Investigation of Using Microscopic Traffic Simulation Tools to Predict Traffic Conflicts Between Right-Turning Vehicles and Through Cyclists at Signalized Intersections

by

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Abstract

Researchers have been questioning if traffic microsimulation tools can be used for road safety evaluations. This thesis examines if these tools have the potential to predict conflicts between right-turning vehicles and through cyclists at signalized intersections. Moreover, this thesis evaluates if calibrating these models to describe the driving behaviour at signalized intersections significantly improves the conflicts' prediction. It was found that VISSIM has the potential to predict traffic conflicts of interest. In particular, a moderate correlation was found between real conflicts and simulated conflicts of the default models ($r = 0.525$). Calibrating the model for travel time improved the correlation between real conflicts and simulated conflicts ($r = 0.618$). However, a one-way ANOVA test indicated that the improvement caused by travel time calibration was not significant. It was also found that VISSIM's prediction accuracy is expected to decrease as either the cyclists' volume or the product of cyclists' volume and right-turning vehicles' volume increase.

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CHAPTER 1: INTRODUCTION

1.1 Background

Traffic collisions have been a major concern to road safety practitioners and government agencies due to their significant social and economic cost. For example, 15,023 traffic collisions were reported in Ottawa, ON in 2013. These reported collisions resulted in 3,658 injuries and 27 deaths (City of Ottawa, 2015). At a national level, 1,923 people were killed and 175,621 injuries were reported in the same year (Transport Canada, 2015). Moreover, the World Health Organization (WHO) estimated that 1.24 million people die because of traffic collisions each year. In fact, WHO predicts that traffic collisions will be the fifth leading cause of death worldwide by 2030 (WHO, 2013).

Although traffic collisions are direct indicators of failures in a transportation system, using them for road safety evaluations is associated with some problems. To start with, many traffic collisions are random and of infrequent nature, and do not necessarily reflect an easily isolated failure in a transportation system. Hence, they are hard to predict. Even if possible, predicting that failure would require collecting datasets over multiple years before being able to draw any strong conclusions. In addition, police records do not consistently provide complete information on traffic collisions (Hauer & Hakkert, 1988). For instance, traffic collisions causing damages worth less than $1,000 do not have to be reported to the police in the province Ontario (MTO, 2013). Consequently, road safety studies that acquire data only from police reports can produce erroneous results (Farmer, 2003).

The problems associated with traffic collisions have encouraged road safety specialists to propose traffic conflicts as an alternative safety indicator to traffic collisions when evaluating the safety aspect in a transportation system. A traffic conflicts is defined as "an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged" (Amundsen & Hyden, 1977). In fact, traffic conflicts have been proposed because of the potential of sharing common attributes with traffic collisions except for the final outcome which does not involve physical contact between road users. They also have a relatively high frequency of occurrence and negligible cost (Hyden, 1987). Initially, traffic conflicts used to be identified by trained observers standing in the field. Nonetheless, this technique has received much criticism because it can be costly, labour intensive, and time-consuming. Furthermore, this technique is prone to depending on the subjective judgments of the observers (Huang, *et al*., 2013). Thus, different surrogate safety indicators have been introduced in the literature to objectively identify conflicts.

The most commonly used surrogate safety indicators are Time to Collision (TTC) and Post-Encroachment Time (PET). Time to Collision (TTC) is a surrogate safety indicator that has been used frequently in the literature. Time to Collision (TTC) is traditionally defined as the time remaining for two road users to collide if they maintain their speed and direction (Hayward, 1972). Post-Encroachment Time (PET) is defined as the time difference between two road users occupying the same area of potential collisions (Allen, *et al.*, 1978). Such surrogate safety indicators are used to distinguish traffic conflicts from other interactions between road users. For a selected surrogate safety indicator, a traffic conflict is identified when an interaction between two road users yields a value

below a predetermined threshold for that surrogate safety indicator. This technique eliminates the observers' subjectivity limitation in the traditional technique and allows to identify conflicts in a consistent manner.

1.2 Research Motivation

Microscopic traffic simulation tools have been used by traffic technologists and engineers to study the operational performance of either existing or proposed transportation systems. Examples of microscopic traffic simulation tools include, but are not limited to, PTV VISSIM, CORSIM, TRANSIM, and TEXAS. Interestingly, a question that has been growing among researchers is if these tools have the potential to assess the safety aspect of transportation systems. In the year 2003, a landmark project proposed by SIEMENS and sponsored by the Federal Highway Administration (FHWA) focused on assessing that potential. The authors of this study found that different surrogate safety indicators can be derived from commonly available microscopic traffic simulation tools (Gettman & Head, 2003). This finding led to the development of the Surrogate Safety Assessment Model (SSAM). SSAM is a software tool that can identify conflicts and determine their type and severity based on surrogate safety indicators derived from simulated vehicles' trajectories (Gettman, *et al.*, 2008). From this study and onwards, many researchers used SSAM to evaluate if microscopic traffic simulation tools have the potential to predict conflicts. Additionally, some researchers proposed alternative approaches than SSAM to identify simulated conflicts. However, all studies recorded in the literature attempted to answer this question based mainly on conflicts between vehicles. In fact, the potential of microscopic traffic simulation tools to predict conflicts between vehicles and cyclists has not been examined. This thesis makes a novel contribution by evaluating this potential using traffic

conflicts between right-turning vehicles and through cyclists at signalized intersections. Addressing this question based on conflicts between vehicles and cyclists is very crucial. The advantages of conflicts are more meritorious when cyclists are studied. The reason is that cyclist collisions are quite rare which limits using them to evaluate cyclists' safety. In spite of their rare occurrence, cyclist collisions are injurious as cyclists are more vulnerable and exposed to the damage of a collision than vehicles' drivers.

1.3 Objectives

This thesis consists of two main tasks. At first, this thesis examines if traffic microsimulation models have the potential to predict conflicts between right-turning vehicles and through cyclists at signalized intersections. To do that, traffic conflicts simulated by these traffic microsimulation models were compared to traffic conflicts observed in the real world. Subsequently, this thesis evaluates if calibrating these models to describe the driving behavioural characteristics at signalized intersections significantly improves the conflicts' prediction.

1.4 Thesis Scope

The scope of this research is limited to certain conditions that were considered to accomplish the stated tasks: (i) this research was limited to signalized intersections with physically segregated bike lanes in the Downtown area of Ottawa. (ii) This research considered PM peak hours' traffic movements in the summer season because it is expected that higher volumes of cyclists will be observed on the roads due to favourable weather conditions. Traffic movements during the PM peak hours were considered because this time of the day witnesses higher volumes of road users. Hence, more interactions between right-turning vehicles and through cyclists are expected to occur. (3) This research was conducted using PTV VISSIM 6 which is a commonly used software in practice and academic research. PTV VISSIM is a multimodal time-step based traffic microsimulation tool for modelling different types of traffic operations. PTV VISSIM was developed by PTV AG, a company based in Karlsruhe Germany (PTV VISSIM 6 User Manual, 2014). (4) Travel time was used as a Measure of Effectiveness (MOE) of the calibration procedure conducted in this research. Travel time was chosen as a MOE because it can be easily measured in the field and is an available output in PTV VISSIM 6. (5) Post-Encroachment Time (PET) was the surrogate safety indicator used in this research to identify simulated conflicts. PET was used because it can objectively measure the proximity of two road users to collide in events that did not end up with a collision (Tarko, *et al.*, 2009). Moreover, the real conflicts datasets obtained for this research were collected based on PET.

1.5 Thesis Organization

This dissertation consists of five chapters. Chapter one offers a background on the topic of road safety, introduces the research motivation, and finally highlights the objectives and thesis scope. Chapter two reviews the relevant road safety studies that have been conducted and recorded in the literature. Chapter three describes the methodology implemented in this research to achieve its objectives. Chapter four presents the results obtained from the implemented methodology, discusses the statistical tests conducted on these results, and reports the findings of this research. Chapter five provides a summary of the findings of this research from which conclusions are drawn and recommendations are made.

CHAPTER 2: LITERATURE REVIEW

2.1 Background

The potential of using microscopic simulation tools for road safety evaluations was initially investigated by Cooper and Ferguson in the late seventies (Cooper & Ferguson, 1976). In their study, they used simulated vehicles' conflicts to investigate traffic scenarios where the risk of collisions is high. The results revealed that the number of conflicts is proportional to the product of the interacting volumes. In addition, the authors claimed that the number of conflicts at a location is independent of speed distribution of vehicles. However, they pointed out that the severity of conflicts slightly increases with the increase of the vehicles' mean speed and speed standard deviation. In other words, the collision risk at a junction is expected to be higher when the traffic is travelling at higher speeds or has a higher dispersion of speeds. Finally, the author found that varying the gap acceptance parameters in the model can significantly affect the number of conflicts.

In a similar study, Darzentas *et al.,* (1980) used microsimulation models for road safety evaluations to investigate the risk of traffic collisions between vehicles at nonurban T-junctions using simulated traffic conflicts. In fact, their simulation model attempted to predict the number and severity of conflicts based on different traffic and behavioural parameters. For instance, the rate of deceleration necessary to avoid a collision was used to measure the severity of a conflict. Moreover, examining the parameters that affect the occurrence of traffic conflicts was of a particular interest. Darzentas *et al.,* found that the more vehicles pass through the junction the greater the number of conflicts. Furthermore, it was found that both the number of conflicts and the percentage of severe conflicts

increase with the increase of the mean speed of vehicles on the main road. Considering uncongested traffic conditions was a shortcoming in this study. The driving behaviour at a junction can noticeably change when the junction is at or beyond its capacity.

In 1994, Sayed *et al.,* (1994) studied traffic conflicts on both 3-leg and 4-leg unsignalized intersections using a simulation model. The simulation model was built using discrete event simulation language called General Purpose Simulation System. Moreover, a graphical animation display was used to observe drivers' characteristic behaviour during the occurrence of traffic conflicts to get an understanding of the behavioral parameters that affect their occurrence. The objective of their research was to study the effect of traffic parameters such as volume and speed on the number and severity of traffic conflicts. In addition, the authors analyzed the effect of combining different aspects of gap acceptance criteria with different driver's characteristics such as sex, age, and waiting time. Then, they used the results of that analysis to extend the gap acceptance criteria to describe driver's behaviour at unsignalized intersections. The authors validated their research's results against field observations from four unsignalized intersections. It was found that the simulation results had a strong correlation with the field conflicts' observations. In particular, the authors found, after analyzing a wide range of traffic volumes, that there is an exponential relationship between traffic volumes and the number of conflicts. Additionally, it was found that an increase in the mean speed is associated with an increase in both the number and severity of conflicts. Thus, the authors suggest raising police activity at unsignalized intersections as a countermeasure to decrease the mean speed and therefore mitigate the number and severity of conflicts. Finally, the authors found that female drivers were less involved in traffic conflicts than male drivers. Based on the

findings, the authors argued that traffic microsimulation tools can be useful in road safety evaluations for unsignalized intersections.

In 2000, Archer (2000) aimed at improving the use of traffic microsimulation tools in road safety evaluations through developing a detailed model of driver driving behaviour. This study focused on urban intersections that usually serve different types of road users. In fact, the author modelled one specific intersection for analysis instead of a large traffic network to reduce the number of simulated objects in the model; hence, allowing the model to dedicate more capacity in the modelling of the driver behaviour. Ultimately, the author argued that the more detailed the modelling of the driver behaviour is the greater the potential of traffic microsimulation tools to be used for assessing road safety. In addition, the author indicated that the calibration and validation of the driving behaviour in the model to reflect the real behaviour should provide relevant safety assessment results. Finally, it was recommended to use surrogate safety indicators to compare field-observed traffic interactions and simulated ones.

In a project sponsored by the Federal Highway Administration (FHWA), Gettman and Head (2003) investigated whether surrogate safety indicators can be derived from existing traffic microsimulation models. The authors argued that such surrogate safety indicators could be beneficial in evaluating the safety performance of different project alternatives that have not yet been built. Moreover, the authors used road users' interactions to collect different surrogate safety indicators. The authors found that various surrogate safety indicators can be derived from different commercially available traffic microsimulation tools. Accordingly, Gettmand and Head proposed the use of Time to Collision (TTC), Post-Encroachment Time (PET), and Deceleration Rate (DR) to measure

the severity of traffic conflicts. The authors also suggested using maximum speed and speed differential to measure the severity of potential traffic collisions.

The findings reported by Gettman and Head in 2003 eventually led to the development of Surrogate Safety Assessment Model (SSAM) in 2008. SSAM is a software tool that can identify conflicts and determine their type and severity based on surrogate safety indicators (*i.e.,* TTC and PET) derived from simulated vehicles' trajectories (Gettman, *et al.*, 2008). This software analyzes the trajectories file output generated by the traffic microsimulation software, and calculates the TTC and PET values for each simulated interaction between any two road users. Then, SSAM compares the calculated TTC and PET values against predefined thresholds of theses surrogate safety indicators. Based on that, SSAM flags all interactions with TTC and PET below these predefined thresholds and identifies them as traffic conflicts. The development of SSAM opened the door for researchers to expand their research and use simulation-derived surrogate safety indicators. Some of the relevant research recorded in the literature used TTC and/or PET to evaluate the potential of using traffic microsimulation tools for road safety evaluations. The second section of this chapter highlights such studies. On the other hand, other studies used less commonly used indicators to evaluate that potential. In fact, some studies proposed new simulation-based surrogate safety indicators for road safety assessment. Such studies are covered and discussed in the third section of this chapter.

