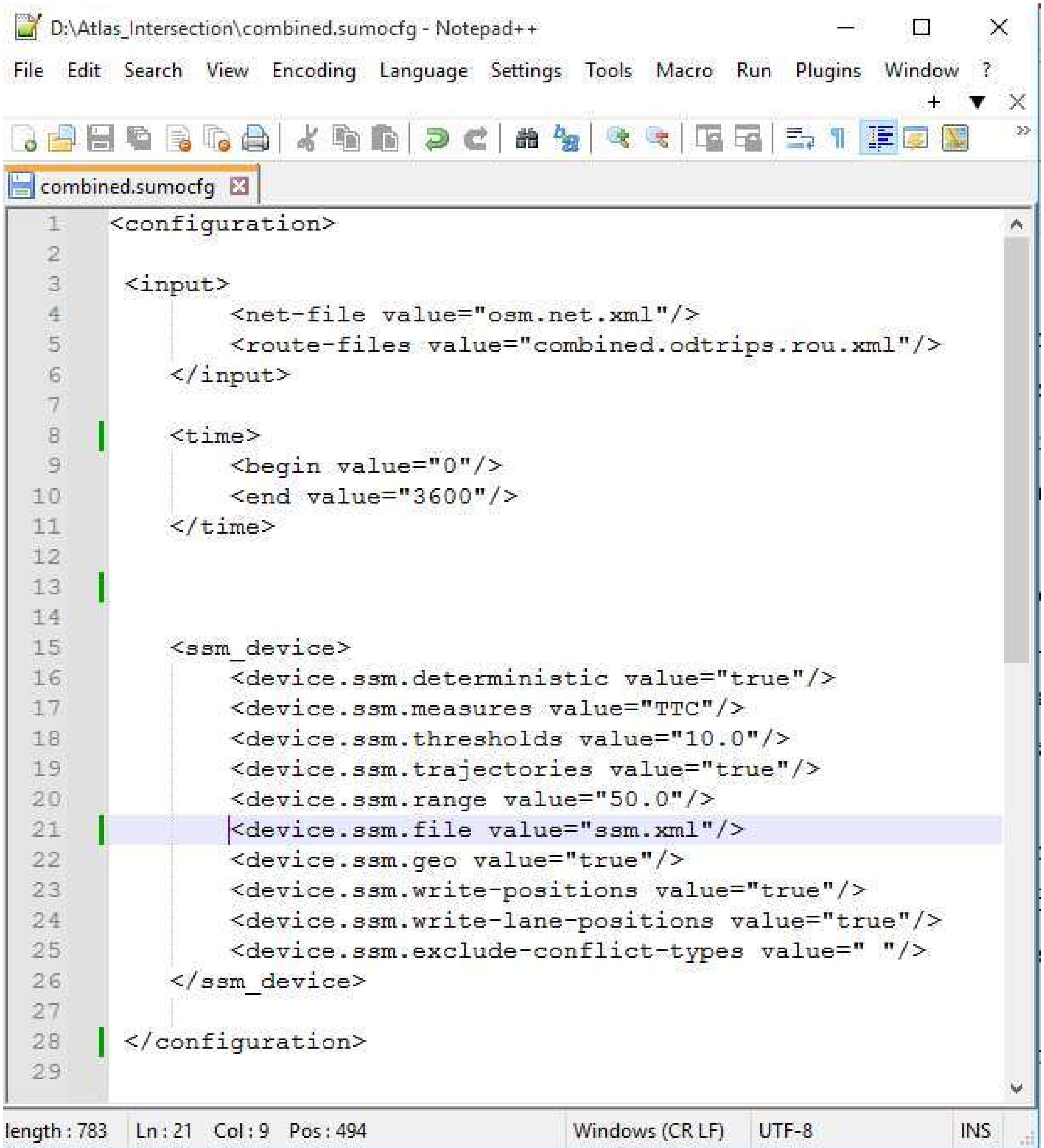


FIGURE 44: SUMO CONFIGURATION FILE TO SIMULATE THE GIVEN SCENARIO FOR ATLAS INTERSECTION

The configuration file mentioned above shows that an SSM device has been installed and specific threshold values have been configured. The information provided for each conflict and the threshold to qualify an encounter as a conflict can be customized by a number of basic parameters to the vehicle. The SSM device parameter's definition and threshold settings are as follows:

1. <device.ssm.deterministic value="true"/> denotes that the SSM device will be activated or installed in the vehicle during simulation.
2. <device.ssm.measures value="TTC"/> determine which SSMs value are calculated. A value of TTC will calculated for the equipped vehicle's encounters.
3. <device.ssm.thresholds value="10.0"/> determine the SSMs threshold value. The interaction of vehicles with TTC value less than or equal to 10 seconds are generated on the output file. The TTC value 10 seconds were selected in order to get the most accumulated TTC value and to include all small TTC values. No longer dangerous if TTC value is greater than 10 seconds.
4. <device.ssm.trajectories value="true"/> determine whether the output should contained the whole time lines of the TTC value. This includes recording types of conflict, positions and speeds of the vehicles, values of the TTC, and locations of conflict points at each simulation time step for the TTC value that meet the threshold. If the value is false only the extremal values for the TTC are written.
5. <device.ssm.range value="50.0"/> determine the device detection range. A threshold of 50 meters is set, beyond which there is no more chance of a collision during peak hour flow.The SSM device tracked the TTC values as soon as another vehicle approaches the equipped vehicle up to a range upstream and downstream from the vehicle's current position within the road network.
6. <device.ssm.file value="ssm.xml"/> determine the output file name that contains the equipped vehicle's conflict information are stored with value of ssm.xml.
7. <device.ssm.geo value="true"/> determine whether the positions in the output file reported in the network's original coordinate reference system due to netedit have its own coordinate system.
8. <device.ssm.write-positions value="true"/> determine whether the positions (coordinates) should be written to the output file.

9. <device.ssm.write-lane-positions value="true"/> denotes that whether to write the lane id and the positions on the lanes to the output file of the equipped vehicle at each simulation step within the threshold.

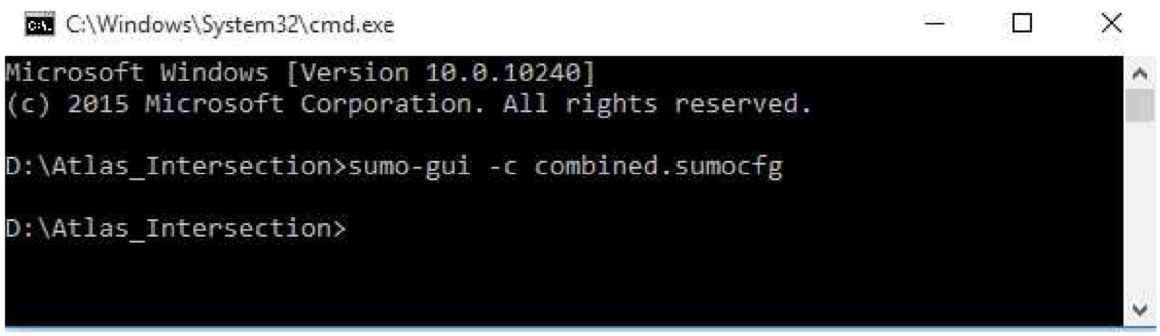


FIGURE 45: COMMAND TO START SIMULATION USING SUMO-GUI

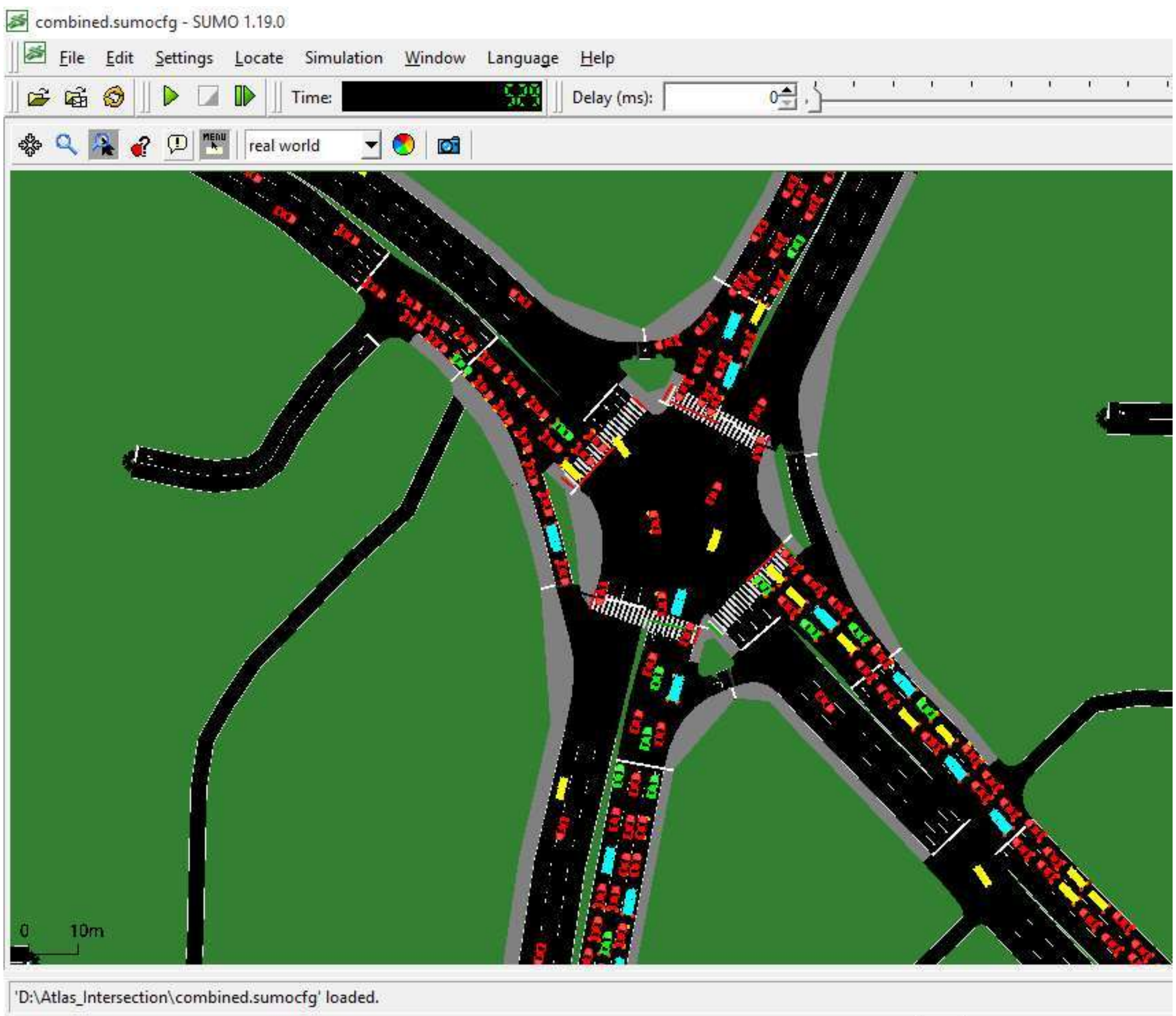
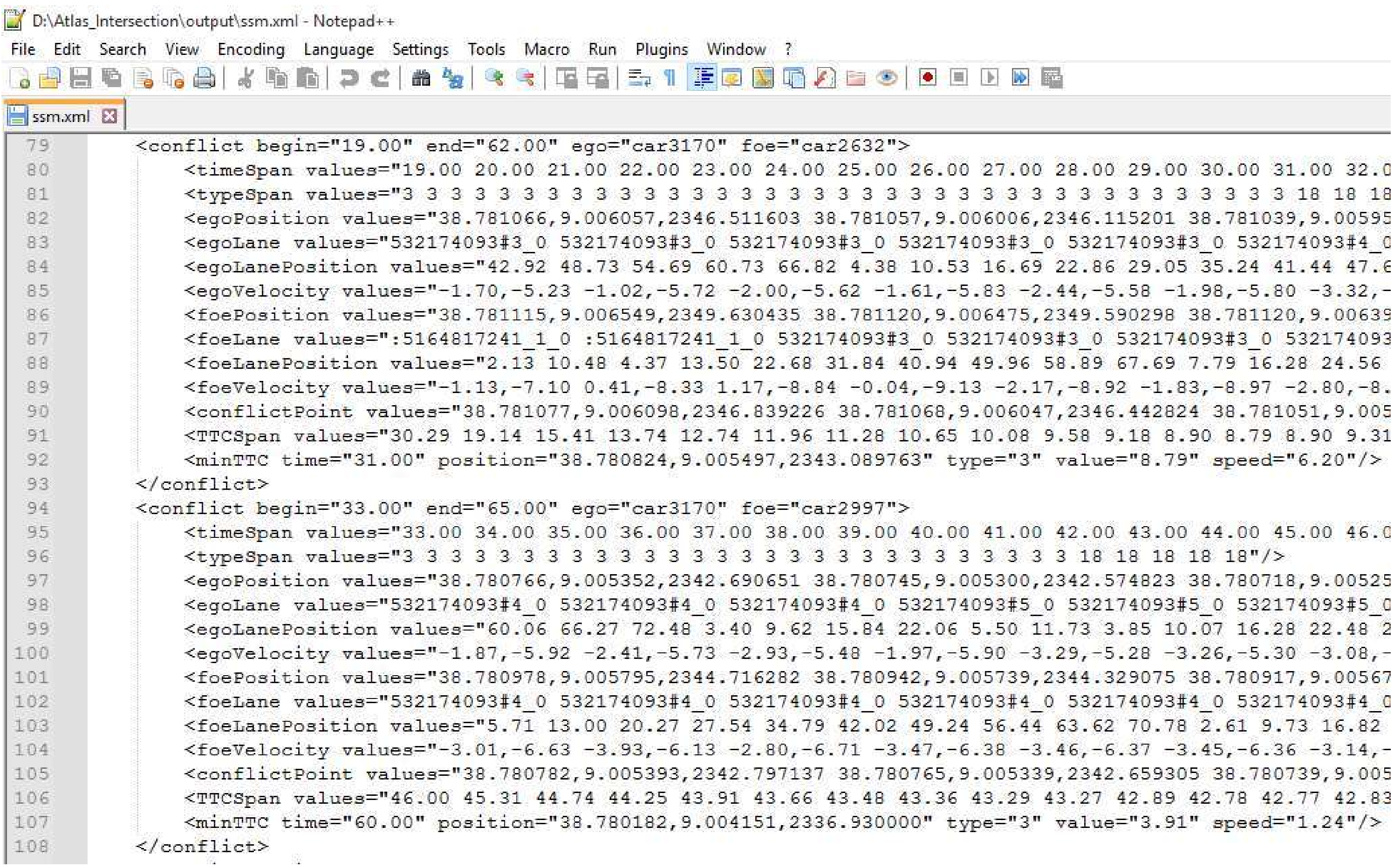


FIGURE 46: SIMULATION RUNNING USING SUMO-GUI

Step 5: SUMO surrogate safety measure output

An SSM device's output is written to a file that the specified by the parameter *device.ssm.file* mentioned on the above step 4. A parameter *device.ssm.trajectories* determine whether to report complete trajectories for vehicles, the tracked SSMs, and the encounter types. A parameter s*sm.measures* determine which SSMs are to report.

A root element called <*SSMLog*>, which includes many <*conflict*> components. Every reported <*conflict*> relates to a tracked encounter where the criticality threshold of TTC value was crossed during the simulation.




```
<conflict begin="19.00" end="62.00" ego="car3170" foe="car2632">
    <timeSpan values="19.00 20.00 21.00 22.00 23.00 24.00 25.00 26.00 27.00 28.00 29.00 30.00 31.00 32.0
    <typeSpan values="3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 18 18 18
    <egoPosition values="38.781066,9.006057,2346.511603 38.781057,9.006006,2346.115201 38.781039,9.00595
    <egoLane values="532174093#3_0 532174093#3_0 532174093#3_0 532174093#3_0 532174093#3_0 532174093#4_0
    <egoLanePosition values="42.92 48.73 54.69 60.73 66.82 4.38 10.53 16.69 22.86 29.05 35.24 41.44 47.6
    <egoVelocity values="-1.70,-5.23 -1.02,-5.72 -2.00,-5.62 -1.61,-5.83 -2.44,-5.58 -1.98,-5.80 -3.32,-
    <foePosition values="38.781115,9.006549,2349.630435 38.781120,9.006475,2349.590298 38.781120,9.00639
    <foeLane values=":5164817241_1_0 :5164817241_1_0 532174093#3_0 532174093#3_0 532174093#3_0 532174093
    <foeLanePosition values="2.13 10.48 4.37 13.50 22.68 31.84 40.94 49.96 58.89 67.69 7.79 16.28 24.56
    <foeVelocity values="-1.13,-7.10 0.41,-8.33 1.17,-8.84 -0.04,-9.13 -2.17,-8.92 -1.83,-8.97 -2.80,-8.
    <conflictPoint values="38.781077,9.006098,2346.839226 38.781068,9.006047,2346.442824 38.781051,9.005
    <TTCSpan values="30.29 19.14 15.41 13.74 12.74 11.96 11.28 10.65 10.08 9.58 9.18 8.90 8.79 8.90 9.31
    <minTTC time="31.00" position="38.780824,9.005497,2343.089763" type="3" value="8.79" speed="6.20"/>
</conflict>
<conflict begin="33.00" end="65.00" ego="car3170" foe="car2997">
    <timeSpan values="33.00 34.00 35.00 36.00 37.00 38.00 39.00 40.00 41.00 42.00 43.00 44.00 45.00 46.0
    <typeSpan values="3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 18 18 18 18 18"/>
    <egoPosition values="38.780766,9.005352,2342.690651 38.780745,9.005300,2342.574823 38.780718,9.00525
    <egoLane values="532174093#4_0 532174093#4_0 532174093#4_0 532174093#5_0 532174093#5_0 532174093#5_0
    <egoLanePosition values="60.06 66.27 72.48 3.40 9.62 15.84 22.06 5.50 11.73 3.85 10.07 16.28 22.48 2
    <egoVelocity values="-1.87,-5.92 -2.41,-5.73 -2.93,-5.48 -1.97,-5.90 -3.29,-5.28 -3.26,-5.30 -3.08,-
    <foePosition values="38.780978,9.005795,2344.716282 38.780942,9.005739,2344.329075 38.780917,9.00567
    <foeLane values="532174093#4_0 532174093#4_0 532174093#4_0 532174093#4_0 532174093#4_0 532174093#4_0
    <foeLanePosition values="5.71 13.00 20.27 27.54 34.79 42.02 49.24 56.44 63.62 70.78 2.61 9.73 16.82
    <foeVelocity values="-3.01,-6.63 -3.93,-6.13 -2.80,-6.71 -3.47,-6.38 -3.46,-6.37 -3.45,-6.36 -3.14,-
    <conflictPoint values="38.780782,9.005393,2342.797137 38.780765,9.005339,2342.659305 38.780739,9.005
    <TTCSpan values="46.00 45.31 44.74 44.25 43.91 43.66 43.48 43.36 43.29 43.27 42.89 42.78 42.77 42.83
    <minTTC time="60.00" position="38.780182,9.004151,2336.930000" type="3" value="3.91" speed="1.24"/>
</conflict>
```


FIGURE 47: SURROGATE SAFETY MEASURES OUTPUT

TABLE 10: SAMPLES OF SUMMARIZED OUTPUT OF SUMO SSMS FOR LEAD-FOLLOW CONFLICT TYPES

No	Conflict begin (seconds)	Conflict end (seconds)	Ego vehicle	Foe vehicle	Minimum TTC					
					Simulation time(second)	Position			Conflict type	value (second)
						Longitude (degree)	Latitude (degree)	Elevation (meter)		
1	16	22	motorcycle2532	car2997	17	38.781134	9.006806	2348.557	2	2.77
2	30	66	car3533	car3611	33	38.779128	8.997211	2323.039	2	4.67
3	24	83	pickup4515	car4260	34	38.779251	8.997712	2325.954	3	4.88
4	17	86	pickup1572	car1342	80	38.779919	9.003942	2335.353	3	1.77
5	16	87	car2632	motorcycle2532	62	38.78015	9.004155	2336.930	3	3.56
6	25	88	car1419	car1388	52	38.777743	9.005452	2335.725	2	8.04
7	76	88	car63	car9	77	38.780366	9.003713	2335.893	3	8.75
8	24	107	car1135	pickup1590	92	38.779904	9.003955	2335.299	2	8.13
9	50	111	car1235	car1407	108	38.779898	9.00398	2335.282	2	4.54
10	69	110	car1857	motorcycle1437	103	38.779812	9.004092	2335.173	2	8.45
11	100	112	car4260	pickup4500	107	38.780129	9.003522	2333.470	2	1.79
12	91	118	car3439	car3533	108	38.780183	9.003519	2333.470	3	3.42
13	80	122	car1280	car1407	105	38.779915	9.00396	2335.302	3	3.01
14	106	125	car1745	car1375	121	38.777311	9.005891	2341.751	2	3.13
15	62	128	car198	mini_bus523	123	38.780521	9.003551	2336.000	2	2.61
16	97	116	car1407	car1135	100	38.779905	9.003953	2335.300	2	9.94
17	79	98	car1342	pickup1590	82	38.779867	9.003985	2335.262	3	7.3
18	85	114	motorcycle1437	car1378	105	38.779926	9.003975	2335.299	2	2.59
19	71	146	car1856	car1814	131	38.780175	9.003931	2335.890	3	5.01
20	128	147	car1067	car1145	131	38.779902	9.003958	2335.295	2	6.79
21	61	149	car2956	car2359	74	38.780235	9.004195	2336.930	2	2.02
22	62	146	car2359	car2997	73	38.780209	9.004123	2336.930	2	1.89
23	57	152	car2988	car3022	74	38.78021	9.004202	2336.930	2	1.97
6022	3364	3599	car629	car660	3368	38.784206	8.999824	2343.652	2	3.07
6023	3400	3599	car629	car642	3428	38.784303	8.999755	2343.340	3	1.91
6024	3577	3599	car635	car650	3598	38.784454	8.999619	2342.989	3	3.92
6025	3571	3599	car641	car822	3579	38.784222	8.999747	2343.450	3	2.26
6026	3400	3599	car642	car664	3406	38.784478	8.999654	2342.987	3	2.61
6027	3593	3599	car650	car682	3596	38.784545	8.99957	2343.225	3	4.16
6028	3349	3599	car660	mini_bus592	3361	38.784162	8.99985	2343.904	2	2.03
6029	3564	3599	car670	car717	3568	38.784418	8.999692	2343.111	2	3.33
6030	2922	3599	car672	car94	2930	38.784043	8.999938	2344.561	3	1.98
6031	3139	3599	car755	car771	3143	38.783981	8.999907	2344.583	2	2.93
6032	3168	3599	car755	car820	3429	38.781416	9.002499	2334.809	3	1.69
6033	2976	3599	car763	car888	2983	38.783404	9.000417	2342.699	3	1.81
6034	3275	3599	car769	car850	3292	38.783962	8.999922	2344.601	3	1.85
6035	3281	3599	car769	car791	3559	38.782756	9.001055	2339.114	2	2.84
6036	3136	3599	car771	car778	3427	38.781331	9.002596	2334.865	3	1.43
6037	3362	3599	car795	mini_bus923	3368	38.783155	9.000666	2342.334	3	2.22
6038	2954	3599	car805	car846	2959	38.783274	9.000543	2342.503	2	3.4
6039	3061	3599	car814	car836	3568	38.780428	9.003562	2335.929	3	1.41
6040	3574	3599	car822	mini_bus527	3599	38.783947	8.999944	2344.619	2	1.8
6041	3521	3599	car847	car904	3526	38.783905	8.999959	2344.650	3	3.45
6042	3156	3566	car854	car900	3159	38.78195	9.001893	2336.417	2	3.98
6043	3122	3599	mini_bus501	mini_bus539	3255	38.781338	9.002628	2334.873	3	3.63
6044	3576	3599	mini_bus512	mini_bus513	3583	38.782023	9.001819	2336.204	2	2.28

Where

- Ego vehicle is any potential vehicle that equipped SSM device since it serves as the simulation's primary focus point and source of interest. For instance, when a vehicle traveling through a city, it is surrounded by numerous vehicles within certain range. The term "ego vehicle" refers to the studying vehicle.
- Foe vehicle is a vehicle that surrounds the ego vehicle.
- Conflict type refers to the corresponding conflict type. When Ego vehicle is following the foe vehicle the value equals to 2 and when foe vehicle is following the ego vehicle the value equals to 3.
- Min TTC value refers to the minimum measured TTC-value.

4.2 Analysis of SUMO output

All collected geometric and traffic characteristics data were used as input for SUMO for each intersections. On this section we mainly focus on analysis of SUMO output, surrogate safety measure, particularly the value of minimum TTC. As I mentioned on the section of 1.3, the purpose of the research is to develop probabilistic model for the occurrence of potential conflict in terms of TTC. The time to collision is a continuous number with a value of above 0 second. A Weibull probabilistic distribution model were selected from a continuous probabilistic distribution model based on the actual minimum TTC distribution. The minimal TTC distribution looks a bell-shaped curve with some skewness, as shown on figure 48. As a result, the Weibull distribution were chosen and represents the distribution in a better way.

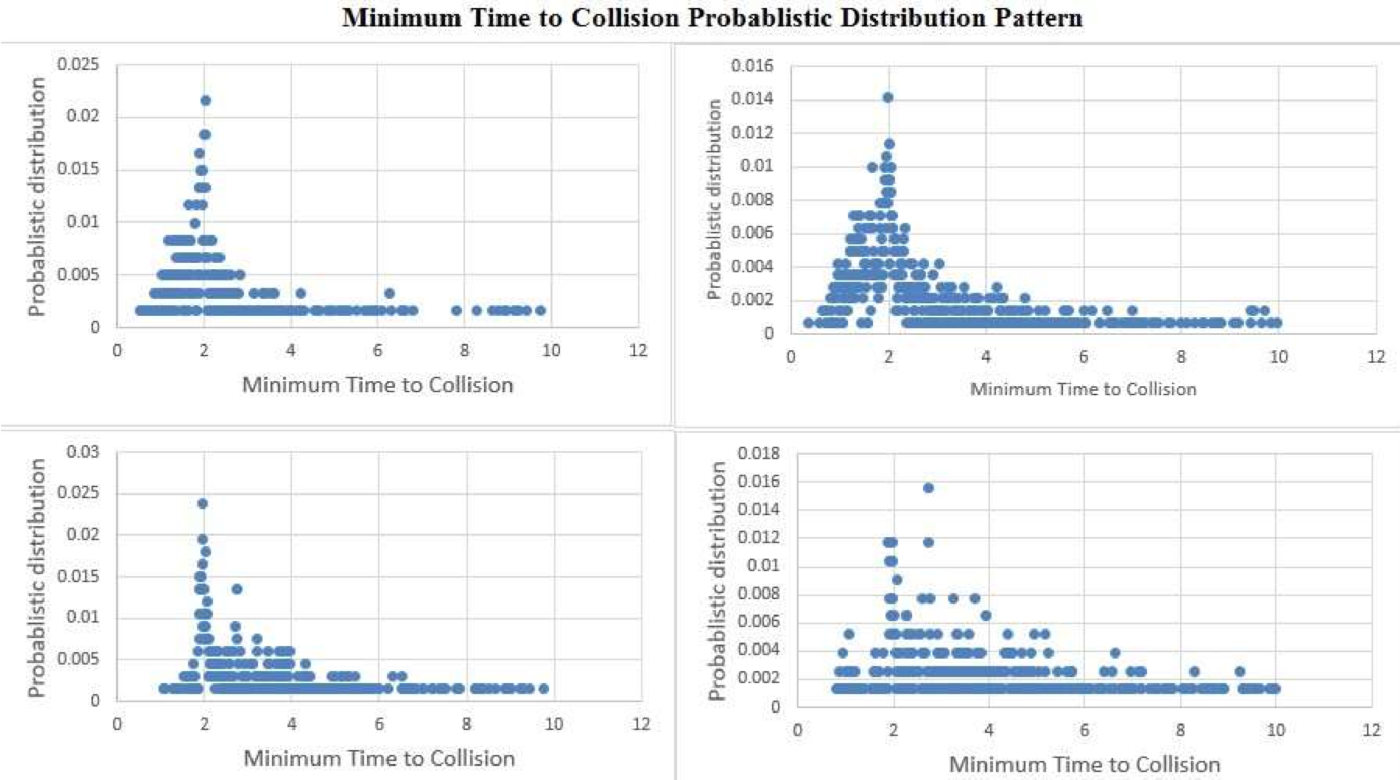


FIGURE 48: TIME TO COLLISION PROBABILISTIC DISTRIBUTION PATTERN

Development of Weibull distribution function

Weibull distribution represent the random variable X with parameter of α and β, the probabilistic density function is given by:

$$f(x;\alpha,\beta)=\frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1}e^{-(x/\beta)^{\alpha}}$$

and the cumulative distribution function is given by

$$F(x;\alpha,\beta)=1-e^{-(x/\beta)^{\alpha}}$$

Where X is a random variable with a value above 0 and α and β is the shape and scale factor respectively with the value above 0.

To represent the minimum TTC value with Weibull distribution function the only required parameter is α and β. The following are the steps to determine α and β using MS-EXCEL.

Step-1: Prepare the value of minimum TTC in ascending order.

Step-2: Convert in to frequency distribution table.

Step-3: Prepare cumulative distribution for the discrete value.

Step-4: Assume reasonable α and β value.

Step-5: Prepare cumulative Weibull distribution for the minimum TTC using trial α and β value.

Step-6: Calculate R^2 between the actual and the Weibull distribution.

Step-7: Using Excel's Solver, determine the values of α and β through trial and error, by setting the objective of maximizing the value of R^2 by changing the parameter α and β.