2.2 Microsimulation Studies Based on TTC and PET

Among the surrogate safety indicators used in the literature for simulation-based road safety studies, Time to Collision (TTC) and Post-Encroachment Time (PET) tend to be the ones used the most. This may be attributed to the fact that these two indicators were among the three that Gettman and Head proposed to identify conflicts. Another reason may be that many studies used the Surrogate Safety Assessment Model (SSAM) which identifies traffic conflicts based on predefined TTC and PET thresholds. This section presents different simulation-based road safety studies that used TTC and/or PET in the analysis.

Pirdavani *et al.,* (2010) used S-Paramics (S-Paramics, 2005) to evaluate the safety effects of changing speed limits on unsignalized 4-leg intersections under different uncongested traffic volumes. The type of unsignalized intersections considered in this study was two-way stop-controlled intersections where vehicles on the minor road have to stop at the stop line and give way to vehicles on the major road. Moreover, only uncongested traffic conditions were considered because they allow drivers to drive at their desired speed. Consequently, evaluating the safety performance at different speed limits becomes feasible. Post-Encroachment Time (PET) was used in this study to describe the crash risk at the analyzed intersections. Since PET is not an available output in Paramics, the authors had to develop a procedure to derive the PET values out of the simulation output. In particular, four loop detectors were defined on the outgoing links of the four legs of the intersection. Then, these detectors would collect the speed and position of each vehicle approaching the intersection from any of the four legs. Finally, the collected information would be used to obtain the PET values out of the simulation output. The

authors found that the values of PET decrease when the speed limit on both roads increases. The results suggested that when the speed limit on the major road increases, drivers on the minor road will accept smaller gaps when crossing over or turning on the intersection. In addition, Pirdavani *et al.,* found that the values of PET decrease when the traffic volume of both roads increase as long as there is no traffic congestion. The authors argued that higher traffic volumes on the major road will force vehicles on the minor road to accept shorter gaps. Based on that, the authors claimed that the effect of increasing both speed limits and traffic volumes on PET values reflect these increases' harm on the road safety.

In another study, Dijkstra *et al.,* (2010) examined if a quantitative relationship exists between simulated traffic conflicts and recorded crashes in the real world. This study was limited to investigating the relationship between simulated traffic conflicts and crashes at intersections only. Furthermore, the study was limited to vehicles' crashes between 2002 and 2007 that led to injury or property damage and occurred on weekdays between 6 AM and 10 AM. The software S-Paramics (S-Paramics, 2005) was used to simulate 569 intersections in the west of Netherlands. In addition, Time to Collision (TTC) was used to identify simulated traffic conflicts with a predefined threshold of 2.5 seconds. The authors classified the results of their study based on the type of intersection, the type of conflict and the traffic volume classes. First, the authors found that 3-leg unsignalized intersections have the least number of crashes per intersection as well as the least number of calculated conflicts when compared with other types of intersections. The highest number of crashes per intersection and the highest number of conflicts per intersection were found at 4-leg signalized intersections and 3-leg signalized intersections, respectively. Second, Dijkstra *et al.,* reported that the type of conflicts and crashes witnessed the most at signalized

intersections was rear-end conflicts and crashes. However, significant differences were found between the number of lateral crashes[1] and the number of lateral conflicts at signalized intersections. Third, the authors found that an increase in the average volume of passing vehicles[2] is associated with an increase in the average number of crashes and the average number of simulated conflicts. Finally, regression analyses indicated that a statistical relationship exists between the number of observed crashes and the number of conflicts.

Caliendo and Guida (2012) investigated whether traffic collisions at unsignalized intersections can be predicted using traffic conflicts. The study was conducted on nine intersections in the City of Salerno in Italy, each monitored for six different one-hour periods. The microsimulation software AIMSUN (AIMSUN, 2010) was used to model the traffic flow at the nine intersections. Interestingly, the authors used AIMSUN's default values of the parameters that describe the driving behaviour. The authors found reasonable conformity between the simulated traffic flow and that observed in the real world. After that, a file that contains the simulated vehicles' trajectories was generated from AIMSUN and input into the Surrogate Safety Assessment Model (SSAM). SSAM analyzed the trajectories file to identify simulated traffic conflicts based on TTC and PET thresholds of 1.5 seconds and 5 seconds, respectively. Moreover, the authors developed a traffic-conflict-based crash prediction model and compared its goodness of fit with the one of a traffic-

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[1] The term "lateral crashes" probably means side swipe or lane-change related crashes. However, it was not clear to the author after reviewing the original publication as no definition or illustration was provided of what this term means.

[2] The term "average volume of passing vehicles" probably refers to the average volume of crossing vehicles or through vehicles in an intersection. However, it was not clear to the author after reviewing the original publication as no definition or illustration was provided of what this term refers to.

volume-based crash prediction model that they also developed. The authors found a significant relationship between traffic conflicts and recorded crashes at unsignalized intersections. As for the crash prediction models, they found that the traffic-conflict-based crash prediction model fit the crash data slightly better than the traffic-volume-based crash prediction model.

In a recent study, Huang *et al.,* (2013) examined whether using VISSIM and SSAM to identify traffic conflicts at signalized intersections provides reasonable estimates of the conflicts observed in the field. The authors were also interested in checking if calibrating VISSIM models and adjusting the TTC and PET thresholds in SSAM improve the prediction of observed conflicts. This study was conducted using 80 hours of traffic data collected at ten signalized intersections in the City of Nanjing in China. Observers watched the collected videos to identify different types of traffic conflicts at the ten considered intersections. The types of traffic conflicts considered in this study were rear-end, crossing, and lane-change traffic conflicts. Furthermore, the observers used vehicle's brake lights, vehicle's speed, vehicle's swerving maneuver, and noticeable deceleration to identify traffic conflicts. The authors used a two-stage procedure to calibrate the simulation models in an attempt to make the results of the simulated conflicts consistent with the observed ones. In the first stage, the created VISSIM models were calibrated to reproduce performance measures observed in the field such as volume, speed, and headways. In the second stage, the focus was on adjusting SSAM's TTC and PET thresholds and VISSIM's parameters to which simulated conflicts are sensitive in order to replicate the traffic conflicts observed in the field. The Mean Absolute Percent Error (MAPE) was used to

calculate the difference between the observed and simulated conflicts. The MAPE value was calculated using the following equation:

$$\text{MAPE} = \frac{1}{\text{n}} \sum_{i=0}^{n} \left| \frac{C_m^i - C_f^i}{C_f^i} \right| \qquad \textbf{Equation 2.1}$$

Where:

n : Number of time intervals

C_m^i : Number of conflicts simulated for time interval i

C_f^i : Number of conflicts observed in the field during time interval i

The results indicated that the two-stage calibration procedure improved the goodness-of-fit between the simulated and observed traffic conflicts. The MAPE value for total conflicts was found to be 43% after the first calibration stage whereas it was reduced to 24% after the second one. More specifically, the MAPE was reduced from 24% to 16% for the rear-end conflicts, from 70% to 23% for the crossing conflicts, and from 85% to 79% for the lane-change conflicts. However, the authors pointed out that the proposed procedure did not significantly improve the goodness-of-fit of lane-change conflicts. Furthermore, linear regression analysis was conducted to examine if simulated traffic conflicts provided reasonable estimates of the observed ones. This analysis indicated a statistically significant relationship between the simulated and observed conflicts. The R^2 values for the total conflicts, rear-end conflicts, and crossing conflicts were found to be 0.783, 0.573, and 0.831, respectively. Nonetheless, the R^2 for the lane-change conflicts was found to be 0.188. This verified that simulated lane-change conflicts did not provide reasonably good estimates for the observed lane-change conflicts. The authors explained

that such traffic conflicts were observed in the field usually after unexpected driving maneuvers like illegal lane-changes which could not be simulated in VISSIM. Based on that, the authors argued that such results reflect a limitation in using traffic microsimulation tools for road safety evaluations at signalized intersections. The technique used in this study to identify conflicts in the field appears to suffer from subjectivity which could have affected the findings of this study. For instance, if different observers who are more conservative were to identify traffic conflicts in the field, the number of traffic conflicts observed in the field may be different.

Fan *et al.,* (2013) applied a very similar two-stage calibration procedure but on rear-end and lane-change traffic conflicts at freeway merge areas. A total of 88 hours of traffic data were recorded at seven freeway merge areas in the City of Nanjing in China. The results indicated that the two-stage calibration procedure improved the goodness-of-fit between the simulated and observed traffic conflicts. The MAPE value for total conflicts was found to be 71% after the first calibration stage whereas it was reduced to 19.9% after the second one. More specifically, the MAPE was reduced from 69.6% to 24.4% for the rear-end conflicts, and from 76.2% to 27.4% for the lane-change conflicts. In addition, linear regression analysis was conducted to examine if simulated traffic conflicts provided reasonable estimates of the observed ones. This analysis showed a statistically significant relationship between the simulated and observed conflicts. The R^2 values for the rear-end conflicts, lane-change conflicts, and total conflicts were found to be 0.88, 0.86, and 0.91, respectively. These results indicated that a reasonable correlation exists between simulated and observed traffic conflicts at freeway merge areas. Based on that, the authors argued

that the simulation-based procedure that they proposed has the potential to be used in road safety evaluations at freeway merge areas.

In the next section, studies that used surrogate safety indicators other than TTC and PET in their simulation-based road safety evaluations are presented. In fact, some of these studies proposed new simulation-based surrogate safety indicators for road safety assessment.

2.3 Microsimulation Studies Based on other Surrogate Safety Indicators

This section highlights studies that investigated the potential of using traffic microsimulation tools for road safety evaluations using surrogate safety measures other than TTC and PET. In particular, some studies used available but less commonly used surrogate safety indicators whereas others proposed new ones. Cunto and Saccomanno (2007) used VISSIM to evaluate the safety effects of replacing a four-legged stop-controlled intersection that consisted of a major and a minor road with a signalized intersection. In their study, Cunto and Saccomanno introduced a surrogate safety indicator called Crash Potential Index (CPI) that they used in their road safety evaluation. This indicator was defined as the probability that a given vehicle's Deceleration Rate needed to Avoid a Crash (DRAC) exceeds its Maximum Available Deceleration Rate (MADR). DRAC is defined as the required deceleration rate for a vehicle to come to a timely stop or match the speed of a leading vehicles to avoid a rear-end crash. The results of this study revealed that the number of rear-end conflicts increased after installing the traffic signals. On the other hand, a decrease in angle conflicts was witnessed after installing the traffic

signals. Finally, the authors found that the total CPI nonlinearly decreased after signalizing the intersection.

Ozbay *et al.,* (2008) suggested a modification to the Time to Collision (TTC) and proposed a new surrogate safety indicator that can capture the probability of rear-end traffic collisions as well as their severity. The authors criticized that former studies estimated TTC on the assumption that vehicles approaching each other maintain their speeds until they get in a collision. However, the authors argued that this assumption will only identify traffic conflicts where the speed of the following vehicle is larger than the speed of the leading one. Moreover, Ozbay *et al.,* explained that ignoring the actual acceleration and deceleration of vehicles leads to missing many potential conflicts unidentified. Thus, the authors proposed a Modified TTC (MTTC) indicator that takes into account the relative distance, relative speed, and relative acceleration of vehicles following each other. Besides that, a Crash Index (CI) was proposed as a new surrogate safety indicator that predicts the severity of potential traffic collisions. This indicator is based on the effect of speed on the kinetic energy involved in collisions. It also takes into account the elapsed time before the conflict occurrence to estimate the probability and severity of potential traffic conflicts. Additionally, CI incorporates the MTTC indicator to determine the likelihood of identified conflicts ending up in traffic collisions. These two proposed indicators were validated using a well-calibrated simulation model of a section of the New Jersey Turnpike. More specifically, they were validated by comparing the simulation results to real rear-end and sideswipe crash records for the period 1996-2005 from the same site. The microsimulation tool Paramics (Paramics, 2008) was used in this study to run and analyze the simulation model. The results of this study indicated a strong relationship between the proposed

surrogate safety indicators and real crash records. In particular, the authors reported that the CI indicator provided both a better consideration of all possible rear-end conflicting scenarios and better estimates of collision severity than TTC.