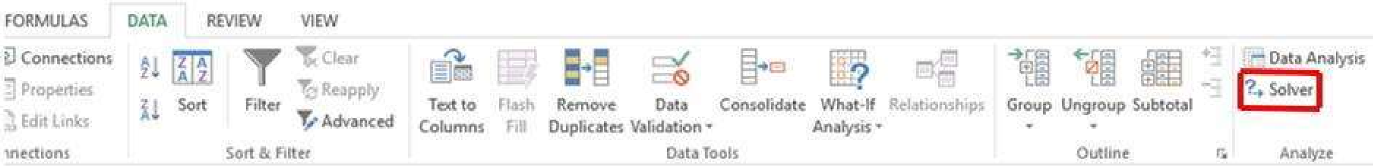


FIGURE 49: CALCULATE ALPHA AND BETA USING EXCEL

TABLE 11: CALCULATION OF ALPHA AND BETA OF WEIBULL DISTRIBUTION

I94 =WEIBULL.DIST(C94,M2,N2,TRUE)

	No	minTTC_value	Frequency	Cumulative	Actual CDF	Webull CDF	Actual CDF variation from the mean	Square of Absolute difference between actual and the weibull distribution difference	R2	alpha	beta
86	85	1.8	2	218	0.362728785	0.391505798	0.050185993	0.000828116	0.974195	3.380899	2.213829
87	86	1.81	7	225	0.37437604	0.39719435	0.045103162	0.000520675			
88	87	1.82	1	226	0.376039933	0.402903986	0.044399191	0.000721677			
89	88	1.83	1	227	0.377703827	0.408633655	0.043700758	0.000956654			
90	89	1.84	4	231	0.384359401	0.414382291	0.040962395	0.000901374			
91	90	1.85	3	234	0.389351082	0.42014882	0.038966763	0.000948501			
92	91	1.86	4	238	0.396006656	0.425932155	0.036383439	0.000895536			
93	92	1.87	3	241	0.400998336	0.431731196	0.034504085	0.000944509			
94	93	1.88	8	249	0.414309484	0.437544834	0.029736107	0.000539881			
95	94	1.89	2	251	0.417637271	0.443371952	0.028599483	0.000662274			
96	95	1.9	8	259	0.430948419	0.44921142	0.024274472	0.000333537			
97	96	1.91	10	269	0.447587354	0.455062101	0.019366545	5.58718E-05			
98	97	1.92	9	278	0.462562396	0.460922851	0.015422832	2.68811E-06			
99	98	1.93	8	286	0.475873544	0.466792516	0.01229383	8.24651E-05			
100	99	1.94	9	295	0.490848586	0.472669936	0.00919729	0.000330463			
101	100	1.95	7	302	0.50249584	0.478553945	0.007098947	0.000573214			
102	101	1.96	9	311	0.517470882	0.48444337	0.004799747	0.001090817			
103	102	1.97	3	314	0.522462562	0.490337034	0.004133015	0.00103205			
104	103	1.98	5	319	0.53078203	0.496233755	0.003132536	0.001193583			

The Weibull distribution modeled the TTC distribution with R^2 value above 95% for all roads approaches of intersection

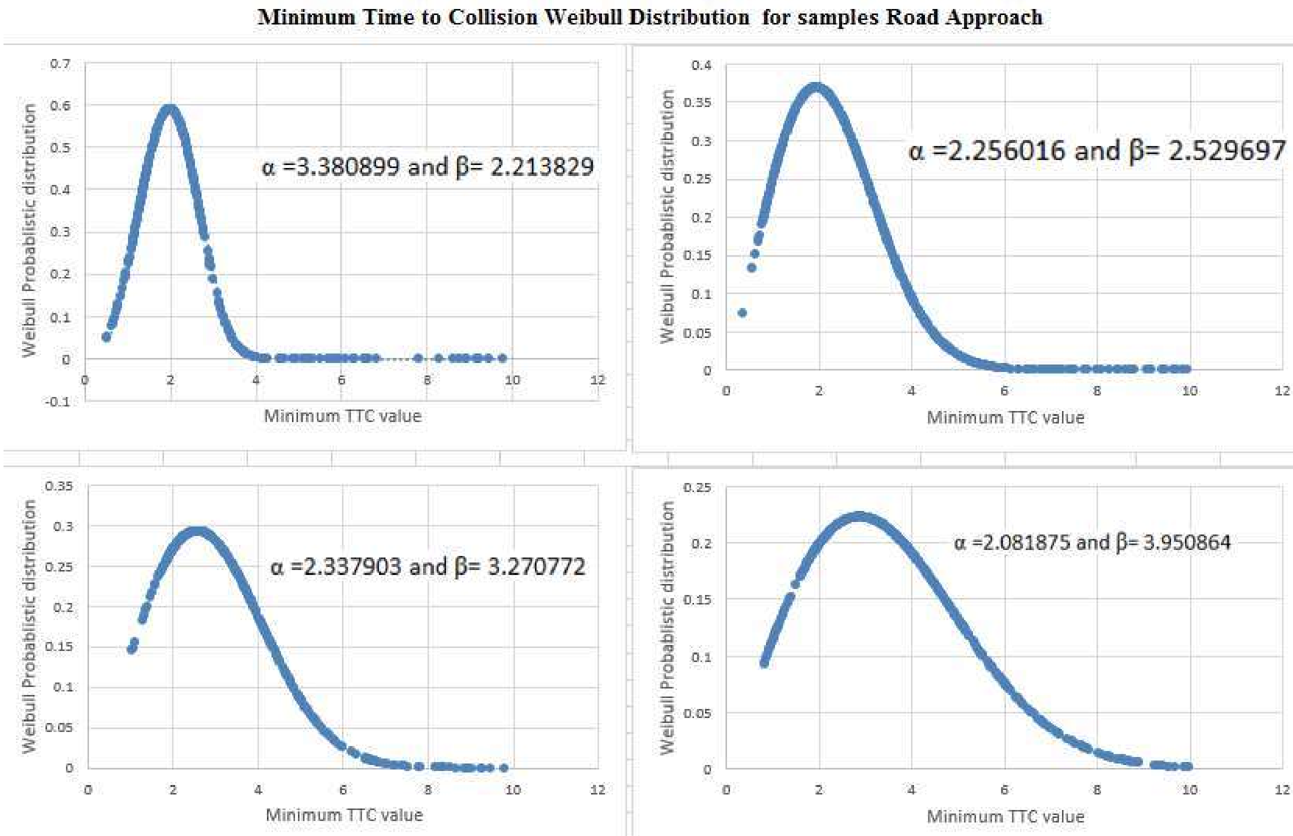


FIGURE 50: WEIBULL DISTRIBUTION FOR SAMPLES OF ROAD APPROACH FOR MINIMUM TTC

The mean and standard deviation of the TTC distribution is calculated by :

$$\mu = \beta\Gamma\left(1 + \frac{1}{\alpha}\right)$$

$$\sigma = \beta\sqrt{\Gamma\left(1 + \frac{2}{\alpha}\right) - \left[\Gamma\left(1 + \frac{1}{\alpha}\right)\right]^2}$$

Where Γ represent the gamma function and the values were calculated using MS Excel. After getting the gamma function value, mean and standard deviation were calculated using substitution

The mean represents the average or expected value of the distribution, while the standard deviation provides a measure of the spread or variability around the mean.

- From the above figure indicated that the Weibull distribution with a lower mean value and a lower standard deviation for the road approaches will indicate that susceptible to occurring potential conflict with high chance. When the larger mean and standard deviation value have low chance of occurring potential conflict.

4.3 Evaluation of the selected Intersection Road Approach

Evaluating the intersection approach road is based on the probability of the occurrence of the potential conflict along the road approaches of the intersection. The probability of the Weibull function is affected by parameter α and β at the same time. So we need to calculate the Weibull cumulative probability for the critical TTC. Safe time to collision should be greater than perception reaction time. (AASHTO, 2018) AASHTO Green book recommends perception reaction time of 2.5 seconds. We have adopting 2.5 second as critical measure of potential conflict.

The cumulative Weibull distribution function for (TTC≤2.5s) for each approaches all intersection of is calculated by $F(x;\alpha,\beta) = 1 - e^{-(x/\beta)^{\alpha}}$

Where α and β represent shape and scale factors of Weibull distribution for the value of TTC respectively.

The following table 12 showed that the summarized values of lane width, number of lanes, grade, traffic volume, speed, normalized speed deviation, and number of leg for the selected intersection of each approaches.

TABLE 12: SUMMARIZED GEOMETRIC AND TRAFFIC CHARACTERISTICS DATA

Intersection No	Approach road	TAZ	Lane Width	Number of Lanes	Grade(%)	Traffic Volume/lane	Speed deviation	Vehicle Speed(Km/hr)	No of leg
1	1	TAZ1	3.00	2	-4.62	204	0.37	23	4
	2	TAZ3	3.37	3	2.26	433	0.46	30	4
	3	TAZ5	3.00	2	-5.00	247	0.51	17	4
	4	TAZ7	3.00	2	1.33	301	0.30	22	4
2	5	TAZ1	3.50	3	1.25	318	0.37	21	4
	6	TAZ3	3.42	3	2.19	419	0.42	42	4
	7	TAZ5	3.50	3	-7.19	407	0.44	25	4
	8	TAZ7	3.20	3	2.77	383	0.22	19	4
3	9	TAZ1	3.25	3	3.38	699	0.38	21	3
	10	TAZ3	3.25	3	-3.26	421	0.42	35	3
	11	TAZ5	3.05	2	-3.92	224	0.30	19	3
4	12	TAZ1	3.25	3	-3.00	408	0.50	28	3
	13	TAZ3	3.20	3	-5.84	153	0.38	34	3
	14	TAZ5	3.00	3	2.84	686	0.43	30	3
5	15	TAZ1	3.39	4	4.33	586	0.33	32	4
	16	TAZ3	3.39	4	-4.33	704	0.28	44	4
	17	TAZ5	3.45	1	-2.77	315	0.26	22	4
	18	TAZ7	3.90	1	2.63	289	0.36	26	4
6	19	TAZ1	3.25	3	-1.00	337	0.42	45	4
	20	TAZ3	3.25	3	2.14	487	0.45	35	4
	21	TAZ5	3.40	2	-2.15	163	0.47	21	4
	22	TAZ7	3.40	2	1.70	187	0.49	26	4
7	23	TAZ1	3.39	4	1.39	534	0.30	46	3
	24	TAZ3	3.39	4	-1.85	595	0.36	23	3
	25	TAZ5	3.00	2	-3.24	156	0.36	23	3
8	26	TAZ1	3.25	3	-7.02	102	0.26	43	4
	27	TAZ3	3.25	3	-1.74	216	0.29	25	4
	28	TAZ5	3.25	3	2.30	517	0.32	23	4
	29	TAZ7	3.00	2	-2.03	74	0.22	33	4

Weibull cumulative probability for TTC less than 2.5 second were calculated for all intersections of each approaches.

The following table 13 showed that the value of alpha, beta, mean, standard deviation and Weibull cumulative probability for eight intersections with 29 approach roads.

TABLE 13: PROBABILITY FOR THE OCCURRENCE OF POTENTIAL CONFLICT FOR ALL APPROACH

Intersection No	Approach road	TAZ	Alpha	Beta	Gamma (1+(1/alpha))	Gamma (1+(2/alpha))	Mean	standard deviation	Weibull Comulative Distribution for TTC<2.5
1	1	TAZ1	2.106	4.117	0.886	0.980	3.647	1.820	0.295
	2	TAZ3	2.732	2.540	0.890	0.915	2.259	0.893	0.616
	3	TAZ5	2.565	3.622	0.888	0.926	3.216	1.345	0.320
	4	TAZ7	2.212	3.819	0.886	0.963	3.382	1.615	0.324
2	5	TAZ1	3.444	3.119	0.899	0.891	2.804	0.900	0.373
	6	TAZ3	2.653	2.745	0.889	0.920	2.440	0.990	0.542
	7	TAZ5	2.338	3.271	0.886	0.947	2.898	1.317	0.413
	8	TAZ7	2.561	3.220	0.888	0.926	2.859	1.197	0.407
3	9	TAZ1	3.381	2.214	0.898	0.893	1.988	0.649	0.779
	10	TAZ3	2.765	2.668	0.890	0.913	2.374	0.928	0.566
	11	TAZ5	2.082	3.951	0.886	0.984	3.499	1.764	0.320
4	12	TAZ1	2.874	2.666	0.891	0.908	2.376	0.898	0.565
	13	TAZ3	2.368	3.614	0.886	0.944	3.203	1.439	0.342
	14	TAZ5	2.277	2.229	0.886	0.955	1.974	0.919	0.727
5	15	TAZ1	2.781	3.036	0.890	0.912	2.702	1.051	0.442
	16	TAZ3	2.370	2.807	0.886	0.944	2.488	1.117	0.532
	17	TAZ5	2.414	4.697	0.887	0.939	4.165	1.839	0.196
	18	TAZ7	2.513	4.959	0.887	0.930	4.401	1.874	0.164
6	19	TAZ1	2.040	3.610	0.886	0.992	3.198	1.643	0.377
	20	TAZ3	2.607	2.539	0.888	0.923	2.256	0.930	0.617
	21	TAZ5	3.593	3.677	0.901	0.889	3.313	1.024	0.221
	22	TAZ7	3.041	3.591	0.894	0.901	3.208	1.152	0.283
7	23	TAZ1	2.919	3.050	0.892	0.906	2.720	1.013	0.429
	24	TAZ3	2.131	3.006	0.886	0.976	2.662	1.315	0.491
	25	TAZ5	2.679	4.456	0.889	0.918	3.962	1.594	0.191
8	26	TAZ1	2.464	4.441	0.887	0.934	3.939	1.707	0.215
	27	TAZ3	2.788	3.348	0.890	0.912	2.981	1.157	0.358
	28	TAZ5	2.256	2.530	0.886	0.957	2.241	1.051	0.622
	29	TAZ7	2.059	5.772	0.886	0.988	5.113	2.604	0.164

Calculation of Weibull cumulative function for Intersection No.1 for the road approaches 1 has shown below:

F (TTC; α, β) =1-e$^{-(TTC/\beta)\text{ to power of }\alpha}$ =

F (2.5; 2.106, 4.117) = 1-e$^{-(2.5/4.117)\text{ to the power of }2.106}$

F (2.5; 4.117, 3.647) =1- e$^{-0.35}$ =1-(1/e$^{0.35}$)

F (2.5; 4.117, 3.647) =1-0.705=**0.295**

The cumulative Weibull of 0.295 or 29.5% indicated that the road approaches 1 has 29.5% chance of occurring potential conflict.

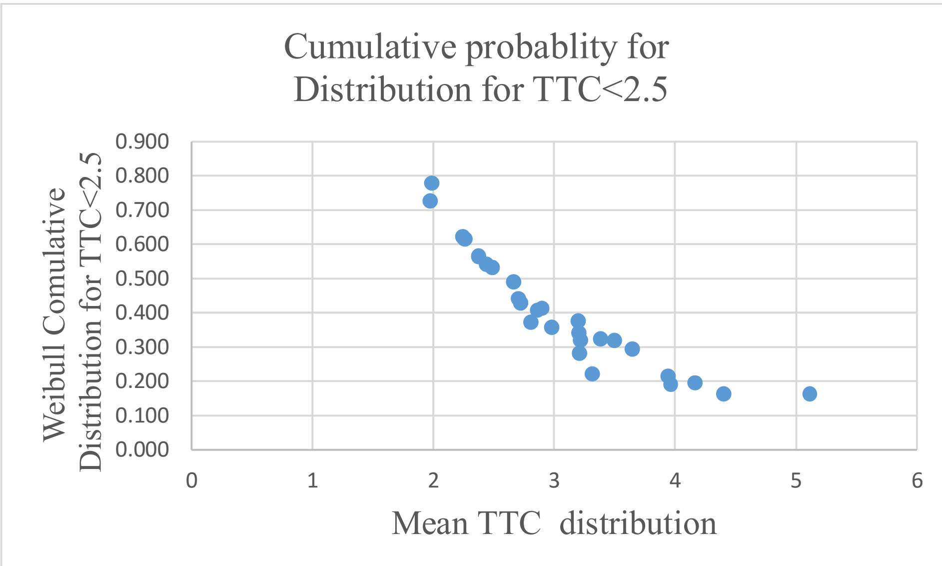


FIGURE 51: CUMULATIVE PROBABILITY FOR (TTC <2.5 SECONDS) WITH MEAN TTC

The mean of the TTC distribution varies from 1.974 seconds to 5.11 seconds. When the mean value of TTC increases, the Weibull cumulative probability will decreases due to vehicles have higher values of Time to Collison.

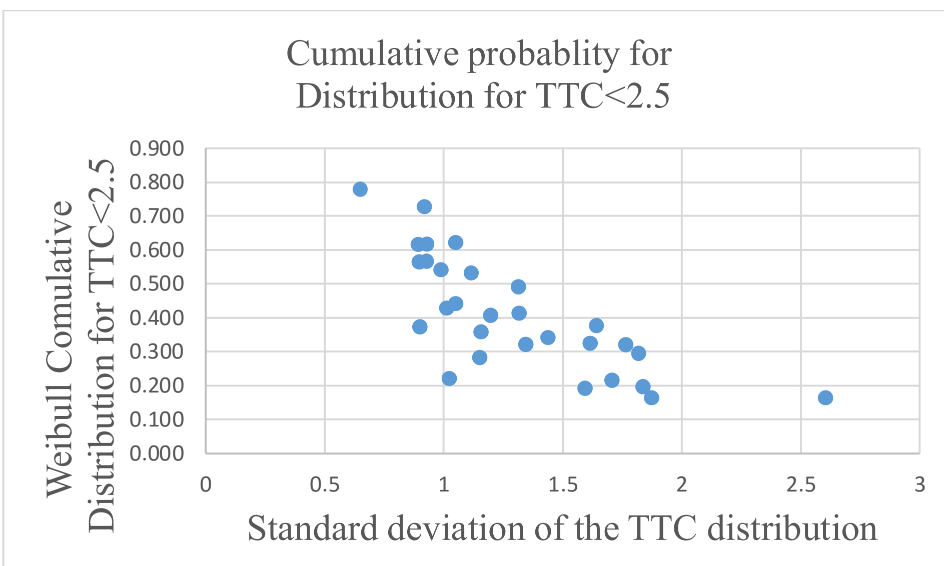


FIGURE 52: CUMULATIVE PROBABILITY FOR (TTC <2.5 SECONDS) WITH STANDARD DEVIATION

The standard deviation of the TTC distribution varies from 0.649 seconds to 2.64 seconds. When the standard deviation increases, with increasing mean of the distribution then the Weibull cumulative probability will decreases due to vehicles have disperse TTC distribution.

The probability of occurrence of potential conflict is affected by both mean and standard deviation.

From all road approaches the largest mean TTC is 5.113 seconds with a standard deviation of 2.604, was obtained from the Latica Bakery to the Salitmhiret junction, which has a relatively low chance of occurring potential conflict. The second lowest mean value of TTC, 1.988 seconds with a standard a minimum standard deviation of 0.649, was obtained from the Jacross to Gerji Meberat Hayel intersections, which are highly susceptible to potential conflict from all road approaches.

From the table 14 below, the Weibull cumulative probability at intersection number 8 roads from TAZ 7, roads or from Latica bakery to Salithmhiret intersection has a smallest value of 0.164 or 16.4%. This indicated that the occurrence of potential conflict will occur with 16.4% chance. Roads from latica bakery to salithmhiret junction has two number of lanes, lane width of 3.0M, a grade of -2.03%, traffic flow of 74veh/h/lane and has a speed of 33 km/hr with 22% speed deviation. And

Weibull cumulative probability at intersection number 3 from TAZ 1 roads from Jacross to Gerji meberat-hayel junction has a largest value of 0.779 or 77.9 %. This indicated that the occurrence of potential conflict will occur with high chance of 77.9%. The approach road from Jacross to Gerji meberat-hayel junction has three number of lanes, lane width of 3.25m with a grade of 3.38%, traffic flow of 699 vehicle/h/lane and 21km/hr with 38% speed deviation.

4.4 Prediction Models for occurrence of potential conflict

Prior to anything else, ascertain whether the independent and dependent variables are correlated. The effect of lane width, number of lanes, grade, traffic volume per lane, speed and speed deviation on the cumulative distribution of TTC.

	Weibull Comulative Distribution for TTC<2.5	*Lane Width*	*Number of Lanes*	*Grade(%)*	*Traffic Volume/lane*	*Vehicle Speed(Km/hr)*	*Speed deviation*
Weibull Comulative Distribution for TTC<2.5	1						
Lane Width	-0.146359431	1					
Number of Lanes	-0.616464792	0.21457	1				
Grade(%)	-0.41639026	0.27062	0.13073824	1			
Traffic Volume/lane	0.83422499	0.31455	0.63329375	0.46875981	1		
Vehicle Speed(Km/hr)	0.166300946	0.23619	0.49145482	-0.0319389	0.199686053	1	
Speed deviation	0.307180809	0.06526	-0.0335887	0.01782855	0.07706867	-0.074612761	1

FIGURE 53: CORRELATION BETWEEN DEPENDENT AND INDEPENDENT VARIABLES

The correlation between the Weibull Cumulative Distribution of TTC, or the probability of possible traffic conflicts, and the independent variables has been shown in Figure 53 above, with particular situations in which the Time to Collision (TTC) is less than 2.5 seconds.

The Lane Width**:** A lane width have negative correlation (-0.15) with the probability of potential traffic conflicts with TTC<2.5 seconds. The probability of a potential conflict and lane width had a relatively inverse relationship. When lane widths decreases, vehicles often feel more restricted and drivers perceive less margin for maneuvering and which causes them to react more quickly and it may cause conflict when they try to change lanes. The probability of a possible collision will reduce as lane width increases because drivers may unconsciously believe there is more space to maneuver. As a result, they may be less cautious and respond more slowly to any potential conflicts.

Number of Lanes: There is a moderate negative connection (-0.62) between the number of lanes and the likelihood of possible conflict for the data caries from number of lane 1 to number of lane 4. More lanes improve traffic flow and make it easier for vehicles to maneuver with adequate space between them.

Grade (%): A grade has moderately negative correlation (-0.42) indicates that steeper roads has decrease the probability of occurrence of potential conflict due to slow traffic speed and increasing the reaction time.

Traffic Volume/lane: The strong positive correlation (0.83) indicated that higher traffic volumes per lane can increase the probability of potential conflicts because of vehicles has less room for the maneuvering and cause lane changes more frequently, and make it harder to keep a safe distance between them and when the traffic volume per lane increases the traffic congestion also increases, as a result the probability of rear-end collisions, side-impact collision, and conflicts at intersections increases.

Vehicle Speed (Km/hr): A weak positive correlation (0.17) results between vehicle speeds and probability of potential conflicts from the data of speed ranges from minimum of 19km/hr to maximum of 46Km/hr. When speed of vehicle increases the probability of potential conflict increases due to drivers' reaction times get shorter at higher speeds. Drivers may have less time to observe and react in circumstances demanding quick maneuvers, including avoiding obstructions or reacting to unexpected events, which raises the possibility of collisions.

Speed Deviation: The moderate positive correlation (0.31) indicates that an increase in speed deviation corresponds to a higher probability of potential traffic conflicts. Variations in vehicle speeds, or speed deviations, can shorten the time available for reactions and narrow the space between vehicles, which can lead to a higher probability of potential conflicts.

This study used the Multiple Linear Regression (MLR) model to construct a prediction model that uses the Time to collision to estimate the probability of a potential conflict using MS-Excel data analysis Tool Pak. The model have been developed by taking lane width, grade, traffic volume/lane, speed, and speed deviation as explanatory variables while probability of the occurrence of TTC below 2.5 seconds are the dependent variable. A total of 29 observations as shown below in Table 14.

TABLE 14: SUMMARIZED DEPENDENT AND INDEPENDENT VARIABLE VALUES FOR MODEL DEVELOPMENT

Intersection No	Approach road	TAZ	Weibull Comulative Distribution for TTC<2.5	Lane Width	Number of Lanes	Grade(%)	Traffic Volume/lane	Vehicle Speed(Km/hr)	Speed deviation	No of leg
1	1	TAZ1	0.295	2.68	2	-4.62	204	23	0.37	4
	2	TAZ3	0.616	3.37	3	2.26	433	30	0.46	4
	3	TAZ5	0.320	2.55	2	-5.00	247	17	0.51	4
	4	TAZ7	0.324	2.69	2	1.33	301	22	0.30	4
2	5	TAZ1	0.373	3.50	3	1.25	318	21	0.37	4
	6	TAZ3	0.542	3.42	3	2.19	419	42	0.42	4
	7	TAZ5	0.413	3.50	3	-7.19	407	25	0.44	4
	8	TAZ7	0.407	3.20	3	2.77	383	19	0.22	4
3	9	TAZ1	0.779	3.25	3	3.38	699	21	0.38	3
	10	TAZ3	0.566	3.25	3	-3.26	421	35	0.42	3
	11	TAZ5	0.320	3.05	2	-3.92	224	19	0.30	3
4	12	TAZ1	0.565	3.25	3	-3.00	408	28	0.50	3
	13	TAZ3	0.342	3.20	3	-5.84	153	34	0.38	3
	14	TAZ5	0.727	3.00	3	2.84	686	30	0.43	3
5	15	TAZ1	0.442	3.39	4	4.33	586	32	0.33	4
	16	TAZ3	0.532	3.39	4	-4.33	704	44	0.28	4
	17	TAZ5	0.196	3.45	1	-2.77	315	22	0.26	4
	18	TAZ7	0.164	3.90	1	2.63	289	26	0.36	4
6	19	TAZ1	0.377	3.25	3	-1.00	337	45	0.42	4
	20	TAZ3	0.617	3.25	3	2.14	487	35	0.45	4
	21	TAZ5	0.221	3.40	2	-2.15	163	21	0.47	4
	22	TAZ7	0.283	3.40	2	1.70	187	26	0.49	4
7	23	TAZ1	0.429	3.39	4	1.39	534	46	0.30	3
	24	TAZ3	0.491	3.39	4	-1.85	595	23	0.36	3
	25	TAZ5	0.191	2.63	2	-3.24	156	23	0.36	3
8	26	TAZ1	0.215	3.25	3	-7.02	102	43	0.26	4
	27	TAZ3	0.358	3.25	3	-1.74	216	25	0.29	4
	28	TAZ5	0.622	3.25	3	2.30	517	23	0.32	4
	29	TAZ7	0.164	2.70	2	-2.03	74	33	0.22	4

Multiple Linear Regression model is used to predict the probability of TTC value will below 2.5s this model was developed using the MS-Excel Data Analysis Tool Pak. The model has a form of the equation: $Y = b + b1x1 + b2x2 + \cdots + bnxn$

Whereas: Y is probability of the occurrence of potential conflict (a dependent variable); X1, X2, ..., Xn are the independent variables; b is Y-intercept and b1, b2, …, bn, are the coefficients of the independent variables.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.89598874
R Square	0.80279583
Adjusted R Square	0.74901287
Standard Error	0.08504058
Observations	29

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	0.647685401	0.10794757	14.926584	9.18609E-07
Residual	22	0.159101805	0.0072319		
Total	28	0.806787206			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.13893394	0.190739987	0.72839443	0.0478596	-0.25663658	0.5345045
Lane Width	-0.086291	0.057235945	-1.5076357	0.1458745	-0.20499103	0.0324091
Number of Lanes	-0.0492047	0.030452726	1.61577276	0.1203947	-0.0139504	0.1123598
Grade (%)	-0.0054716	0.005619736	0.97364594	0.3408171	-0.00618299	0.0171263
Traffic Volume/lane	0.00062503	0.000135995	4.5959677	0.0001407	0.000342993	0.0009071
Vehicle Speed(Km/h)	0.00040366	0.002243171	-0.1799487	0.85884	-0.00505571	0.0042484
Speed deviation	0.5539923	0.1967724	2.81539639	0.0100767	0.145911324	0.9620733

It has been found that the P-values associated to certain independent variables that are lower than the standard threshold point of 0.05 for 95% confidence level. This result suggests that these specific variables do not exhibit statistical significance and do not satisfy the requirements for strong explanatory power. As a result, we decided to focus our analysis and attention on the independent variables that show statistical significance with P-values below 0.05.

This is the revised model after deducting the variables with statically insignificant

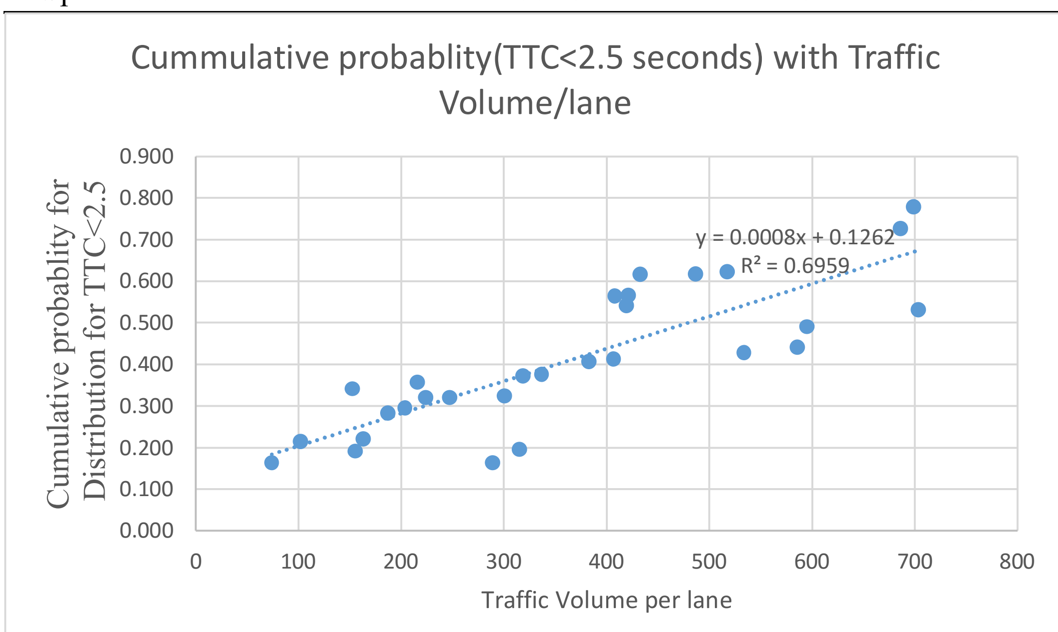
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.86906761
R Square	0.75527851
Adjusted R Square	0.73645378
Standard Error	0.08714227
Observations	29

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.609349037	0.30467452	40.121611	1.12911E-08
Residual	26	0.197438169	0.00759378		
Total	28	0.806787206			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.0517217	0.07982886	-0.6479078	0.0459426	-0.21581231	0.1123688
Traffic volume/lane	0.00076186	9.09177E-05	8.37962452	7.335E-09	0.000574972	0.0009487
Speed deviation	0.50114603	0.199578455	2.51102271	0.0185875	0.090906644	0.9113854



From the above table shown, Traffic Volume/lane has ranges from 74veh/hour/lane to 704 veh/hr/ lane and has a positive correlation (0.83) with $R^2 = 0.6959$ indicated that higher traffic volumes per lane can increase the probability of potential conflicts because of vehicles has less room for the maneuvering and cause lane changes more frequently, and make it harder to keep a safe distance between them and when the traffic volume per lane increases the traffic congestion also increases, as a result the probability of rear-end collisions, side-impact collision, and conflicts at intersections increases.