Guido *et al.,* (2011) examined the ability of 7 different built-in car following models in TRITONE (TRITONE, 2011) to accurately reproduce values of TTC and DRAC estimated from field-observed vehicles' interactions. This study was conducted on a 160 metres section of a two-lane undivided rural highway in the City of Cosenza in Italy during two weekdays between 9:30 AM and 10:30 AM. The observed estimates of TTC and DRAC were obtained from a video image processing algorithm. The authors found that the best estimates of simulated TTC were obtained when using one of the three following car-following models:

1- Wiedenmann psychophysical model (Wiedemann, 1974)
2- Fritzsche psychophysical model (Fritzsche, 1994)
3- FRESIM model (Halati, *et al.*, 1997)

As for DRAC, the simulated values were comparable to the observed values when the Van Aerde car-following model was used (Van Aerde, *et al.*, 1996). However, all other car-following models resulted in simulated DRAC values noticeably lower than the observed ones.

Astarita *et al.,* (2012) used TITRONE to examine the safety impacts of converting a four-legged stop-controlled intersection to a roundabout. Two surrogate safety indicators, TTC and DRAC, were derived from the simulated vehicles' trajectories of each scenario; then, the simulated values of each scenario were compared with each other to evaluate how the safety was affected. After running both scenarios in TRITONE based on the same

traffic flow, the average simulated TTC value for the intersection and roundabout scenarios were found to be 3.53 and 7.46 seconds, respectively. In addition, the average simulated DRAC value for the intersection and roundabout scenarios were found to be 0.54 and 0.33 m/s^2, respectively. Based on that, the authors argued that the safety conditions are better in the roundabout scenario.

In a recent study, Wang and Stamatiadis (2013) proposed a new surrogate safety indicator called the Aggregated Crash Propensity Metric (ACPM) for simulation-based conflict studies. This indicator can be defined as the sum of crash probabilities of all simulated conflicts of the same type. A probabilistic crash propensity model was developed to estimate the crash probability of each simulated conflict. The authors pointed out that this model takes into account human and vehicle variability and variations in reaction times and braking capabilities when determining the crash probability. This model is also able to determine the crash probability for three different types of collisions which are rear-end, crossing, and lane-change collisions. The validity of this proposed indicator was examined by simulating 12 four-legged signalized intersections along three arterials in Kentucky in VISSIM. Travel time calibration was conducted on the simulated models to ensure they reflect the driving behaviour in the field. Then, SSAM was used to derive the TTC values of all simulated conflicts based on the trajectories file output from VISSIM. These TTC values were used as data input in the probabilistic crash propensity model to estimate the ACPM. Spearman correlation coefficient was used to determine the associations between the ACPM of each collision type and historic crash data for these intersections. The Spearman correlation coefficient indicated strong correlations between the historic crash data and the ACPM values of the three collision types. In particular, this coefficient was

found to be 0.777 for rear-end collisions, 0.788 for crossing collisions, 0.801 for lane-change collisions, and 0.756 for total collisions. After that, the Highway Safety Manual (HSM) procedures were used to predict the annual crash frequency of the three considered types of collisions for the 12 intersections. Again, the correlation between these annual crash frequencies and the historic crash data for the 12 intersections was tested in the same way. The Spearman correlation coefficient was found to be -0.133 for rear-end collisions, 0.203 for crossing collisions, 0.252 for lane-change collisions, and 0.301 for total collisions. Based on that, the authors reported that the ACPM can better describe traffic collisions at signalized intersections than the annual crash frequencies of the HSM procedure. Besides that, regression models were developed to evaluate the potential of the proposed indicator to predict real traffic collisions and were found to provide reasonable estimates of the real crashes.

2.4 Summary

In this chapter, a review of the recorded studies in the literature that are relevant to this research was presented. More specifically, the first section covered the initial research efforts to investigate using traffic microsimulation tools for road safety evaluations. In the second section, simulation-based road safety studies that used TTC and/or PET surrogate safety indicators in their analysis were highlighted. Finally, the third section discussed simulation-based road safety studies that used surrogate safety indicators other than TTC and PET in their research. The third section also discussed different new surrogate safety indicators that were proposed to be used in simulation-based road safety studies. Although different useful findings were reported in the aforementioned studies, these studies only investigated traffic conflicts between vehicles. In other words, the potential of using traffic

microsimulation tools to predict traffic conflicts of other road users was not addressed. In fact, all reviewed studies that focused on intersections did not even study the impact of cyclists on vehicles' movements nor they incorporated cyclists' volumes in the simulation models. This research aims to evaluate the potential of traffic microsimulation tools to predict traffic conflicts between right-turning vehicles and through cyclists at signalized intersections. This is a key novelty in the research presented in this thesis.

CHAPTER 3: RESEARCH METHODS

The research approach implemented in this thesis consisted of three main phases. The first phase was collecting the data needed in this research. The data collected in the first phase was used to complete the second and third phase in this research. The second phase dealt with building a model of the site selected for this research in VISSIM and calibrating it for travel time. Finally, the third phase focused on producing output data that describes the conflicts simulated by VISSIM. The output data obtained from the third phase was used to address the question that motivated this research.

3.1 Data Collection

3.1.1 Site Description

The site selected for this research was a 750 metre segment of the Laurier Ave W corridor that is located in the Downtown area of the City of Ottawa; Canada's capital. This segment was selected because it contains the intersections at which the real traffic conflicts were identified. A detailed description of what real conflicts are and how they were identified in the field is in section 3.1.3. As shown in Figure 3.1, this segment intersects with five cross-streets. It initially intersects with Metcalfe St, and then it passes towards the west through O'Connor Street, Bank St, Kent St, and finally Lyon St. This segment contains lanes for vehicles, physically segregated bike lanes for cyclists, and crosswalks for pedestrians. Finally, the season and time of the day considered in this research were summer season and weekday PM Peak hours, respectively. This research considered PM peak hours' traffic movements in the summer season because it is expected that higher

volumes of cyclists will be observed on the roads due to favourable weather conditions. Traffic movements during the PM peak hours were considered because this time of the day witnesses higher volumes of road users. Hence, more interactions between right-turning vehicles and through cyclists are expected to occur.

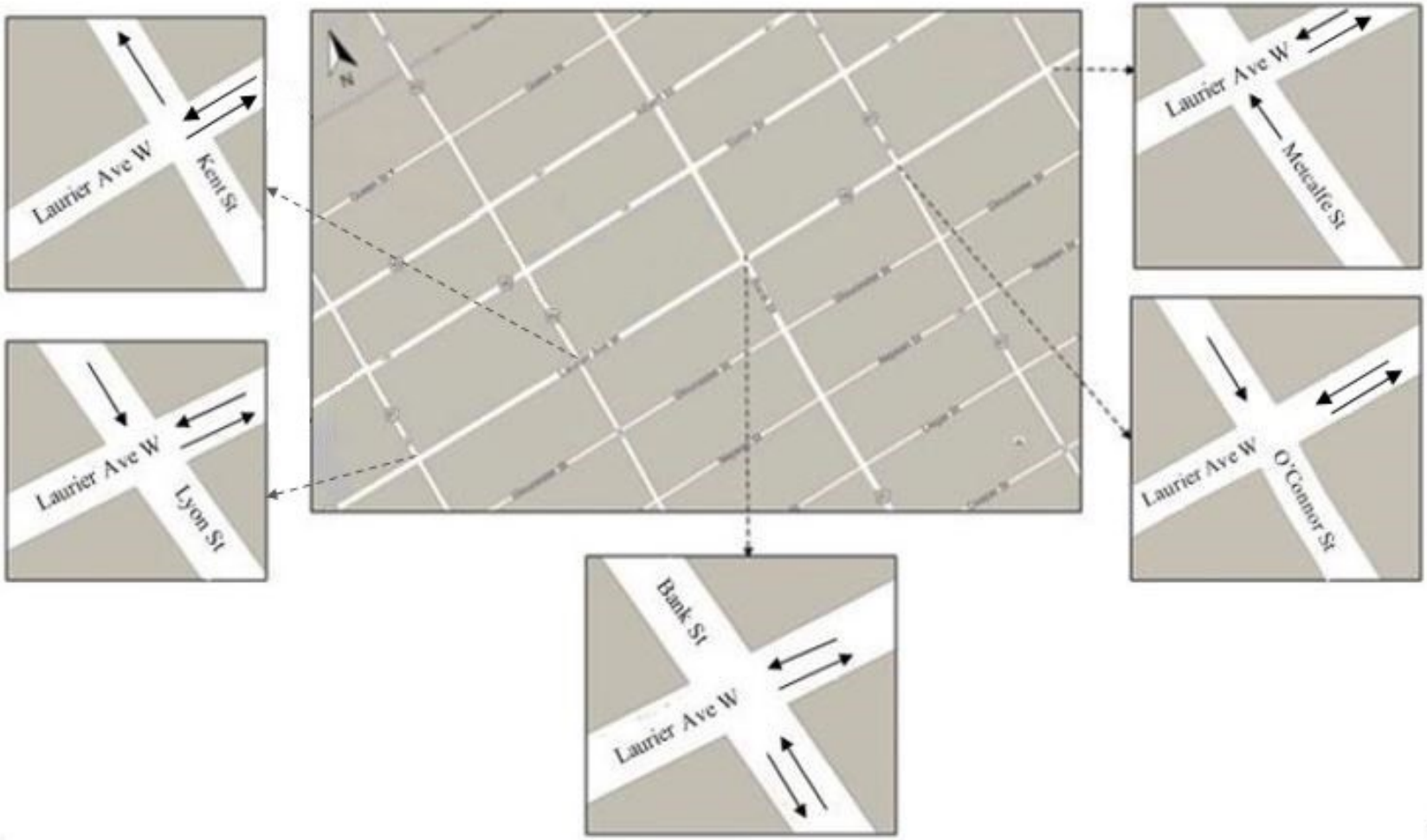


Figure 3.1: Site of the Study (Google, 2015)

3.1.2 Real-Time Volumes & Travel Time

To complete the second phase of the implemented methodology, the following types of data were required: 1- Real-time travel time data which was used to calibrate VISSIM's model to describe the driving behavioural characteristics in the field. 2- Real-time Traffic volumes of different road users which were used to replicate the traffic movements observed in the field in VISSIM's model. Real-time travel time was measured for the two travel directions in the site using a floating car survey based on the guidelines recommended by Dowling *et al*., (2004). A floating car is a vehicle following the traffic stream that travels the entire length of a selected road segment for several runs during the analysis period. In each run, an observer inside this vehicle measures the elapsed travel time between the first and last point of the road segment. The average travel time is then computed using the measured travel time of each run. In this study, this survey was conducted on a Friday between 3:30 PM and 5:30 PM during the summer. In the first travel direction, the floating car started the survey at Metcalfe St and then traveled west until Lyon St. As for the second travel direction, the floating car started at Lyon St and traveled east until Metcalfe St. (E → W) and (W → E) will be used to refer to the first and second travel directions, respectively. Travel time measurements can witness variability depending on factors like traffic density and traffic signals' timing schedules at the selected site. The variability in travel time measurements was accounted for by measuring the real-time travel time in each travel direction multiple times. In particular, the maximum number of runs that could be taken for each travel direction during the time considered in this study is eight. The real-time travel time for each run was measured by an observer in the passenger seat using a stopwatch. In each travel direction, the observer started and stopped

the stopwatch when the front wheels of the floating car passed the stop line of the first and last intersections, respectively. Table 3.1 shows the real-time travel time obtained from the floating car survey for each travel direction. The two travel directions were separated because they can witness different types of behavioural characteristics such as traffic density, gap acceptance and travel time especially when one of them is busier than the other. The difference between the two travel directions in this research can be seen in their elapsed real-time travel time.

Table 3.1: Real-Time Travel Times Obtained from Floating Car Survey

Run No.	Measured Travel Time (sec)	
	E → W	W → E
1	212.50	287.80
2	168.87	423.52
3	226.41	324.74
4	222.02	437.08
5	166.63	399.24
6	217.21	289.71
7	293.40	401.57
8	276.67	211.68
Average	222.97	346.92

As for the traffic volumes, cameras were fixed one-by-one on a light pole at each intersection to record the traffic movements of different road users. The five cameras recorded the traffic movements on the same day and time of the floating car survey. This was done to ensure that the recorded real-time volumes reflected the travel times obtained from the survey. After that, five pieces of video footage were independently reviewed by two observers to count the traffic volumes. In each video, the observers counted the through, left-turning, and right-turning vehicle volumes for vehicles, the through cyclist volumes, and the pedestrian volumes at each crosswalk and recorded all these counts per 5 minute intervals. The counts of the two observers were compared against each other to eliminate any possible counting error. Whenever the difference between the two recorded

values for any count exceeded five, that count was reviewed by the main researcher and updated. The rationale behind setting a threshold of 5 was that roads do not witness the exact traffic volumes every weekday. In other words, traffic volumes may slightly vary from day to day for a given road under the same conditions. However, accepting a higher threshold may no longer explain that variation and can therefore lead to erroneous and misleading results. Very few by-law violations were witnessed at the selected site. For example, vehicles are not allowed to turn right on a red signal in all five intersections and are not allowed to turn left on Bank St intersection during PM peak hours. These rarely witnessed violations could not be independently modeled and were therefore discarded. Counting traffic movements at all five intersections during PM peak hours yielded a total of 13,394 vehicle counts, 1,721 cyclist counts, and 14,196 pedestrian counts. The counts were categorized based on turning directions for each road user and for each intersection. As mentioned earlier, real-time traffic volumes were counted and recorded per five minute intervals. Based on that, 5 minute intervals were defined in VISSIM's model and the volumes were input accordingly. This was done to minimize the effect of random assignment and create a more realistic simulation model. To the author's knowledge, no study in the literature used such short intervals to improve the accuracy of a simulation model. In addition, the stochastic nature of VISSIM was mitigated by conducting multiple simulation runs on the model which will be explained in greater details in Section 3.2.