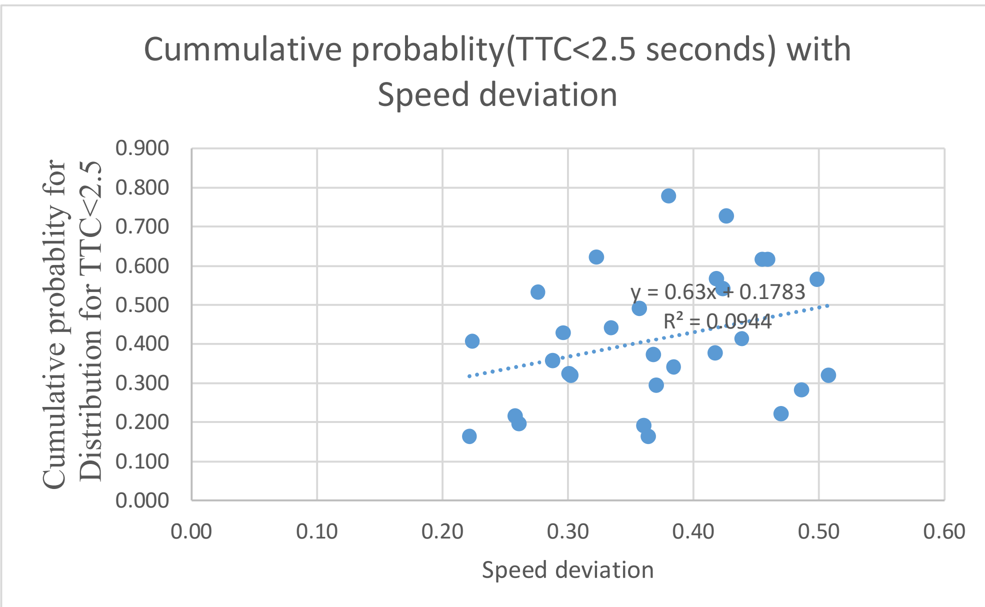


FIGURE 54: CUMULATIVE PROBABILITY (TTC<2.5) WITH SPEED DEVIATION

Speed Deviation has a value ranges from 0.22 to 0.51 and a moderate positive correlation (0.31) with R^2 of 0.1 indicates that an increase in speed deviation corresponds to a slightly increase of the probability of potential traffic conflicts. Variations in vehicle speeds, or speed deviations, can shorten the time available for reactions and narrow the space between vehicles, which can lead to a higher probability of potential conflicts.

From the above regression output, the equation of cumulative probability for (TTC≤ 2.5 seconds) is

$$F\ (TTC \leq 2.5) = -0.0517217 + 0.00076186x_1 + 0.50114603x_2$$

Where: $F\ (TTC \leq 2.5)$ is the cumulative probability of TTC to be below 2.5 seconds.

X1 = Number of Vehicle per hour per lane = Number of vehicles divided by number of lanes and the values ranges from 74veh/hr/lane to 704veh/hr/lane

And X2 = Speed deviation and calculated by dividing standard deviation of speed by mean speed that are taken from speed distribution of the approach road and the values ranges from 0.22 to 0.51.

From the regression statistics output: the multiple R value is found to be 0.86906, the multiple R value indicated how the dependent variables correlated with the independent variable. A 0.869 or 86.9% correlation value implies the parameters has a good positive correlation between them.

The R square value of 0.7553, indicated that the model fit our input data of 75.53% from 29 observations which shows that the equation is good predictive model.

From the ANOVA output: the significance F is 1.12911E-08 which is much less than 0.05, we can conclude that the model is statistically significant. And every updated independent variable in the equation has a P-value of less than 0.05, indicating that all of the model's independent variables are statistically significant.

And the P-value of all revised independent variables in the equation is also less than 0.05 which implies the independent variables in the model except those not found in the equation are statistically significant to predict the probability of time to collision to be less than 2.5 seconds.

The coefficients of number of vehicles per lane is positive 0.00076186 indicated that for every increase of 100 vehicles results the probability of the occurrence of potential conflict increased by 0.076 or 7.6%, the coefficient of speed deviation is 0.50114603 for every increase of speed deviation by 0.1 the probability of the occurrence of potential conflict increased by 0.0501 or 5.01%.

4.4.1 Validation of the model

Mean Squared Error (MSE) was used as an indication to evaluate the multiple linear regression model's predictive ability with the actual original data. The mean squared error (MSE) is calculated by averaging the squared deviations between the observed and anticipated values. Better model performance is indicated by a lower MSE.

TABLE 15: MODEL VALIDATION USING MEAN SQUARE ERROR

1	2	3	4	5	6	7
Road Approach	**Traffic Volume/lane**	**Speed deviation**	**Observed cumulative probability for (TTC<2.5 Seconds)**	**Predicted cumulative probability for (TTC<2.5 Seconds)**	**Square of the difference between Column 4 & 5**	**Mean Square Error (Average of column 6)**
1	204	0.37	0.295	0.289	0.000	**0.007**
2	433	0.46	0.616	0.508	0.012	
3	247	0.51	0.320	0.391	0.005	
4	301	0.30	0.324	0.328	0.000	
5	318	0.37	0.373	0.375	0.000	
6	419	0.42	0.542	0.480	0.004	
7	407	0.44	0.413	0.478	0.004	
8	383	0.22	0.407	0.352	0.003	
9	699	0.38	0.779	0.671	0.012	
10	421	0.42	0.566	0.479	0.008	
11	224	0.30	0.320	0.270	0.002	
12	408	0.50	0.565	0.509	0.003	
13	153	0.38	0.342	0.257	0.007	
14	686	0.43	0.727	0.684	0.002	
15	586	0.33	0.442	0.562	0.014	
16	704	0.28	0.532	0.623	0.008	
17	315	0.26	0.196	0.319	0.015	
18	289	0.36	0.164	0.351	0.035	
19	337	0.42	0.377	0.414	0.001	
20	487	0.45	0.617	0.547	0.005	
21	163	0.47	0.221	0.308	0.008	
22	187	0.49	0.283	0.334	0.003	
23	534	0.30	0.429	0.503	0.006	
24	595	0.36	0.491	0.580	0.008	
25	156	0.36	0.191	0.247	0.003	
26	102	0.26	0.215	0.155	0.004	
27	216	0.29	0.358	0.257	0.010	
28	517	0.32	0.622	0.504	0.014	
29	74	0.22	0.164	0.116	0.002	

The MSE value of 0.007 is comparatively low, indicating that the squared differences between the actual and projected values are generally small.

This implies that the equation below is able to predict the value of cumulative probability (TTC≤2.5) for the other scenario in a good way.

$F(TTC \leq 2.5) = -0.0517217 + 0.00076186x_1 + 0.50114603x_2$

Where: $F(TTC \leq 2.5)$ is the cumulative probability of TTC to be below 2.5 seconds.

X1 = Number of Vehicle per hour per lane = Number of vehicles divided by number of lanes and the values ranges from 74veh/hr/lane to 704veh/hr/lane

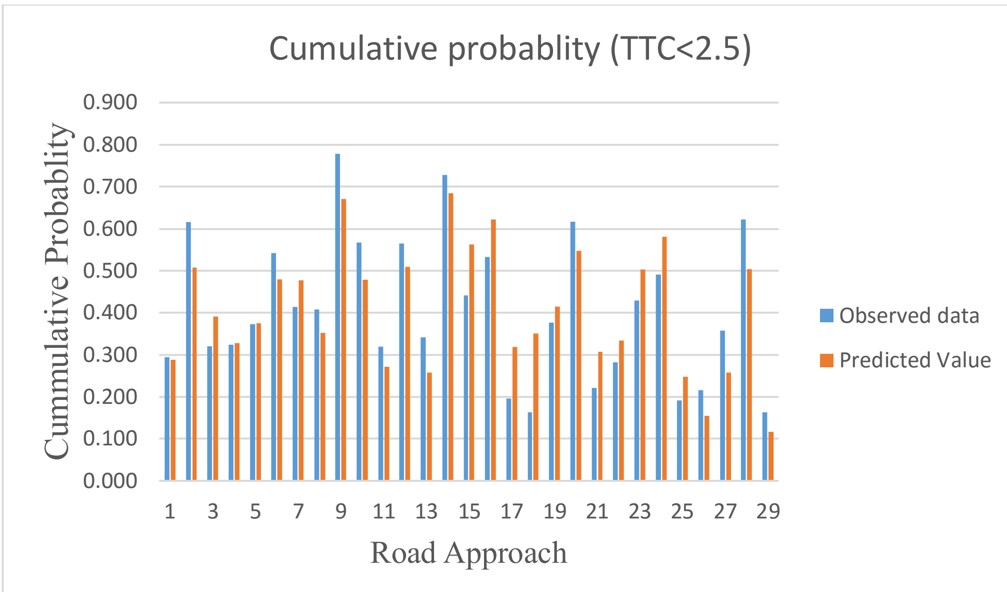


FIGURE 55: COMPARISON OF ACTUAL AND PREDICTED CUMULATIVE PROBABILITY VALUE (TTC<2.5SEC)

As we can see in the chart the predictive model accurately predicted with slightly small error.

4.4.2 Sensitivity Analysis

Sensitivity analysis determines the impact of varying independent variable values on a specific dependent variable. We have two independent variables and the sensitivity analysis carried one at a time. For practical reasons, the sensitivity analysis in this study is conducted using one-factor-at-a-time OAT. Given that the one variable that would be clearly linked to any change in output, this seems like a reasonable approach. Moreover, by making changes to one variable at a time while keeping the others constant at their baseline values. (*Sensitivity Analysis - Wikipedia*, 2023).

The independent variables used in this paper are Traffic volume per lane and speed deviation:

4.4.2.1 Traffic volume per lane

The required changes in traffic volume per lane are specified by adding 100 vehicle/hour/lane from minimum value up the maximum values from the collected data.

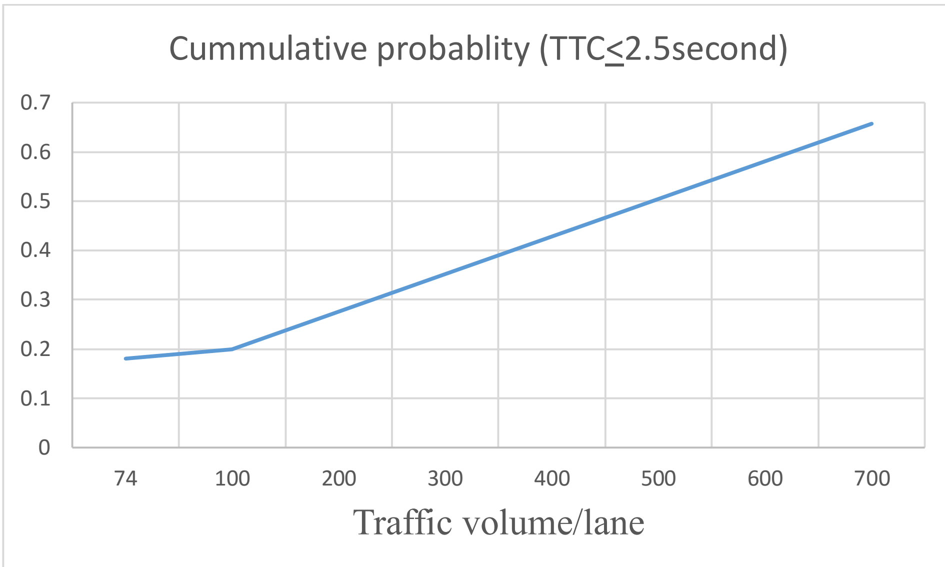


FIGURE 56: CUMULATIVE PROBABILITY FOR (TTC<2.5 SECOND) BY VARYING TRAFFIC VOLUME/LANE

As can be seen from the figure above, when the value of traffic volume per lane increases the cumulative probability increases with different rates. When the vehicle volumes up to 100veh/hour/lane the increment of the cumulative probability of potential risk is slow rate and after 100veh/hr/lane the probability of potential risk will increase with a high rate. For small vehicle numbers the effect of traffic volume is less due to vehicles has easily maneuver with a considerable spacing between them.

4.4.2.2 Speed deviation

The required changes in speed deviation are specified by adding 0.05 from minimum value up the reached the maximum values from the collected data.

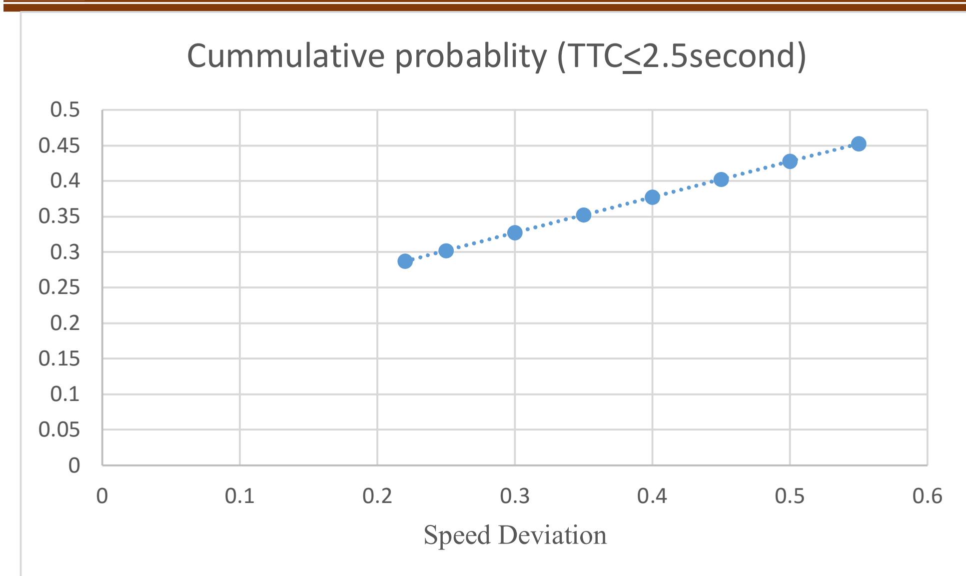


FIGURE 57: CUMULATIVE PROBABILITY OF TTC<2.5S BY VARYING SPEED DEVIATION

As can be seen from the figure above, when the value of speed deviation increases then the cumulative probability of potential risk will increases in a constant rate. This implies when speed deviation decreases the traffic flow become safer.

CHAPTER 5: CONCLUSION and RECOMMENDATIONS

5.1 Conclusion

The main objective of the study is to construct a model to describe the probabilistic occurrence of potential conflict in terms of geometric and traffic characteristic data, and to evaluate traffic safety indirectly through the use of surrogate safety measures. Simulation of Urban mobility Sumo was used to conduct the microscopic traffic simulation. Time to collision was selected based on earlier research from a number of surrogate safety measures generated from Sumo. Analysis of the time to collision distribution along the approaches of the chosen intersections was done. Based on the sumo output analysis, the following conclusions were drawn.

- Time to collision has a distribution of a bell shaped with some skewness and Weibull distribution function has a best function to represent the Time to Collison distribution with R^2 value of above 95% for all approaches.
- From the Weibull distribution with a lower mean value and lower standard deviation road will susceptible to occurring potential conflict with high chance and when the mean and standard deviation of higher value indicated that the chance of occurring potential conflict will decrease. Both mean and standard deviation effect has shown on the cumulative probability.
- The roads from Jacross to Gerji meberat-hayel junction have the highest probability value of 0.779, or 77.9% chance of occurring potential conflict, while the roads from Latica bakery to Salithmhiret intersection have the lowest cumulative probability value of 0.164, or 16.4% chance of occurring potential conflict.

From the analysis of the correlation analysis between the dependent variable and the independent variable:

- The probability of occurring potential conflict has a strong positive correlation (0.83) with traffic volume/lane especially for a vehicle number above 100veh/hour/lane and has a moderately significant relationship (0.31) with speed deviation with statistically significant effect.
- In summary, our research shows that a clear correlation between heavy traffic volume and speed deviation, which raises the possibility of danger on particular routes.

5.2 Recommendations

It is advised to investigate methods to expand road capacity and provide alternative route in order to mitigate the increased risks associated with traffic volume on certain highways. Expanding the capacity of current roadways helps ease traffic congestion, facilitating a more seamless flow of traffic and, as a result, lowering the risk of conflicts. Furthermore, funding the development of alternate roads gives vehicles practical alternatives to distribute traffic, reducing congestion on important thoroughfares. This dual strategy helps create a more resilient and efficient urban mobility infrastructure while also improving safety. To effectively execute and maintain these recommendations, cooperation will be necessary between government, transport engineers, urban planners, and community stakeholders.

The Addis Ababa City Traffic Management Agency, which is in charge of protecting traffic safety in Addis Ababa, by inspect high-risk areas. They currently used conventional methods by analyze traffic crash data and I recommend AACTMA to implement microscopic simulation to evaluate traffic safety because traffic crash data has many limitations as discussed earlier, unlike conventional crash data analysis, microscopic-simulation analyzes examine the dynamics and behavior of individual vehicles. This aids in identifying any issues before they arise.

5.3 Proposed Future Research Direction

I propose to widen the study's scope beyond the signalized intersections in Bole Sub-city, Addis Abeba, that were chosen. This expansion could include a wider range of intersections including un-signalized intersections in order to give a compressive view of urban mobility safety and enable insightful comparisons. Additionally, beyond the current focus on lead/follow conflicts during peak hours, future research should take into account a wider range of conflict forms, such as merging and diverging conflict types.

For further research, the integration of detailed traffic conflict data together with surrogate safety measures could enhance the precision of collision risk assessments. The development of dynamic simulation models incorporating real-time factors like weather conditions and pavement condition, could offer a more adaptive approach to urban mobility safety.

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ANNEXES

Appendix A: Video Traffic Count Transcription Sheet

Appendix B: Weighted Average of 85th Percentile Spot Speed of the Junctions

Appendix C: Minimum Time to Collision Distribution Chart for the Approaches of the Junctions

Appendix A: Video Traffic Count Transcription Sheet

1. Adey Ababa intersection converted one hour peak flow

MOTORIZED and NON-MOTORIZED PEAK HOUR VEHICLE COUNT FORM

DATE 12/10/2023

PROJECT: **Adey Ababa Intersection**

DAY √

LOCATION

NIGHT

Direction	Bicycle	Motorcycle	Cars	4WD Station-Wagons and	Mini Buses(≤ 20 Seats)	M/Bus ≤27 Seats	L/Buses	Pickups	S/Trucks	M/Truck	H/Truck	Truck & Trailer	TOTAL
Emperial – Addis Hiwot Hospital	4	8	516	68	36	0	0	56	0	0	0	0	**688**
Emperial – 22 Golagol	4	8	204	8	24	0	0	12	0	4	0	0	**264**
Emperial – Ednamall	8	8	268	12	28	4	0	16	0	0	4	0	**348**
Emperial – Emperial	0	0	0	0	4	0	0	4	0	0	0	0	**8**
Addis Hiwot Hospital – Emperial	8	8	212	52	12	0	0	24	0	4	0	0	**320**
Addis Hiwot Hospital -Ednamall	0	8	32	4	0	0	0	0	0	0	0	0	**44**
Addis Hiwot- 22 Golagol	0	0	32	12	0	0	0	8	0	0	0	0	**52**
Ednamall – 22 Golagol	4	0	120	0	108	0	0	12	0	0	0	0	**244**
Ednamall-Addis Hiowt	0	0	4	0	0	0	0	0	0	0	0	0	**4**
Ednamall-Emperial	0	0	252	12	36	0	0	20	8	4	4	0	**336**
22 golagol – Ednamall	16	4	212	20	68	0	0	40	0	0	0	0	**360**
22 golagol – Addis Hiwot	4	0	68	0	4	0	0	4	4	4	0	0	**88**
22 golagol-Emperial	0	0	44	0	4	0	0	4	0	0	0	0	**52**
TOTAL	**48**	**44**	**1,964**	**188**	**324**	**4**	**-**	**200**	**12**	**16**	**8**	**-**	**2,808**

2. Atlas intersection converted one hour peak flow

MOTORIZED and NON-MOTORIZED PEAK HOUR VEHICLE COUNT FORM — DATE 17/10/2023

PROJECT: **Atlas Intersection** — DAY √ — NIGHT

LOCATION

Route	Bicycle	Motorcycle	Cars	4WD Station-Wagons and	Mini Buses(≤ 20 Seats)	M/Bus ≤ 27 Seats	L/Buses	Pickups	S/Trucks	M/Truck	H/Truck	Truck Trailer	TOTAL
Ednamall – Urael	8	12	368	48	132	0	0	36	4	0	0	0	**608**
Ednamall- Afrrica Godana	0	0	46	4	1	0	0	4	1	0	0	0	**56**
Ednamall- Wiha Limat	0	0	26	4	1	0	0	1	0	0	0	0	**32**
Wiha Limat – Afirca Godana	0	1	82	11	7	0	0	11	0	2	0	0	**114**
Wiha Limat- Urael	1	4	70	5	7	0	0	9	0	0	0	0	**96**
Wiha Limat – Edna Mall	0	2	59	8	3	1	0	0	7	0	0	0	**80**
Wiha Limat – Wiha Limat	0	0	4	3	1	0	0	1	0	0	0	0	**9**
Africa Godana – Wiha Limat	3	5	126	15	5	0	0	15	0	1	0	0	**170**
Africa Godana – Urael	1	1	66	9	7	0	0	4	0	0	0	0	**88**
Africa Godana – Africa Godana	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Africa godana- Ednamall	0	0	32	0	1	0	0	0	0	0	0	0	**33**
Urael – EdnaMall	1	3	99	18	23	7	0	11	0	0	0	0	**162**
Urael – Wiha Limat	1	3	60	6	3	0	0	10	0	0	0	0	**83**
Urael – Urael	0	0	4	0	0	0	0	0	0	0	0	0	**4**
Urael – Africa Godana	0	1	43	11	4	0	0	5	0	0	0	0	**64**
TOTAL	**15**	**32**	**1,086**	**142**	**195**	**8**	**-**	**107**	**12**	**3**	**-**	**-**	**1,600**

3. Gerji- Meberat Hayel intersection converted one hour peak flow

MOTORIZED and NON-MOTORIZED PEAK HOUR VEHICLE COUNT FORM

DATE: 3/10/2023

DJECT: **Gerji Meberat Hayl Junction**

DAY: √

CATION

NIGHT

Time	Bicycle	Motorcycle	Cars	4WD Station-Wagons	Mini Buses(≤ 20 Seats)	M/Bus ≤ 27 Seats	L/Buses	Pickups	S/Trucks	M/Truck	H/Truck	Truck & Trailer	TOTAL
All mart- Jacross	0	0	660	48	120	0	52	124	4	0	8	0	1,016
Allmart – Gerji	0	0	128	0	48	0	0	4	0	0	0	0	180
Jacross – Gerji	0	0	492	40	72	20	4	76	4	0	0	0	708
Jacross – Jacross	0	0	56	4	12	0	0	0	0	0	0	0	72
Jacross – Allmart	8	0	860	40	64	24	48	128	0	20	0	0	1,192
Gerji – Jacross	0	0	252	16	84	16	4	40	8	0	0	0	420
TOTAL	8	-	2,448	148	400	60	108	372	16	20	8	-	3,588

4. Jacross intersection converted one hour peak flow

MOTORIZED and NON-MOTORIZED PEAK HOUR VEHICLE COUNT FORM — DATE 10/10/2023

PROJECT: **Jacross Intersection** — DAY √

LOCATION — NIGHT

Time	Bicycle	Motorcycle	Cars	4WD Station-Wagons and	Mini Buses(≤ 20 Seats)	M/Bus ≤27 Seats	L/Buses	Pickups	S/Trucks	M/Truck	H/Truck	Truck & Trailer	TOTAL
Goro – Gerji Mebrat Hayl	4	32	680	80	84	24	56	116	0	8	20	4	**1,108**
Goro – Salithemihret	0	0	4	0	0	0	0	4	0	0	0	0	**8**
Salithemihret – Gerji Mebrat	8	0	304	28	52	0	4	24	4	0	0	0	**424**
Salithemihret – Goro	0	0	16	4	0	0	0	12	0	0	0	0	**32**
Gerji Mebrat Hayl – Gerji Mebrat Hayl	0	8	320	24	44	8	0	20	8	0	0	0	**432**
Gerji Mebrat Hayl – Goro	0	12	540	36	124	12	52	140	8	0	4	0	**928**
Gerji Mebrat Hayl – Salithe mihr	16	12	372	40	72	4	4	80	8	4	0	0	**612**
TOTAL	**28**	**64**	**2,236**	**212**	**376**	**48**	**116**	**396**	**28**	**12**	**24**	**4**	**3,544**

5. Japan Embassy intersection converted one hour peak flow

MOTORIZED and NON-MOTORIZED PEAK HOUR VEHICLE COUNT FORM

DATE 18/10/2023

PROJECT: Japan embassy Intersection

LOCATION

DAY √

NIGHT

Time	Bicycle	Motorcycle	Cars	4WD Station-Wagons and	Mini Buses(≤ 20 Seats)	M/Bus ≤ 27 Seats	L/Buses >27 Seats	Pickups	S/Trucks ≤ 3.5 Tons	M/Truck	H/Truck	Truck & Trailer	TOTAL
Snap Plaza-Rwanda Embassy	0	16	1824	160	364	0	36	188	4	4	4	0	**2,600**
Snap Plaza-Street 622	0	0	108	40	0	0	0	24	0	0	0	0	**172**
Rwanda Embassy-Snap Plaza	8	24	1380	124	244	12	24	104	8	0	0	0	**1,928**
Rwanda Embassy – Zimbabwe	0	4	256	32	48	0	0	52	0	0	0	0	**392**
Zimbabwe – street 622	4	0	84	8	4	0	0	16	0	0	0	0	**116**
Zimbabwe – Rwanda Embassy	0	4	108	40	12	0	0	4	0	0	0	0	**168**
Zimbabwe – Snap Plaza	0	0	32	0	4	0	0	0	0	0	0	0	**36**
622 street – Rwanda	4	0	28	4	0	0	0	0	0	0	0	0	**36**
Street 622 – Zimbabwe	0	0	0	56	20	4	0	0	4	0	0	0	**84**
Street 622 – Snap Plaza	0	0	0	84	8	28	0	0	8	0	0	0	**128**
TOTAL	**16**	**48**	**3,820**	**548**	**704**	**44**	**60**	**388**	**24**	**4**	**4**	**-**	**5,660**

6. Kokeb - Building intersection converted one hour peak flow

IOTORIZED and NON-MOTORIZED PEAK HOUR VEHICLE COUNT FORM — DATE: 12/10/2023

PROJECT: **24 Kokeb intersection** — DAY: √

LOCATION — NIGHT:

Time	Bicycle	Motorcycl		4WD Station-	Mini Buses(≤ 20 Seats)	M/Bus ≤27 Seats	L/Buses >27 Seats	Pickups	S/Trucks	M/Truck	H/Truck	Truck & Trailer	TOTAL
Megenagna -24 taxi tera	0	12	56	8	48	0	0	20	0	0	0	0	**144**
Megenagna – Anbessa Garaj	0	0	40	0	16	0	0	12	0	8	0	0	**76**
Megenagna – Megenagna	0	0	8	0	0	0	0	0	0	0	0	0	**8**
Megenagna- Lem Hotel	0	4	60	4	20	0	0	8	0	0	0	0	**96**
Anbessa garaj-megenagna	0	0	44	4	16	0	4	24	0	0	0	0	**92**
Anbessa Garaj-Lem hotel	4	24	688	52	76	8	0	148	0	4	0	0	**1,004**
Anbessa garaj-24 taxi tera	4	4	228	24	32	0	0	32	0	0	0	0	**324**
Anbessa garaj -Anbessa Gara	0	0	24	8	0	0	0	4	4	0	0	0	**40**
Lem hotel-Anbessa garaj	8	24	456	68	36	0	4	108	8	0	0	0	**712**
Lem Hotel-lem Hotel	0	0	20	0	0	0	0	4	0	0	0	0	**24**
Lem Hotel – Megenagna	0	4	92	4	12	0	0	12	4	0	0	0	**128**
Lem Hotel- 24 Taxi Tera	0	0	96	16	4	4	0	28	0	0	0	0	**148**
24 taxi – anbessa garaj	0	12	20	0	4	0	0	8	0	0	0	0	**44**
24 taxi – lem hotel	0	0	124	8	36	0	0	16	0	4	0	0	**188**
24 Taxi tera-Megenagna	4	4	76	0	52	0	0	12	0	0	0	0	**148**
TOTAL	**20**	**88**	**2,032**	**196**	**352**	**12**	**8**	**436**	**16**	**16**	**-**	**-**	**3,176**

7. Bole Snap-Plaza intersection converted one hour peak flow

MOTORIZED and NON-MOTORIZED PEAK HOUR VEHICLE COUNT FORM — DATE 19/10/2023

PROJECT: Snap Plaza Intersection — DAY √

LOCATION — NIGHT

Time	Bicycle	Motorcycle	Cars	4WD Station-Wagons and	Mini Buses(≤ 20 Seats)	M/Bus ≤ 27 Seats	L/Buses	Pickups	S/Trucks	M/Truck	H/Truck	Truck & Trailer	TOTAL
Bole Dildy – Japan Emb	4	12	1308	152	324	0	32	168	12	4	0	0	**2,016**
Bole dildy – Sunshine	0	8	276	8	8	0	0	28	0	0	0	0	**328**
Japan Embassy – Sunshi	0	4	332	56	44	0	0	20	4	0	0	0	**460**
Japan Embassy- Japan	0	4	144	32	16	0	0	4	0	0	0	0	**200**
Japan Embassy- Bole dil	0	8	856	108	304	4	16	116	8	8	0	4	**1,432**
Sunshine – Japan Embas	4	4	192	32	52	0	0	24	4	0	0	0	**312**
Sunshine – bole deldiy	0	0	0	0	0	0	0	4	0	0	0	0	**4**
TOTAL	**8**	**40**	**3,108**	**388**	**748**	**4**	**48**	**364**	**28**	**12**	**-**	**4**	**4,752**

8. Bole Snap-Plaza intersection converted one hour peak flow

MOTORIZED and NON-MOTORIZED PEAK HOUR VEHICLE COUNT FORM — DATE 20/10/2023

PROJECT: Salitmihiret Intersection — DAY √

LOCATION — NIGHT

Time	Bicycle	Motorcycle	Cars	4WD Station-Wagons	Mini Buses(≤ 20 Seats)	M/Bus ≤ 27 Seats	L/Buses	S/Trucks	M/Truck	H/Truck	Truck & Trailer	TOTAL
Figa – ECWC	4	4	152	8	12	0	0	0	0	0	0	**216**
Figa – Jacross	8	4	748	64	84	0	12	4	0	0	0	**1,016**
Figa – Gerji Mariam	0	4	240	12	24	4	0	4	0	0	0	**312**
Mariam – Jacross	0	4	296	12	80	16	8	4	4	0	0	**468**
Mariam – Figa	0	0	68	0	32	0	0	0	4	0	0	**120**
Mariam – ECWC	0	0	0	0	8	0	0	0	4	0	0	**24**
ECWC – Figa	8	0	92	0	44	0	0	0	0	0	0	**164**
ECWC – Jacross	4	0	0	0	4	0	0	0	0	0	0	**8**
Jacross – Figa	0	0	64	8	16	4	0	0	0	0	0	**96**
Jacross – Gerji Marian	0	4	120	4	20	4	0	12	0	0	0	**192**
TOTAL	**24**	**20**	**1,780**	**108**	**324**	**28**	**20**	**24**	**12**	**-**	**-**	**2,616**