3.1.3 Real Conflicts

The only remaining dataset needed to complete the data collection work was real conflicts. This type of data was used as a reference to estimate the accuracy of the conflicts simulated by VISSIM. Real conflicts were obtained from previous PhD thesis from the Civil and Environmental Engineering Department (Kassim, 2014). In each intersection, the identified conflicts described the interaction between vehicles making right-turns to exit the corridor and cyclists on the corridor traveling through the intersection on the same side of the right-turning vehicles. A bound is defined in this thesis as an area in a road intersection that gives access to vehicles to enter or leave the intersection. Since four out of five cross-streets are one-way, each of these four contains one bound only through which right-turn vehicles could exit the intersections. The fifth cross-street, Bank St, is a two-way street and contains two bounds that witness the interactions of interest. However, only the south bound of Bank St was monitored by Kassim (2014). Therefore, one bound in each of the five intersections was monitored. The five bounds at which the conflicts were identified are circled and labeled in Figure 3.2.

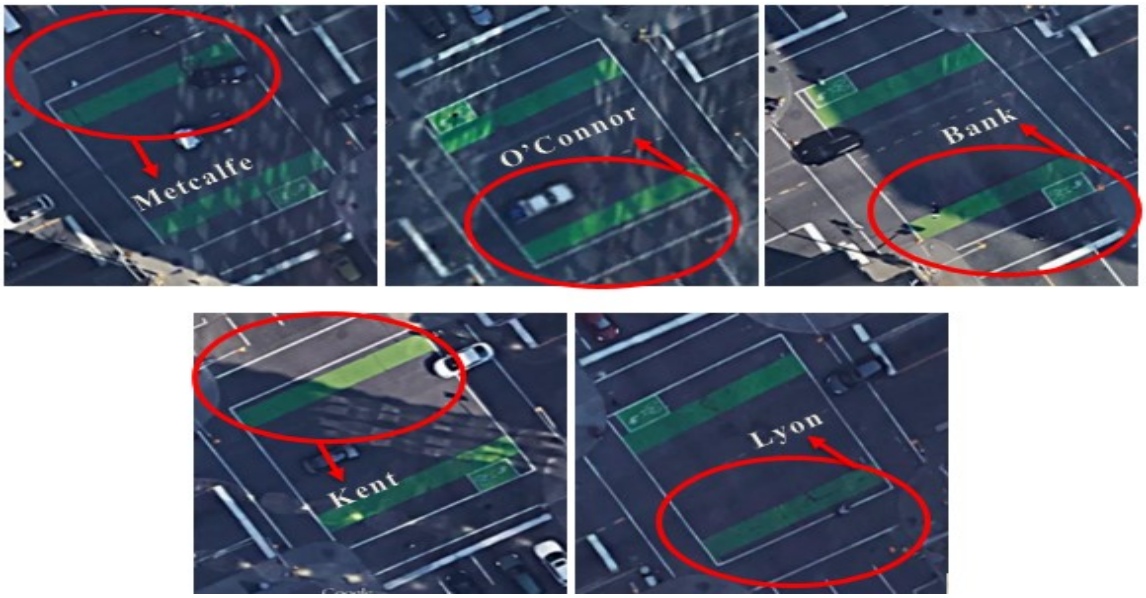


Figure 3.2: Bounds at which Obtained Conflicts were Identified (Google, 2015)

In addition, these conflicts were identified from different videos using the Manual Frame Count Measurement (MFCM) method. The area of potential collision was defined in this method as the intersection point between the paths of vehicle and cyclist. Post-Encroachment Time (PET) was used to identify conflicts based on a threshold of 3 seconds. To illustrate, events with calculated PET values less than or equal to 3 seconds were considered conflicts. Readers who want to access the detailed description of the MFCM method and how the PET was calculated can refer to (Kassim, *et al.*, 2014).

In each bound, the real-time volumes of interacting road users during which the real conflicts were identified were obtained. The obtained volumes dataset consisted of right-turning vehicle volumes, through cyclist volumes, and pedestrian volumes on the crosswalk. Traffic volumes of other movements were not considered in this research. This is a limitation in this research as volumes of other traffic movements might affect the driver behaviour and hence might affect the simulated conflicts results. The months that reflect the obtained data are June 2011 for the first four intersections (Metcalfe → Kent), and July

2011 for the last intersection. As for the time, all conflicts were observed between 3 pm and 6 pm. The datasets of the first four intersections were reported in 3 equal intervals (per hour) whereas the datasets of the last intersection were reported in four unequal intervals. A summary of the obtained conflicts and their real-time volumes is presented in Table 3.2.

Table 3.2: Real Conflicts per Time Interval and their Real-Time Volumes

Intersection	Month/ Year	Time		Right-turning vehicles	Through Cyclists	Ped. volume	Ped. volume	# conflicts
		From	To			(E → W)	(W → E)	
Metcalfe St	Jun-11	3:00 PM	4:00 PM	142	35	238	200	6
Metcalfe St		4:00 PM	5:00 PM	125	87	318	187	12
Metcalfe St		5:00 PM	6:00 PM	114	91	242	130	11
O'Connor St		3:00 PM	4:00 PM	105	82	189	195	9
O'Connor St		4:00 PM	5:00 PM	83	156	242	181	14
O'Connor St		5:00 PM	6:00 PM	85	163	152	163	13
Bank St		3:00 PM	4:00 PM	77	47	268	239	13
Bank St		4:00 PM	5:00 PM	92	95	284	276	23
Bank St		5:00 PM	6:00 PM	92	119	255	160	20
Kent St		3:00 PM	4:00 PM	135	65	152	270	25
Kent St		4:00 PM	5:00 PM	120	133	197	263	23
Kent St		5:00 PM	6:00 PM	121	130	151	187	33
Lyon St	Jul-11	3:00 PM	3:45 PM	26	11	50	17	0
Lyon St		3:45 PM	4:30 PM	35	20	92	27	1
Lyon St		4:30 PM	5:20 PM	22	8	87	31	0
Lyon St		5:20 PM	6:00 PM	19	9	57	35	0

3.2 Travel Time Calibration

In the second phase of the research work, the selected site was modelled in VISSIM and a calibration procedure was applied on the model. The steps in this procedure, shown in Figure 3.3, were based on the one developed by Park and Qi (2005).

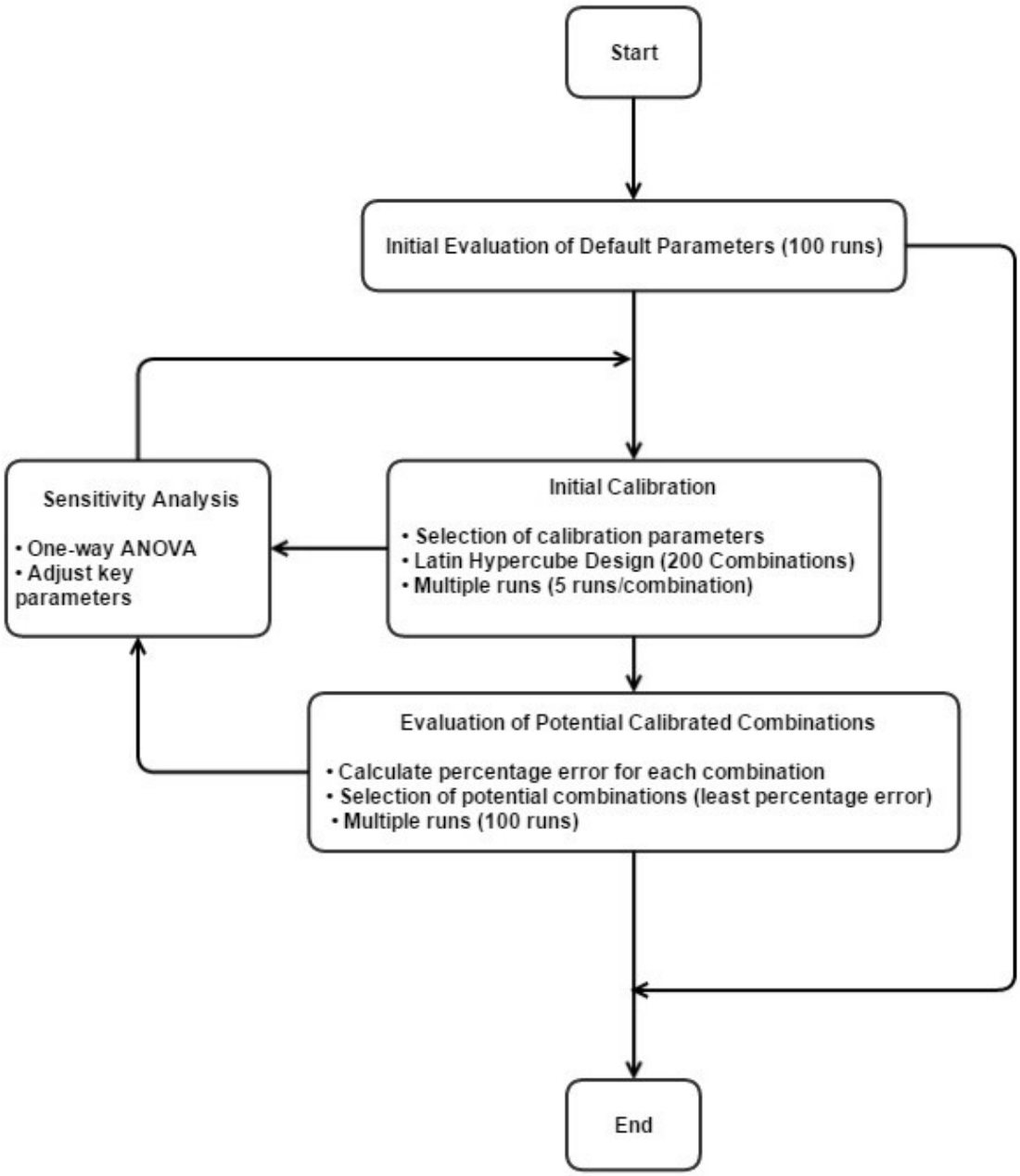


Figure 3.3: Travel Time Calibration Procedure

3.2.1 Model Development and Network Coding

Working with VISSIM involves two stages which are modelling and coding before conducting any simulation runs. In the modelling stage, the user draws the links and connecters that reflect the roads of the analyzed facility. In the coding stage, the user inputs different types of datasets that describe the traffic operations in that facility. In particular, the user inputs the traffic volumes, defines the timing schedules of the signal heads, and models the right of way. The selected corridor segment was modelled in VISSIM with the help of the built-in Microsoft Bing Maps. All the links and connectors were drawn on the background image of the site map. Then, AutoCAD drawings of the five intersections were used to verify the lane widths of the roads, segregated bike lanes, and pedestrians' crosswalks. These drawings were based on detailed field surveys conducted by Kassim using total station (2014). The developed model in VISSIM is shown in Figure 3.4.

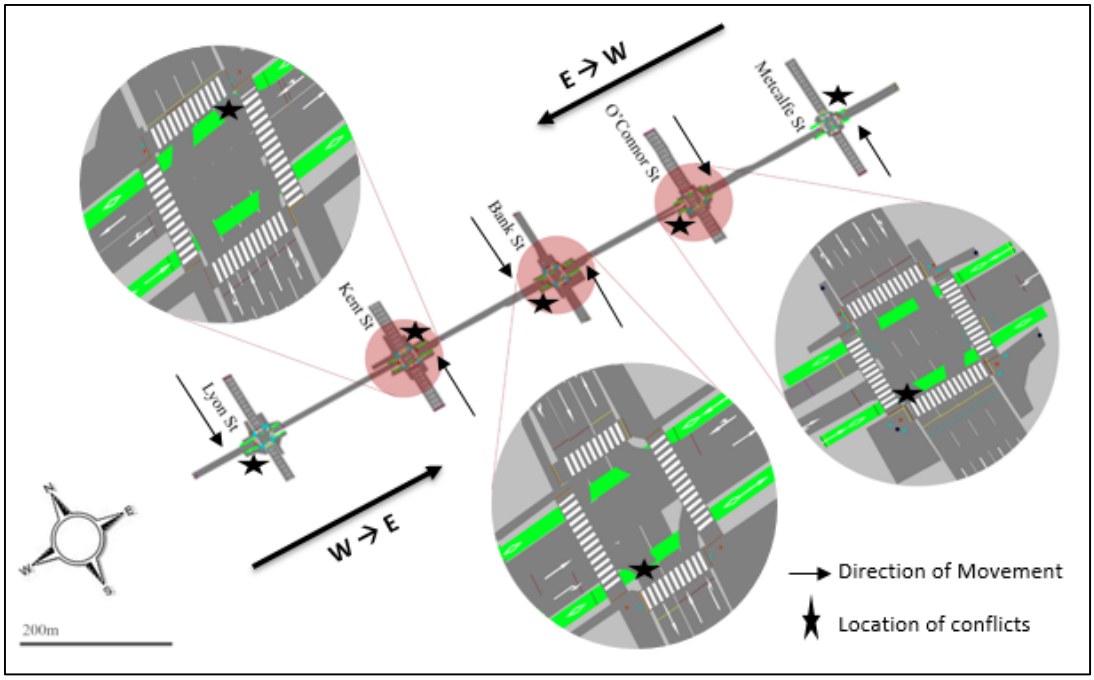


Figure 3.4: VISSIM Model of the Selected Corridor Segment

As can be seen in Figure 3.4, the segregated bike lanes, colored in green, were only modelled at each intersection. Since the bike lanes were physically segregated, cyclists would primarily interact with other road users inside the intersection. Furthermore, modelling the bike lanes this way allowed inputting the cyclists' counts at each intersection just like how they were collected.

As mentioned earlier, the real-time volumes of all road users were collected and aggregated every five minutes intervals. Thus, the two-hour simulation period was divided into five minutes time intervals. This allowed all volumes and route choices to be input in five minutes intervals similar to how they were collected in the site. However, all volumes were converted to equivalent hourly volumes per five minutes intervals. This was done because VISSIM requires inputting the volumes per hour and not per time interval (PTV VISSIM 6 User Manual, 2014). Subsequently, the converted volumes and route choices for all road users were input in VISSIM. Route choices were calculated by dividing the number of vehicles taking the same route over the total number of vehicles in that bound. For example, the percentage of right-turning vehicles in one bound was found by dividing the right-turning vehicles' volume by the total vehicles' volume (*i.e.*, Through, Left-turning, Right-turning) in that bound. VISSIM then randomly assigns the vehicle inputs on each 5 minutes time interval based on the calculated proportions of the route choices.

Figure 3.5: Illustration of Pedestrians' Coding at One Crosswalk

For pedestrians' movements, pedestrians' walking areas were modelled at the corner of each intersection. Since the pedestrians had two possible crosswalks to use in each area, real-time volumes that initiated from that area towards these two crosswalks were summed and coded in that area. The pedestrians' input points are annotated in Figure 3.5 with a star. After that, the pedestrians' route choices (*i.e.*, route splits) on the two crosswalks were coded. The pedestrians' split initial and receiving points are annotated in Figure 3.5 with a circle and a triangle, respectively. As can be seen in Figure 3.5, pedestrians who finished moving from an area to another could be attracted by the pedestrians' split initial point of the new area. If that happened, pedestrians would have walked back to the area where they were generated. Alternatively, they would have taken

the other crosswalk in the new area. This problem had to be dealt with because it could affect the pedestrians' volumes and therefore the accuracy of the model. To resolve this problem, new areas were duplicated above the old ones. In other words, each intersection's corner had two areas at the top of each other. Then, each pedestrians' input and its splits' initial point were moved to the new area (Top Area). The receiving points on each old area (Bottom Area) were left unmoved. By doing this, pedestrians who just finished crossing to the new area would not be visible in the network because they were in the bottom area. Additionally, these pedestrians would not be able to take a new path because the pedestrians' split initial points were in the top area.

As part of the coding stage, conflict areas were used, as recommended by VISSIM manual, to model the right of way at overlapping links (PTV VISSIM 6 User Manual, 2014). Conflict areas in VISSIM are areas that get displayed automatically whenever two links overlap each other. These conflict areas allow the user to model the right of way at any two overlapping links and give the priority to movements on one link over the other.

The desired speed of the cyclists and pedestrians were assumed to be 15 km/h (El-Geneidy, *et al*., 2007) and 5 km/h (Highway Capacity Manual, 2010), respectively. The desired speed distribution for the vehicles was one of the parameters chosen for calibration and will be addressed later in this section.

Finally, the signal timing schedule for each of the five intersections in the selected site was obtained from the City of Ottawa. These schedules were used to code the signal program of each intersection for the time between 3:30 pm to 5:30 pm. The pedestrians had pedestrians' countdown signals at each end of any crosswalk in the site. Theoretically, the flashing Do Not Walk signal is used to encourage pedestrians already on the crosswalk

to finish their crossing maneuver, and discourage those who have not initiated their crossing maneuvers to not do so. However, some pedestrians still decide to start their crossing maneuvers even if the flashing Do Not Walk signal is on. These pedestrians accommodate their decision by increasing their walking speed. Accounting for such pedestrians was a shortcoming in this research as their counts at each crosswalk of the five intersections were not separately collected. Therefore, the compliance rate at each crosswalk could not be calculated. Instead, a compliance rate of 100%, the default value in VISSIM, was used for all the pedestrians' countdown signals in the simulated site.

3.2.2 Initial Evaluation

The default parameters in VISSIM do not always describe the real driving behaviour especially that the behaviour can change throughout the day in the same road depending on the hour of the day. Furthermore, default parameters cannot capture the variation in behavioral characteristics across locations with different topographies, different demographics, different weather conditions, and even different cultures. Hence, using such parameters in simulation models without proper verification can lead to inaccurate results that do not describe the real conditions in the field. In this study, the model was run to check if the default parameters will produce a travel time distribution for each travel direction that contains its average real-time travel time.

Table 3.3 shows the default values of the parameters chosen for calibration. The model was run for 100 times to account for the stochastic nature of VISSIM. Moreover, 100 runs were needed to establish representative results at 95% confidence interval as recommended by Park and Won (2006).

Table 3.3: Default Values of the Parameters Chosen for Calibration

No.	Parameter	Default Value
1	Simulation Resolution (Time Steps / Simulation Second)	5
2	Maximum Look Ahead Distance (metres)	250
3	Number of observed preceding vehicles	4
4	Average Standstill Distance (metres)	2
5	Additive Part of Safety Distance	2
6	Multiplicative Part of Safety Distance	3
7	Front Gap (seconds)	0.5
8	Rear Gap (seconds)	0.5
9	Safety Distance Factor	1.5
10	Vehicles' Desired Speed Distributions (km/h)	40 → 45

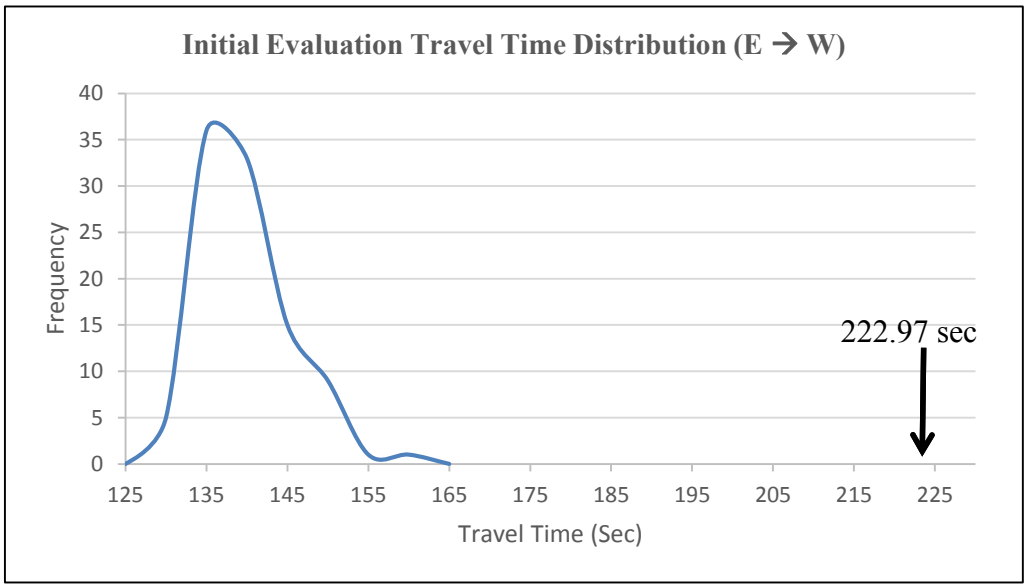


Figure 3.6: Simulated Travel Time Distribution (E→W)

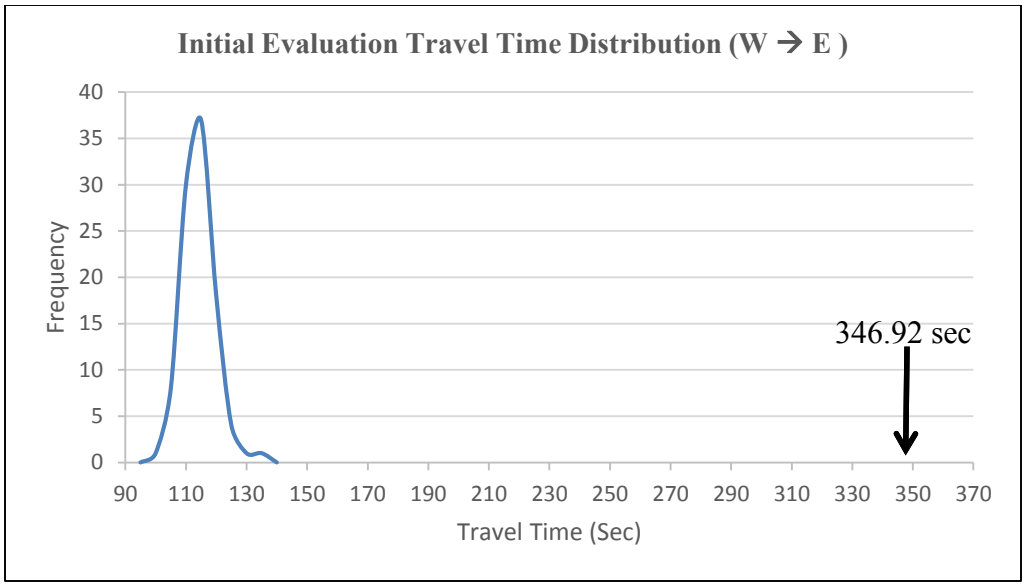


Figure 3.7: Simulated Travel Time Distribution (W→E)

Figure 3.6 and Figure 3.7 show the simulated travel time distribution of the (E → W) and (W → E) travel directions, respectively. It is obvious that the average real-time travel time, shown as an arrow, doesn't fall inside the distribution in either one of the distributions. This indicates that the default parameters of VISSIM cannot describe the driving behaviour in any of the travel direction of the selected site.

3.2.3 Initial Calibration

Any simulation model has to be calibrated to reflect the driving behaviour in the field when the default parameters cannot. To do that, a list of parameters has to be chosen for calibration. Furthermore, a reasonable range for each of the chosen parameters has to be selected. In this research, 10 parameters along with their initial ranges were chosen on the basis of a review of the literature and VISSIM manual. Since the selected corridor segment has only one lane in each travel direction, parameters related to lane change behaviour were not considered for calibration. A list of the selected parameters and their ranges is presented

in Table 3.4. Besides that, a description of each parameter is presented as following (PTV VISSIM 6 User Manual, 2014):

1) Simulation Resolution:

This parameter specifies how often vehicles' and cyclists' positions are recalculated within a simulation second.

2) Maximum Look Ahead Distance:

This parameter describes the maximum distance in metres that a vehicle can see forward in order to react to other vehicles within the same road that are in front of it or to the side of it.

3) Number of Observed Preceding Vehicles:

This parameter specifies the number of preceding vehicles a vehicle can observe and react to. Network objects like signal heads or stop signs get treated by the vehicle of interest as preceding vehicles that it needs to react to.

4) Average Standstill Distance:

This parameter defines the average desired standstill distance in metres between two cars.

5) Additive Part of Safety Distance:

A factor used in the computation of the desired safety distance between two vehicles based on the predefined speed assigned to vehicles in the model.

6) Multiplicative Part of Safety Distance:

A factor used in the computation of the desired safety distance between two vehicles.

7) Front Gap:

This is the time in seconds that must be provided after a vehicle with the right of way has left the conflict area and before a yielding vehicle enters it. A description of what conflict areas in VISSIM are can be found in section 3.2.1.

8) Rear Gap:

This is the minimum gap time in seconds that must be provided after a vehicle controlled by the yield rule has already left the conflict area and before a vehicle with the right of way enters it.

9) Safety Distance Factor:

This factor is used in the computation of the minimum distance a yielding vehicle that is completely inside the conflict area must keep from a vehicle with the right of way. In particular, the minimum distance of the yielding vehicle is determined by multiplying this factor with the normal desired safety distance of the vehicle with the right of way.

10) Desired Speed Distribution:

This is a pair of parameters which characterize the upper and lower bounds of a distribution that represents the desired speed decisions of the vehicles in the analyzed road. This distribution can be modified in VISSIM by changing its lower and upper bounds. (X → Y) format will be used to describe this parameter where X is the lower bound of the distribution and Y is the upper bound.