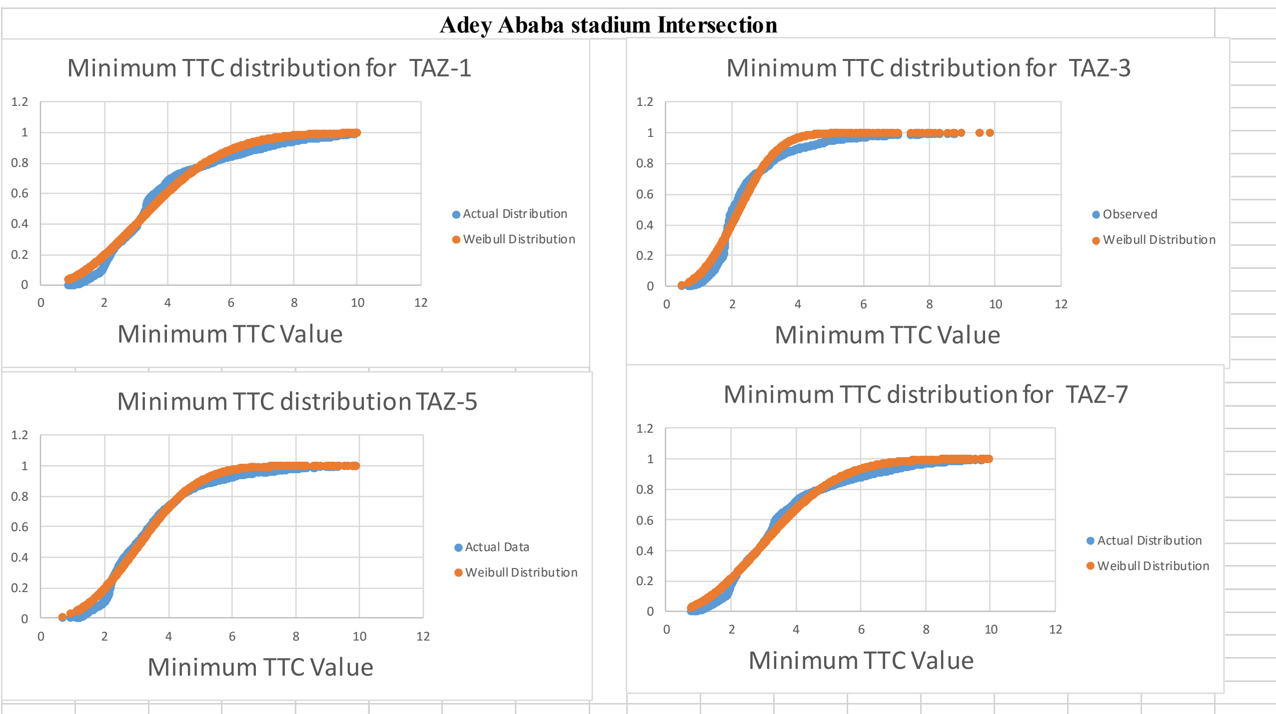
Appendix B: Weighted Average of 85^{th} Percentile Spot Speed of the Junctions

Speed Distribution Value	Approach	85th percentile Spot Speed(Km/hr)	Passenger Car unit Traffic Volume	Weighted Amount	
Adey Ababa Stadium Signal Intersection	Ednamol to Junction	21.97	601	13203.97	
	Junction to Ednamol	30.81	733	22583.73	
	Junction to Emperial	34.47	732	25232.04	
	Emperial to Junction	30.33	1298	39368.34	
	Junction to Golagol	18.8	556	10452.8	
	Golagol to Junction	17.14	494	8467.16	
	Junction to Addis Hiwot Hospital	24.55	780	19149	
	Addis Hiwot Hospital to Junction	23.09	407	9397.63	
		Total	5,601.00	147,854.67	
			Weighted Average	**26.40**	**Km/h**
Atlas Signal Intersection	St Urael to Junction	41.19	1258	51817.02	
	Junction to St Urael	40	1334	53360	
	22 zerihun to Junction	24.92	1220	30402.4	
	Junction to 22 zerihun	31.25	1152	36000	
	Ednamol to Junction	20.81	955	19873.55	
	Junction to Ednamol	34.05	1145	38987.25	
	Rwanda Embassy to Junction	19.36	1148	22225.28	
	Junction to Rwanda Embassy	30.81	951	29300.31	
		Total	9,163.00	281,965.81	
			Weighted Average	**30.77**	Km/h
Jacross Signal Intersection	Gerji Meberat to Junction	30.335	2058	62429.43	
	Junction to Gerji Meberat	37.15	2086	77494.9	
	Junction to Salitmhiret	33.1	624	20654.4	
	Salitmhiret to Junction	33.59	458	15384.22	
	Junction to Goro	37.79	1031	38961.49	
	Goro to Junction	28.34	1224	34688.16	
		Total	7,481.00	249,612.60	
			Weighted Average	**33.37**	Km/h
Lem Hotel around Kokeb Building Signal Intersection	Lem Hotel to Junction	45.25	1010	45702.5	
	Junction To Lem Hotel	35.54	1312	46628.48	
	Junction to Megenagna	29.19	376	10975.44	
	Megenagna to Junction	21.34	326	6956.84	
	Anbessa Garaj to Junction	35.03	1460	51143.8	

Speed Distribution Value	Approach	85th percentile Spot Speed(Km/hr)	Passenger Car unit Traffic Volume	Weighted Amount	
	Junction to Anbessa Garaj	38.5	1036	39886	
	24 taxi tera to Junction	25.79	374	9645.46	
	Junction to 24 taxi tera	30.38	608	18471.04	
		Total	6,502.00	229,409.56	
			Weighted Average	**35.28**	Km/h
Japan Embassy Signal Intersection	Bole Rwanda Bridge to Junction	31.61	2342	74030.62	
	Junction to Bole Rwanda Bridge	48.72	2841	138413.52	
	Junction to Snap Plaza	51.56	2152	110957.12	
	Snap Plaza to Junction	44.38	2814	124885.32	
	Junction to Antica Bar & Restaurant	32.51	285	9265.35	
	Antica Bar & Restaurant to Junction	26.31	289	7603.59	
	Zimbabwe St to Junction	22.14	315	6974.1	
	Junction to Zimbabwe St	20.03	482	9654.46	
		Total	11,520.00	481,784.08	
			Weighted Average	41.82	Km/h
Salitmhiret Signal Intersection	Junction to Figa	43.39	368	15967.52	
	Figa to Junction	23.12	1552	35882.24	
	Junction to latika bekery	33.34	233	7768.22	
	latika bekery to Junction	32.67	148	4835.16	
	Junction to Jacross	24	1529	36696	
	Jacross to Junction	42.54	306	13017.24	
	Salitmhiret to Junction	24.87	648	16115.76	
	Junction to Salitmhiret	36.13	523	18895.99	
		Total	5,307.00	149,178.13	
			Weighted Average	28.11	Km/h
Gerji Meberat Hayel Intersection	Jacross to Junction	21.23	2096	44498.08	
	Junction to Jacross	31.65	1604	50766.6	
	Gerji Roba to Junction	19.32	448	8655.36	
	Junction to Gerji Roba	37.34	916	34203.44	
	Junction to Anbessa Garaj	24.76	1288	31890.88	
	Anbessa Garaj to Junction	34.97	1264	44202.08	
		Total	12,923.00	363,422.68	
			Weighted Average	28.12	Km/h
Bole Snap Plaza Signal Intersection	Bole Japan to Junction	45.85	2134	97843.9	
	Junction to Bole Japan	37.82	2254	85246.28	

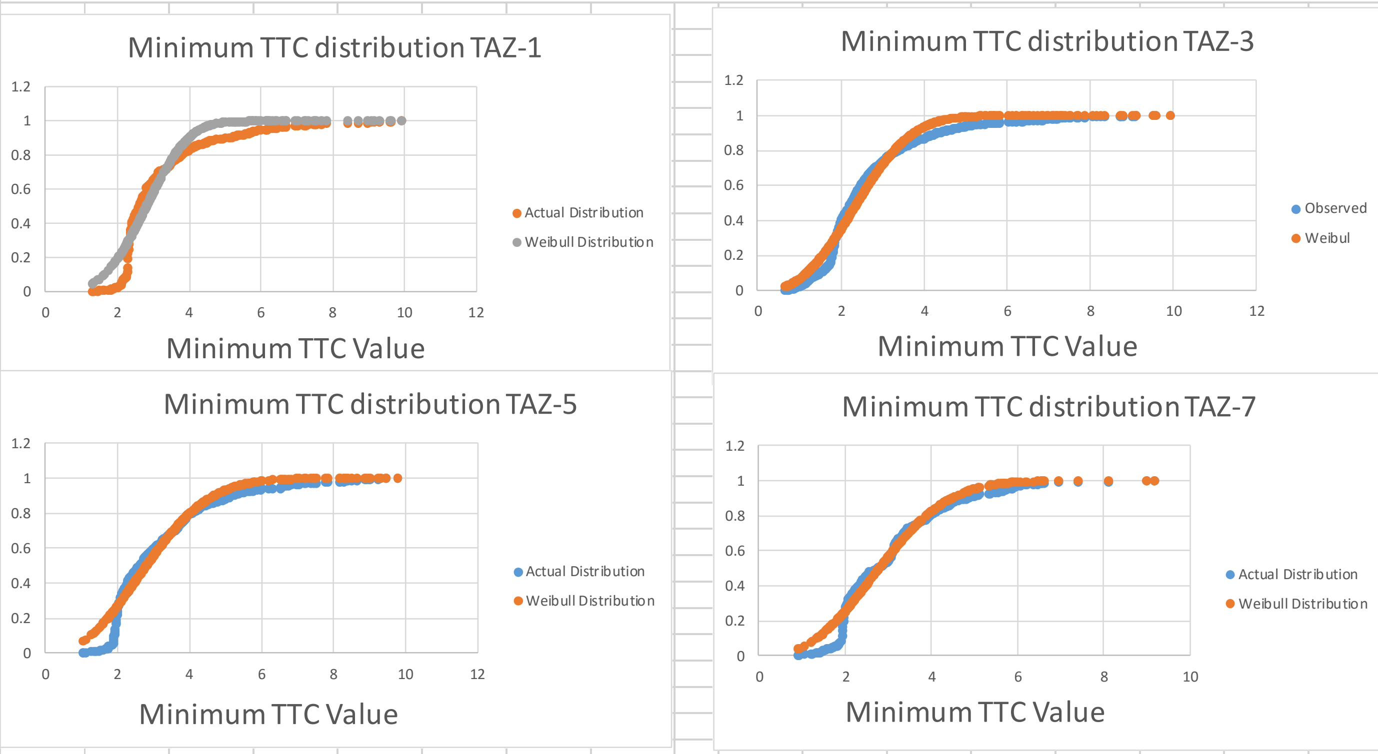
Speed Distribution Value	Approach	85th percentile Spot Speed(Km/hr)	Passenger Car unit Traffic Volume	Weighted Amount
	Junction to Sunshine Buildings	29.68	785	23298.8
	Sunshine Buildings to Junction	23.28	311	7240.08
	Bole deldiy to Junction	23.2	2379	55192.8
	Junction to Bole deldiy	50.89	1475	75062.75
		Total	22,261.00	707,335.41
			Weighted Average	**31.77** Km/h

Appendix C: Minimum Time to Collision Distribution Chart for the Approaches of the Junctions



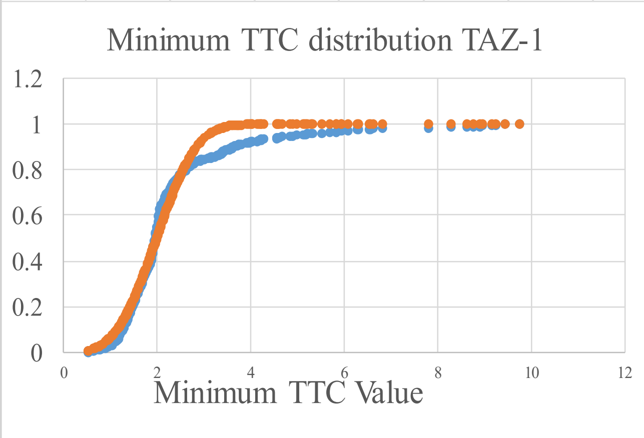
Adey Ababa stadium Intersection.	
TAZ	Weibull Comulative Distribution for TTC<2.5
1	0.295
3	0.616
5	0.320
7	0.324

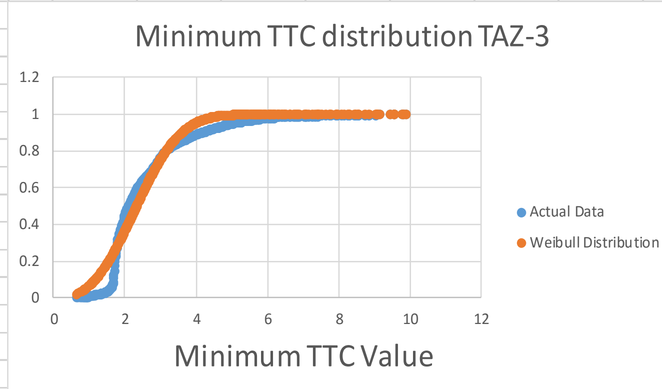
Atlas Intersection

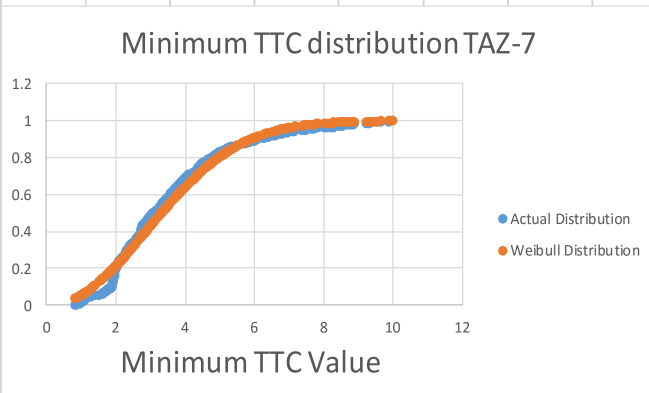


Atlas Intersection	
TAZ	Weibull Comulative Distribution for TTC<2.5
1	0.373
3	0.542
5	0.413
7	0.407