Table 3.4: Selected Parameters for Calibration and Their Initial Ranges

No.	Parameter	Initial Range
1	Simulation Resolution (Time Steps / Simulation Second)	1 – 9
2	Maximum Look Ahead Distance (meters)	200 – 300
3	Number of observed preceding vehicles	1 – 4
4	Average Standstill Distance (meters)	1 – 5
5	Additive Part of Safety Distance	1 – 5
6	Multiplicative Part of Safety Distance	1 – 6
7	Front Gap (seconds)	0.5 – 1.5
8	Rear Gap (seconds)	0.5 – 1.5
9	Safety Distance Factor	0.5 – 1.5
10	Vehicles' Desired Speed Distributions (km/h)	1) 35 → 40 2) 40 → 45 3) 45 → 50

An evaluation was conducted to determine if the real driving behaviour in the site could be described by a combination from the parameters and ranges shown in Table 3.4. Assuming that each parameter contained five possible values inside its range, the number of possible combinations would be $5^{10} = 9{,}765{,}625$. Examining this number of possible combinations was not feasible because it would require a significant amount of time. Instead, the Latin Hypercube Design (LHD) experimental design method was used. LHD is a sampling method in which the entire range of each parameter is divided into a number of regions, defined by the user, of equal probability. LHD then randomly samples one value from each region inside the range of each parameter. After that, LHD matches at random the sampled values of each parameter with the ones of the other parameters in an orthogonal array (McKay, *et al.*, 1979). As a result, a practical number of combinations that reasonably covers the surface of each parameter can be generated using LHD. In this research, a Latin Hypercube Sampling toolbox in Matlab was used to generate 200 combinations from the parameters and ranges in Table 3.4 (Matlab Users' Manual, 2013). According to Park and Qi (2005), using 200 combinations is adequate to cover the entire parameter surface and for computational simulation and calculation.

Each of these combinations was tested in VISSIM for five runs, for a total of 1,000 runs. The five runs were conducted for each combination to reduce the output variability caused by the stochastic components of VISSIM. For each travel direction, 200 travel time averages were obtained where each was based on five runs. Then, the 200 travel time averages were used to construct a travel time distribution. As a result, a travel time distribution was created for each of the two travel directions. These distributions were necessary to examine if the initial ranges contain combinations that reflect the real driving behaviour in the site. The ranges were only accepted when the average real-time travel time of each travel direction fell inside its respective distribution.

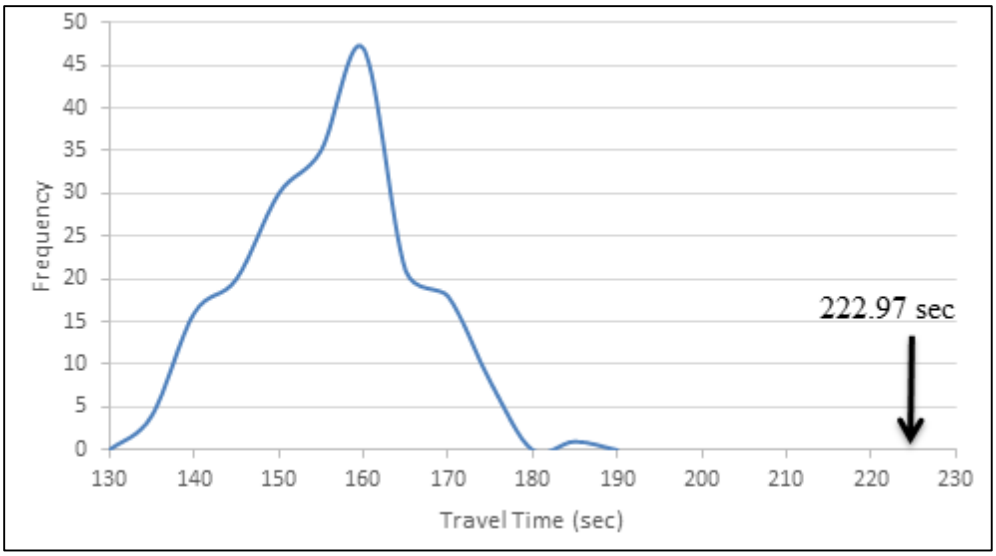


Figure 3.8: Initial Calibration Travel Time Distribution (E→W)

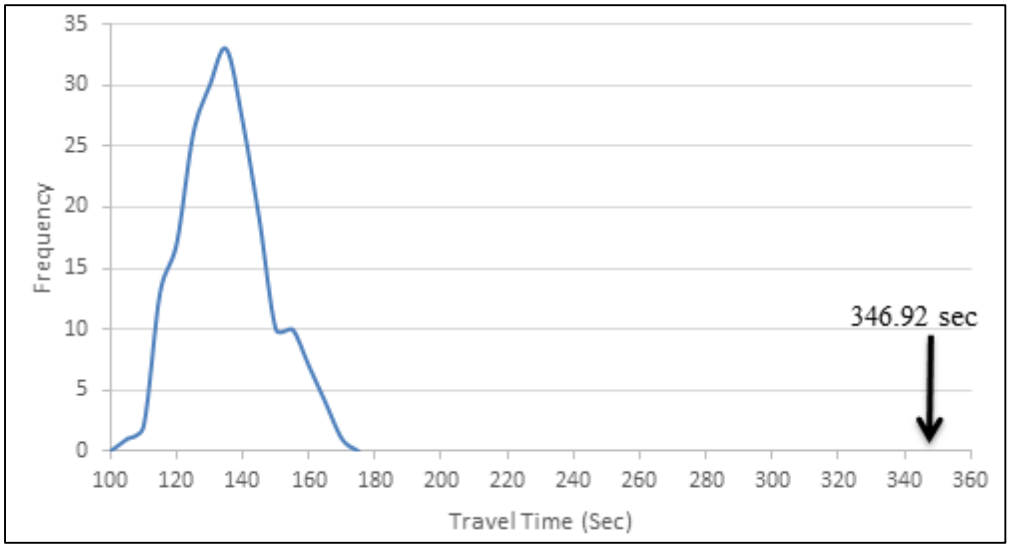


Figure 3.9: Initial Calibration Travel Time Distribution (E→W)

As can be seen in Figure 3.8 and Figure 3.9, the average real-time travel time of both travel directions did not fall inside their travel time distributions. This indicated that none of the 200 combinations can describe the driving behaviour in any of the two travel directions in the field. Consequently, the initial ranges from which these 200 combinations were generated had to be modified.

3.2.4 Sensitivity Analysis

In the initial calibration, the travel time distributions were used to check if initial ranges represented the real driving condition in the site. It was found that none of the travel time distributions contained its respective average real-time travel time. This indicated the initial parameters' ranges did not include a combination that describes the driving behaviour in the site. Therefore, some of these ranges had to be adjusted. In fact, the ranges of the parameters that had significant effect on travel time results were chosen for modification. Thus, it was important to determine which parameters significantly affected the results. One-way ANOVA in SPSS statistical package was used to test the null

hypothesis that the means for two or more groups of each parameter were equal (SPSS, 2013). The effect of a parameter on the output was considered significant when the means for its different groups were significantly different at 95% confidence interval. Parameters that had a significant effect on the output will be referred to as key parameters. Since the ranges of simulation resolution, number of observed preceding vehicles, and desired speed distribution were integers-based, they were divided into groups based on the number of integers inside their ranges. In particular, the ranges of simulation resolution, number of observed preceding vehicles, and desired speed distribution were divided into 9, 4, and 3 groups, respectively. The ranges of the remaining seven parameters were each equally divided into ten different groups. The 200 values of each of the ten calibration parameters were then categorized according to their parameter's group. Table 3.5 presents the results of the one-way ANOVA for both travel directions and highlights the parameters that had a significant effect on the travel time output.

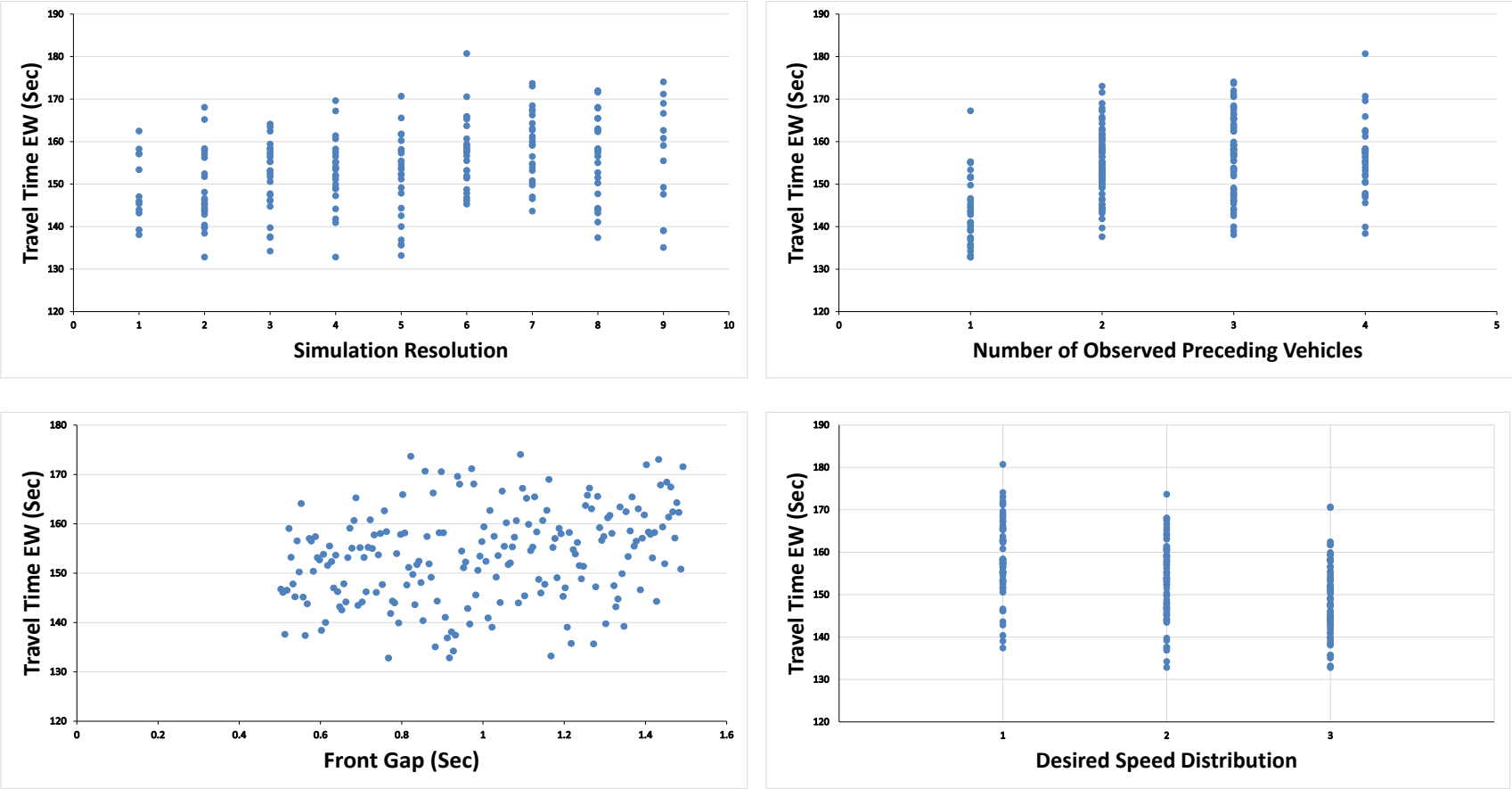
Table 3.5: One-way ANOVA Results for Both travel directions

Parameter	*p-value* (E→W)	Significance	*p-value* (W→E)	Significance
Simulation Resolution	.001	Significant	.396	Not significant
Maximum Look Ahead Distance	.318	Not significant	.192	Not significant
Number of observed preceding vehicles	.000	Significant	.000	Significant
Average Standstill Distance	.118	Not significant	.215	Not significant
Additive Part of Safety Distance	.090	Not significant	.139	Not significant
Multiplicative Part of Safety Distance	.516	Not significant	.106	Not significant
Front Gap	.001	Significant	.001	Significant
Rear Gap	.301	Not significant	.002	Significant
Safety Distance Factor	.392	Not significant	.542	Not significant
Vehicles' Desired Speed Distributions	.000	Significant	.000	Significant

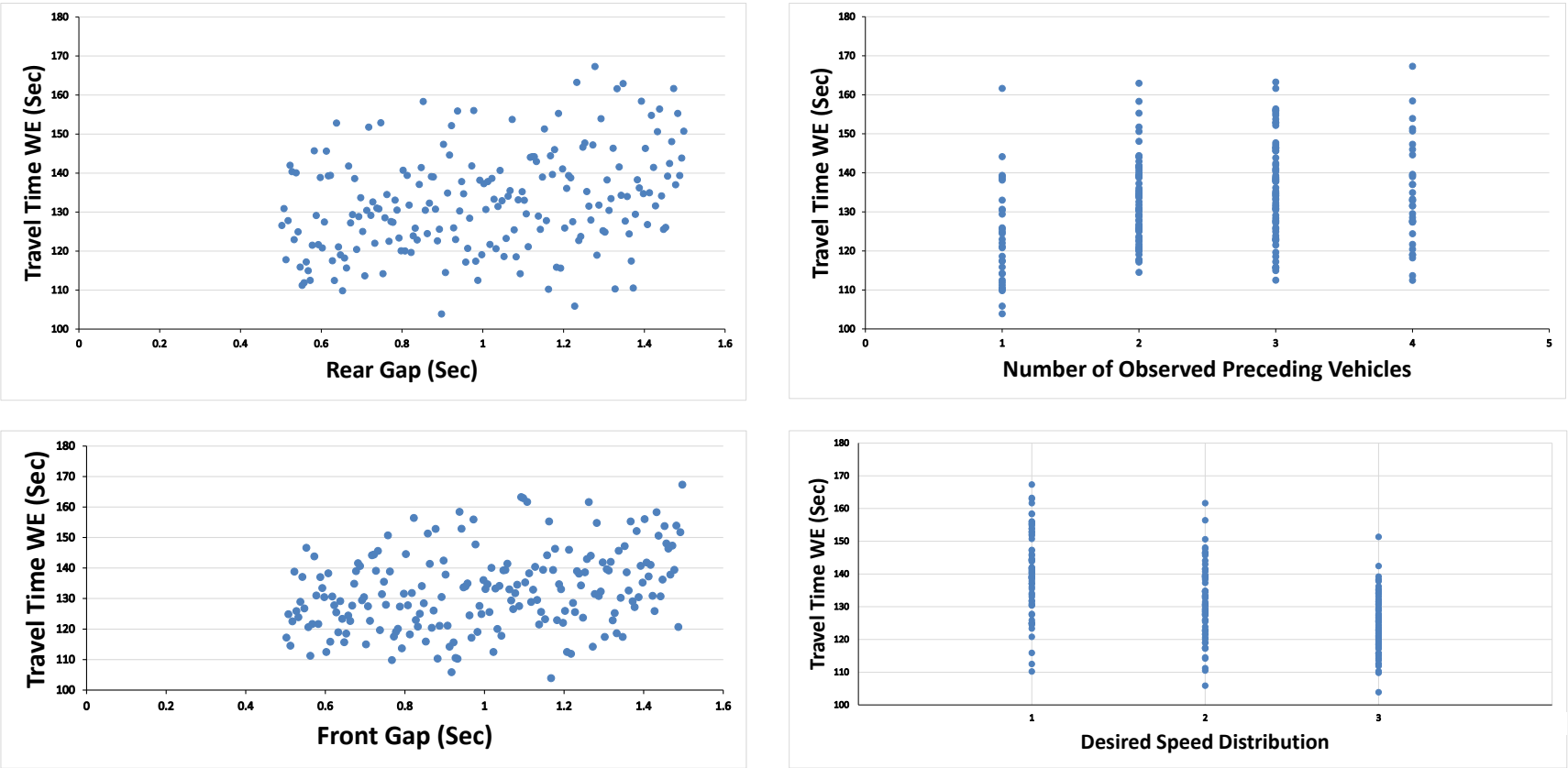
Several parameters were found to have a significant effect on the travel time output of at least one travel direction. However, not all these parameters had a consistent relationship with travel time. Scatter plots were constructed using the values of the key parameters from the LHD combinations and their respective travel time output. These scatter plots, shown in Figure 3.10, were used to determine which of the key parameters caused a consistent change in the travel time. Only such key parameters were selected for modification. This is because it would be easy to anticipate how these parameters should be modified in order to bring the travel time output closer to the real one. The desired speed distribution was the only key parameter that had a clear and consistent relationship with travel time. In fact, the travel time decreased when the desired speed distribution increased. As a result, the desired speed possible distributions had to be decreased. This decrease would increase the simulated travel time output of each travel direction and shift their distributions towards their average real-time travel time.

In spite of its name, Park and Qi used the actual speeds in the field to modify the ranges of the desired speed distribution parameter (2005). Similarly, the distributions in this research were modified based on the observed actual speed of the floating car during the survey. Based on that, the three desired speed distributions in Table 3.4 were changed to 15→20, 15→25, and 15→30, respectively. After that, LHD was used again to generate 200 new combinations based on the implemented modifications. Each combination was simulated in VISSIM for 5 runs and the average travel time of each 5 runs was obtained. Then, the same procedure explained earlier was used to construct the simulated travel time distribution of each travel direction. Figure 3.11 and Figure 3.12 show the new travel time distributions of the modified LHD combinations along with the ones of the initial LHD

combinations. Furthermore, these figure show that each of the modified distributions contained their average real-time travel time. This indicates that each of these new distributions contained a combination of parameters that can describe the driving behaviour in its travel direction.



a) E→W Approach Key Parameters Plots



b) W→E Approach Key Parameters Plots

Figure 3.10: Scatter Plots of Travel Time against Key Parameters for Each Travel Direction

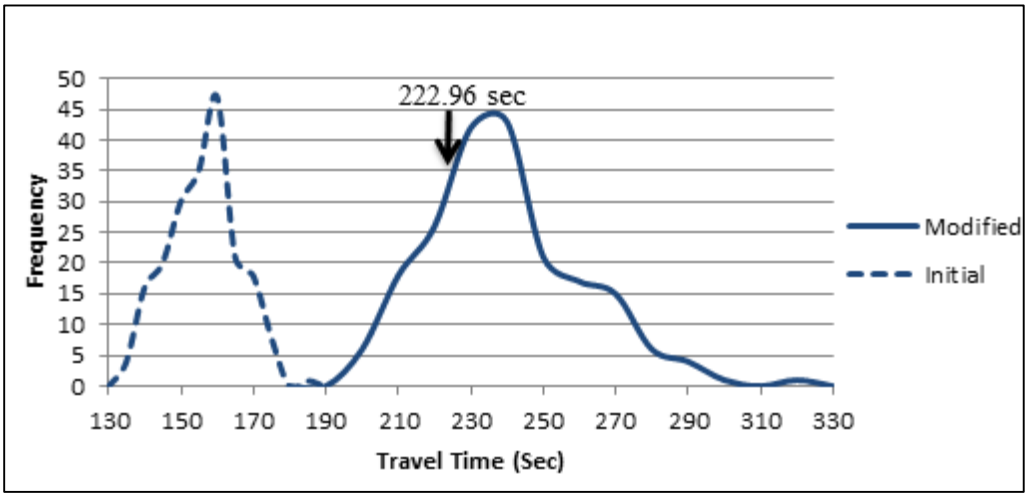


Figure 3.11: Comparison between Initial and Modified Travel Time Distributions (E→W)

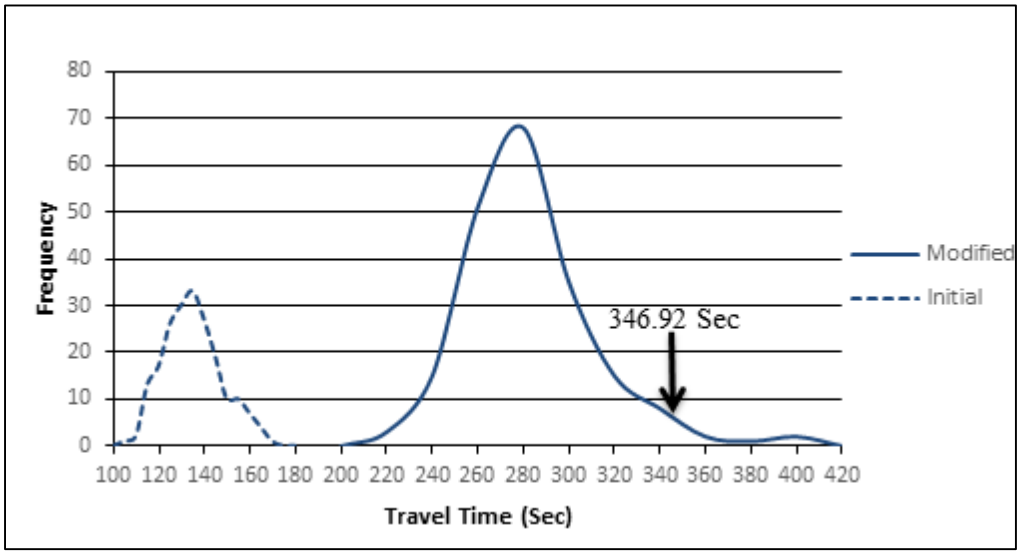


Figure 3.12: Comparison between Initial and Modified Travel Time Distributions (W→E)

3.2.5 Evaluation of Potential Calibrated Combinations

As stated earlier, a simulated travel time distribution that includes its respective average real-time travel time was successfully created for each travel direction. This means that a potential calibrated combination for each travel direction can be found among the new 200 combinations. Percentage error was used to find the calibrated combination of each travel direction. For each travel direction, percentage error was calculated for each combination using its average simulated travel time and the average real-time travel time as shown in the following equation:

$$\text{Percentage Error} = \frac{|t_{combination} - t_{real}|}{t_{real}} \times 100 \qquad \textbf{Equation 4.1}$$

Where:

$t_{combination}$: Average simulated travel time of the five runs conducted on a combination

t_{real}: Average real-time travel time

The combination with the least percentage error in each travel direction was considered a potential calibrated combination and was selected for further evaluation. The two combinations that yielded the least percentage error in their respective travel directions are presented in Table 3.6. All parameters' values shown in Table 3.6 were coded in their respective travel directions in VISSIM except for the simulation resolution. As mentioned earlier, simulation resolution is a parameter that specifies using one value only how frequently the vehicles trajectories in the entire network get recalculated within a simulation second. Furthermore, simulation resolution was earlier found to have a significant effect on the output of the (E → W) travel direction only, as shown in Table 3.5. Therefore, the simulation resolution value of the (E → W) travel direction combination was used in this research.

Table 3.6: Potential Calibrated Combination of Each Travel Direction

Travel Direction	E → W	W → E
Simulation Resolution	4	7
Maximum Look Ahead Distance	290.25	299.25
Number of Preceding Vehicles	3	2
Average Standstill Distance	2.73	4.45
Additive Part of Safety Distance	2.79	4.23
Multiplicative Part of Safety Distance	2.0375	3.2625
Front Gap	1.1075	1.0025
Rear Gap	1.1175	1.2475
Safety Distance Factor	1.1075	1.2475
Desired Speed Distribution	15 → 25	15 → 20

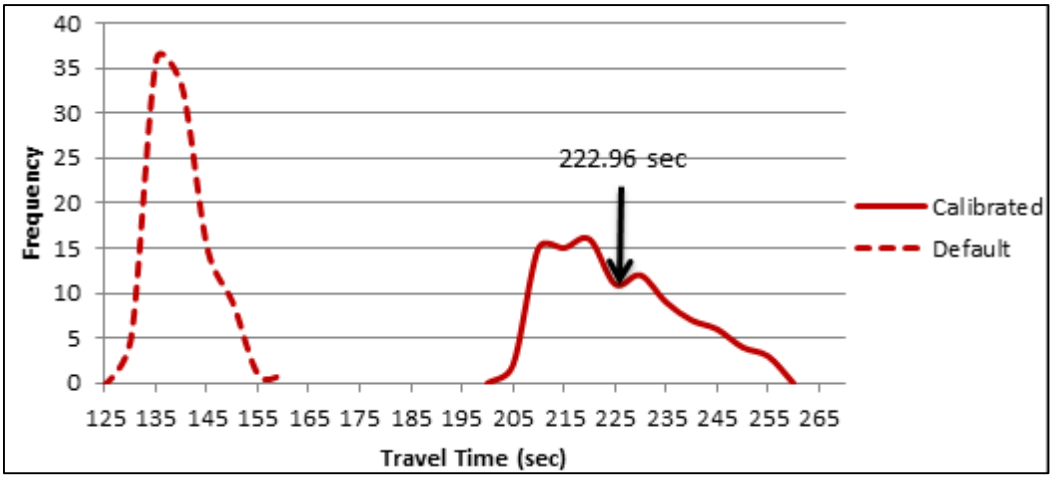


Figure 3.13: Travel Time Distributions of the Default and Calibrated Parameters (E→W)

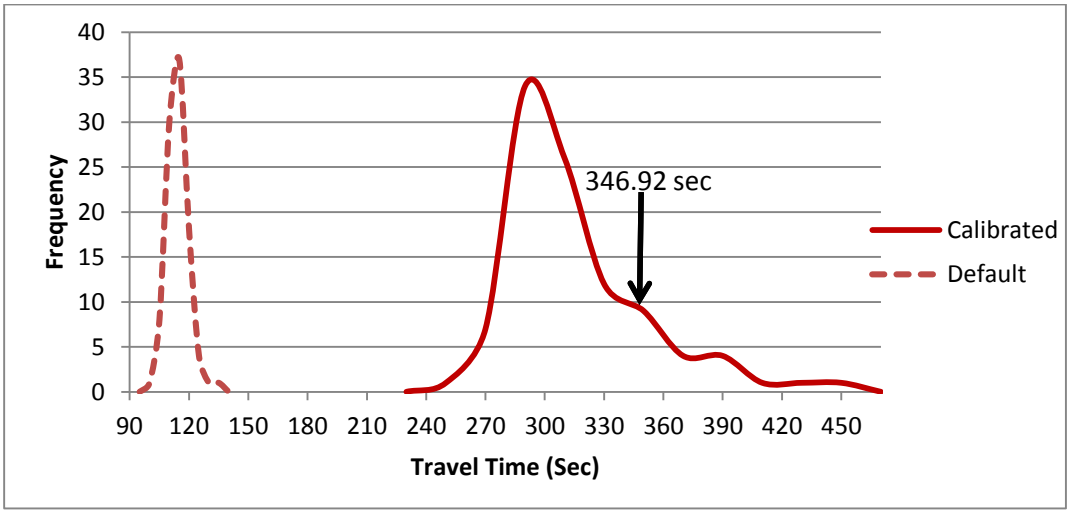


Figure 3.14: Travel Time Distributions of the Default and Calibrated Parameters (W→E)

After that, 100 simulation runs were conducted for the model and were visually checked at random and no animations that indicate errors in modelling and coding were detected. A new distribution was created for each travel direction using the 100 runs' travel time output. It was found that the average real-time travel time of each travel direction was contained by its respective distribution. Figure 3.13 and Figure 3.14 show the default and calibrated parameters' travel time distributions of the (E → W) and the (W → E) travel directions, respectively.