Gerji Meberat-hayel Intersection

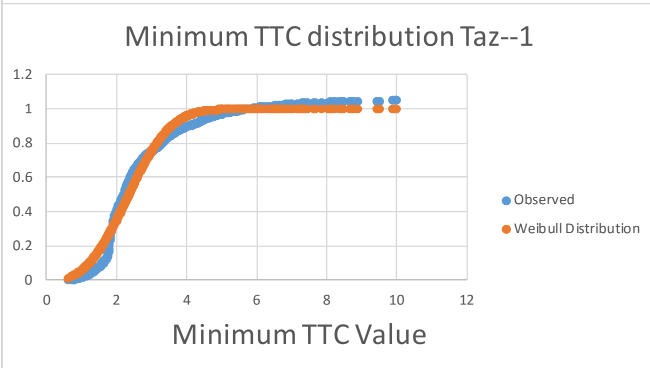


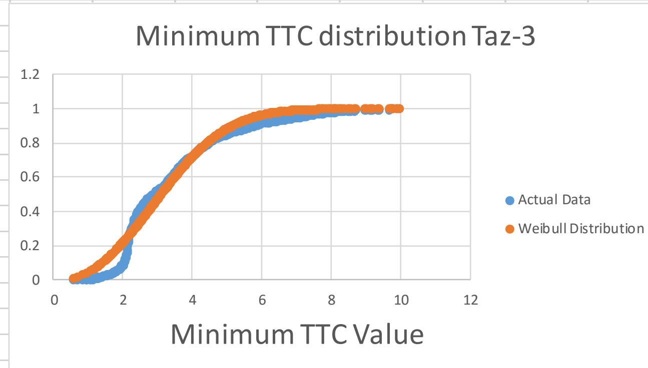


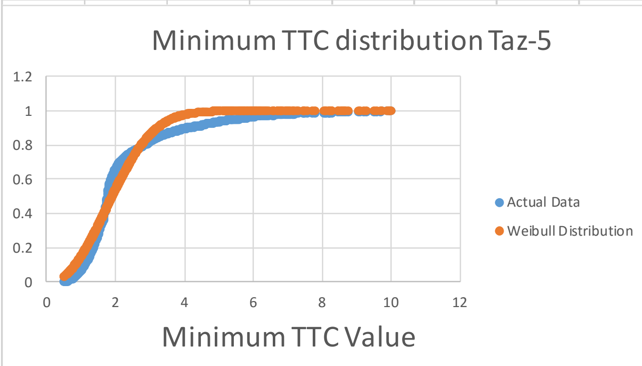


Gerji Meberat-hayel Intersection	
TAZ	**Weibull Comulative Distribution for TTC<2.5**
1	0.779
3	0.566
5	0.320

Jacross Intersection



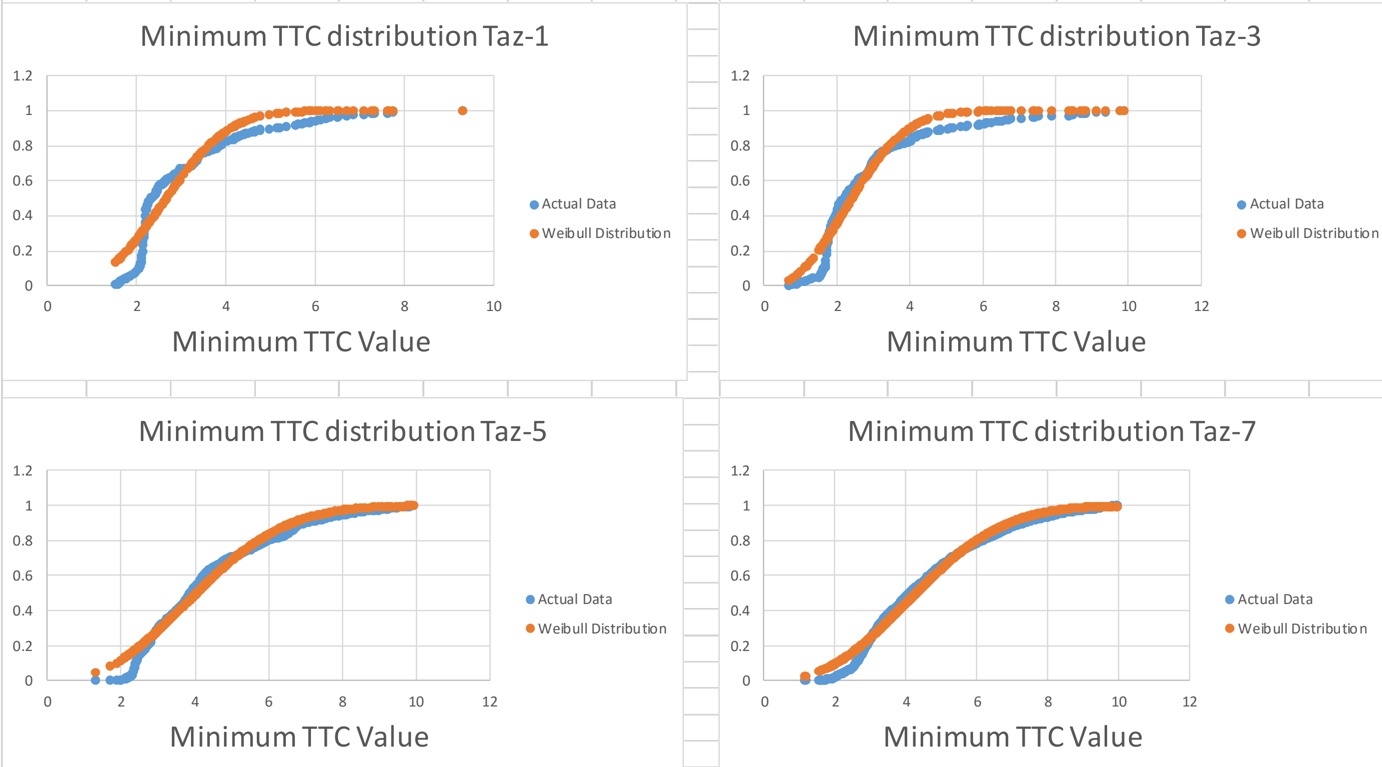




Jacross Intersection

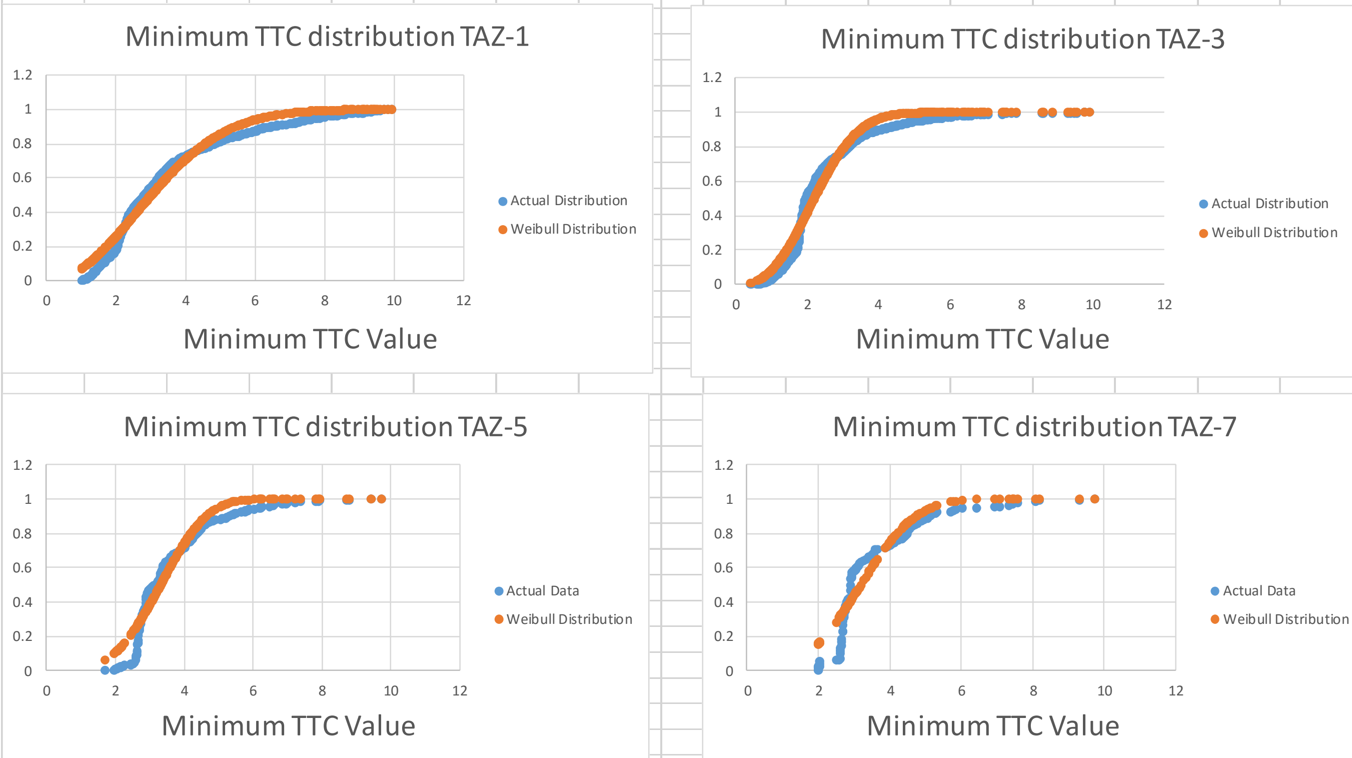
TAZ	Weibull Comulative Distribution for TTC<2.5
1	0.565
3	0.342
5	0.727

Bole-Japan Intersection



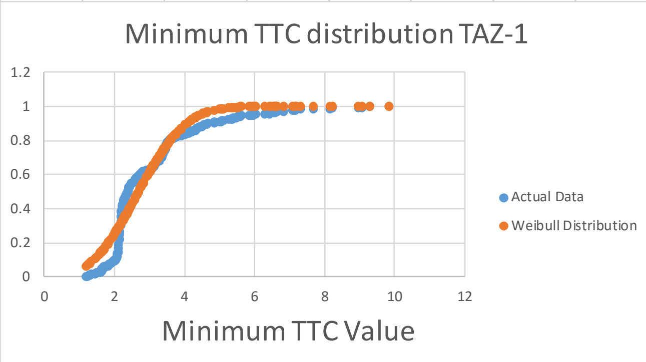
Bole-Japan Intersection	
TAZ	**Weibull Comulative Distribution for TTC<2.5**
1	0.442
3	0.532
5	0.196
7	0.164

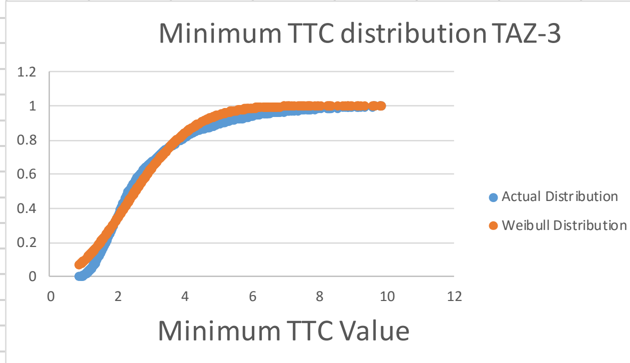
Kokeb Building Intersection

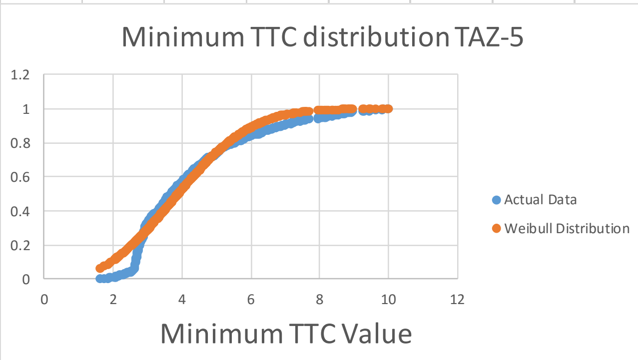


Kokeb Building Intersection	
TAZ	**Weibull Comulative Distribution for TTC<2.5**
1	0.377
3	0.617
5	0.221
7	0.283

Bole-snap plaza Intersection

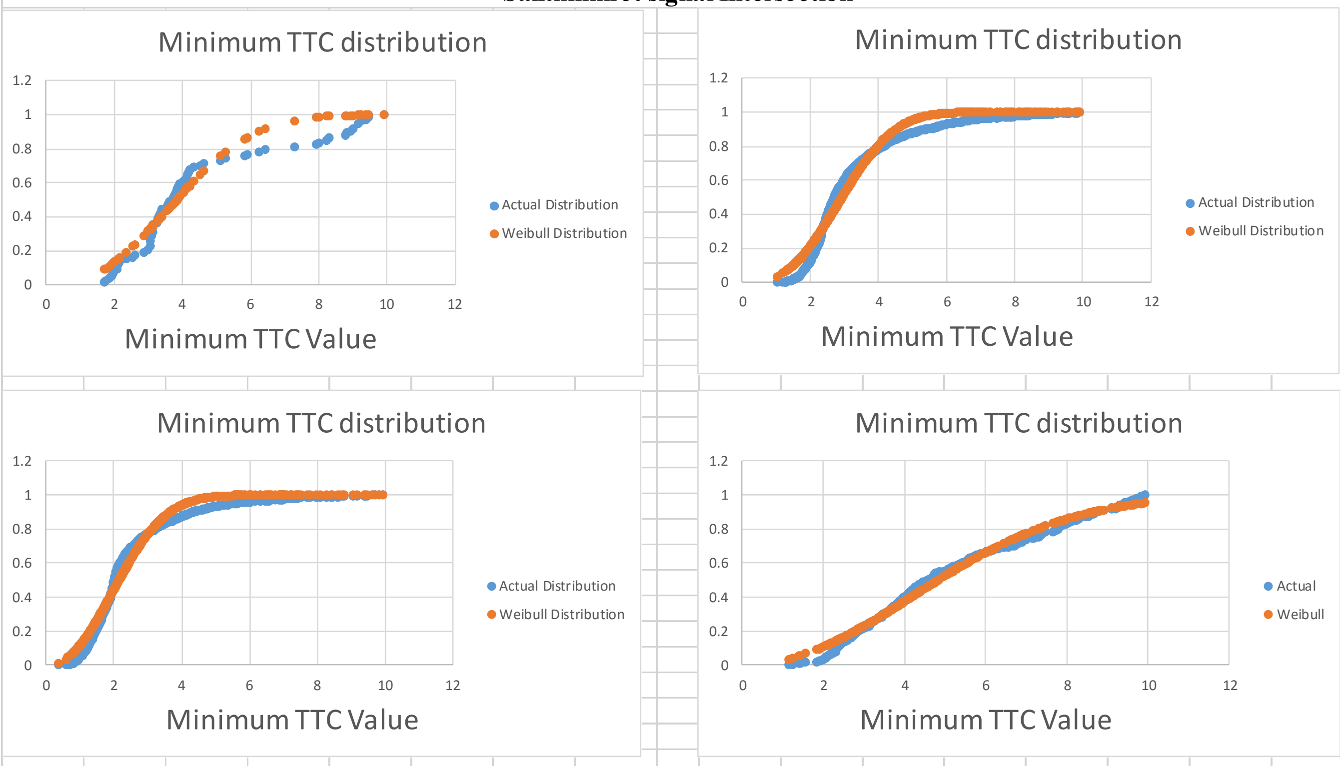






Bole-snap plaza Intersection	
TAZ	**Weibull Comulative Distribution for TTC<2.5**
1	0.429
3	0.491
5	0.191

Salithmhiret signal Intersection



Salithmhiret signal Intersection	
TAZ	**Weibull Comulative Distribution for TTC<2.5**
1	0.215
3	0.358
5	0.622
7	0.164