3.3 Simulated Conflicts Extraction

After finding the calibrated combinations of the (E → W) and (W → E) travel directions, the third phase of this research was initiated. In this phase, each of the five intersections in the selected corridor segment was modelled in VISSIM. Multiple runs were conducted on each model based on its default parameters and calibrated ones. This will be explained in further details in later sections of this thesis. Both types of parameters were investigated to evaluate how travel time calibration affects the models' ability to predict conflicts. Then, trajectories files were extracted from VISSIM based on the conducted runs. Finally, an algorithm was developed using Python language (Python, 2015) to read these files and identify the conflicts between right-turning vehicles and through cyclists. Statistical tests were applied to examine the correlation between the simulated and real conflicts. Moreover, the significance of travel time calibration on VISSIM's ability to predict conflicts was evaluated.

3.3.1 Models Development and TRJ Files Extraction

Five different models were created in VISSIM for the five intersections in the selected corridor segment. As mentioned earlier, right-turning vehicles' volume, cyclists' volume, and pedestrians' volume were recorded three hours (3 pm → 6 pm). In the first four intersections

(Metcalfe → Kent), these volumes were recorded in three equal hourly intervals. The volumes of the last intersection (Lyon) were recorded in four unequal intervals. Therefore, the traffic volumes interacting at the considered bound in each model were coded per interval. The bound considered in each intersection was the same as the one at which the real conflicts were identified.

In addition, all vehicles were assumed to turn right to the most right lane. This indicates that vehicles could be in conflict with through cyclists only when using that lane. However, drivers in reality may turn right to any available receiving lane. As a result, they may conflict with through cyclists in reality while using any of the receiving lanes. This assumption was made because the splits of right-turning vehicles on the available receiving lanes were not available.

Since cyclists can occasionally overtake each other, two cyclists may be observed next to each other while crossing the intersection as shown in Figure 3.15. This can happen when a cyclist is approaching an intersection at a higher speed than a cyclist who has just started to accelerate after the signal turned green. After that, the faster cyclist moves back laterally in front of the slower one as they are leaving the intersection. To account for such events, overtaking was permitted on the segregated bike lanes in each model. These events were observed on a few occasions during simulation. An example of such an event occurring during simulation is presented in Figure 3.16. It should be noted that the majority of cyclists were observed on the right side of the segregated bike lanes. The left side was only occupied when a cyclists overtook a queue of slower cyclists.

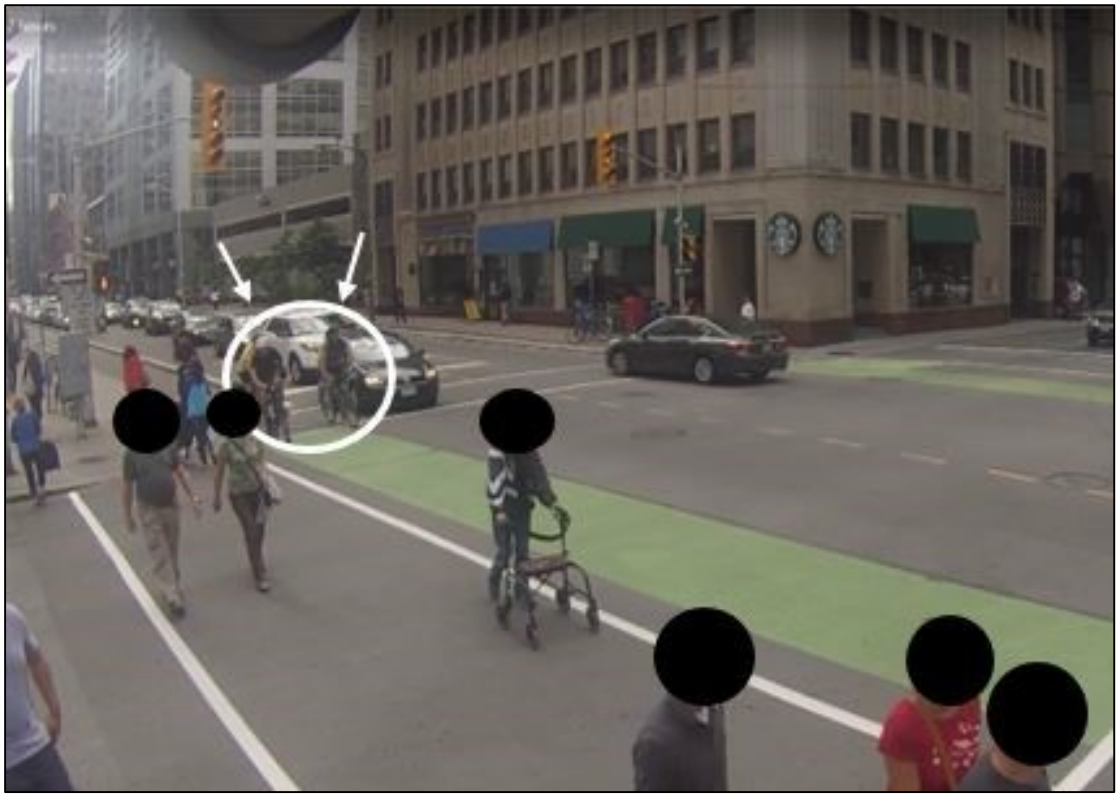
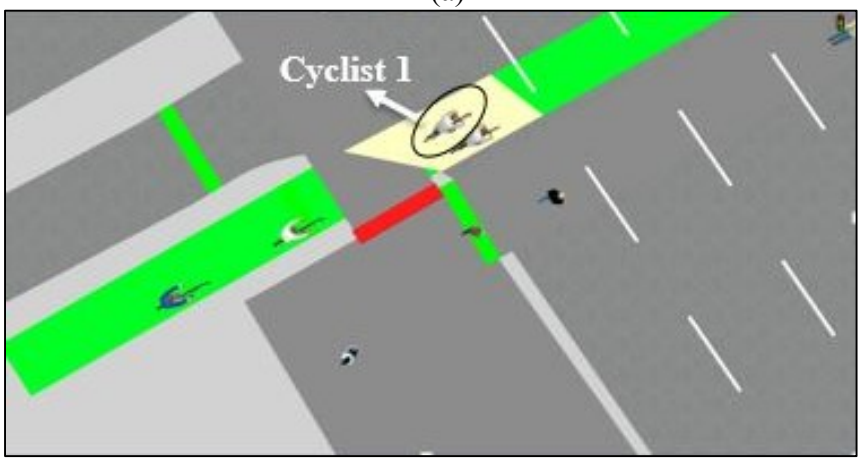
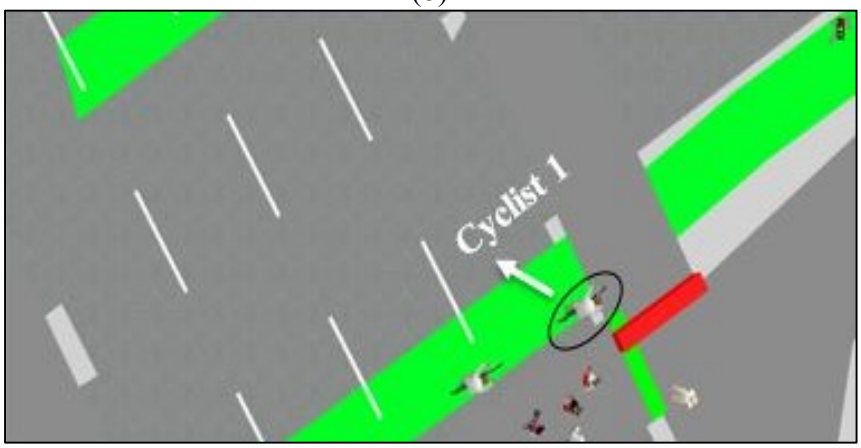


Figure 3.15: Overtaking Event Observed Between Cyclists in the Field

(a)



(b)



a) Cyclist 1 overtaking the cyclists' queue as they are approaching the intersection

b) Cyclist 1 joining the cyclists' queue as they are leaving the intersection

Figure 3.16: Overtaking Event Observed Between Cyclists during Simulation

Finally, each model was simulated twice, once based on the default parameters and once based on the calibrated parameters. Furthermore, 100 runs were used to simulate each of the two conditions in each model. These runs produced trajectories files that were later used to identify simulated conflicts. Additionally, these files contained the trajectories of cyclists and vehicles at each time step. A sample of the information available in a trajectories file is shown in Figure 3.17.

Timestep	Vehicle ID	Link ID	Lane ID	Front X	Front Y	Rear X	Rear Y	Length	Width	Speed	Acceleration
75.4	4	2	1	-304.28326	-176.7018	-307.89645	-178.86449	4.211	2.003672	8.587387	2.226487
75.4	3	61	1	-175.20888	-106.54764	-176.72997	-107.461975	1.77475	0.627504	0	0
75.4	2	61	1	-174.70053	-107.28575	-176.22128	-108.20065	1.77475	0.627504	0	0
75.6											
75.6	4	2	1	-302.76794	-175.79482	-306.38116	-177.9575	4.211	2.003672	9.072684	2.4264867
75.6	3	61	1	-175.20888	-106.54764	-176.72997	-107.461975	1.77475	0.627504	0	0
75.6	2	61	1	-174.70053	-107.28575	-176.22128	-108.20065	1.77475	0.627504	0	0
75.8											
75.8	4	2	1	-301.16934	-174.83798	-304.78256	-177.00067	4.211	2.003672	9.557972	2.42644
75.8	3	61	1	-175.20888	-106.54764	-176.72997	-107.461975	1.77475	0.627504	0	0
75.8	2	61	1	-174.70053	-107.28575	-176.22128	-108.20065	1.77475	0.627504	0	0
76											
76	4	2	1	-299.48996	-173.83276	-303.10318	-175.99545	4.211	2.003672	10.014521	2.2827435
76	3	61	1	-175.20888	-106.54764	-176.72997	-107.461975	1.77475	0.627504	0	0
76	2	61	1	-174.70053	-107.28575	-176.22128	-108.20065	1.77475	0.627504	0	0
76.2											
76.2	4	2	1	-297.73563	-172.78271	-301.34885	-174.94542	4.211	2.003672	10.431069	2.0827434
76.2	3	61	1	-175.20888	-106.54764	-176.72997	-107.461975	1.77475	0.627504	0	0
76.2	2	61	1	-174.70053	-107.28575	-176.22128	-108.20065	1.77475	0.627504	0	0
76.4											
76.4	4	2	1	-295.91446	-171.69266	-299.52768	-173.85535	4.211	2.003672	10.793771	1.8135045

Figure 3.17: Sample of Information Available in a Trajectories File

3.3.2 Surrogate Safety Assessment Model (SSAM)

The Surrogate Safety Assessment Model (SSAM) is a software package developed by Siemens and sponsored by the Federal Highway Administration (FHWA). SSAM performs statistical tests on trajectories files obtained from microsimulation models. To illustrate, SSAM uses these trajectories files to identify conflicts and then calculates these conflicts' surrogate safety measures. In fact, SSAM uses two surrogate safety measures which are Time to Collision (TTC) and Post Encroachment Time (PET) to identify conflicts. SSAM uses the thresholds set by the user for these two measures to determine the number of conflicts. However, SSAM firstly compares the events' TTC values it computed against the predefined TTC threshold. Only events with lower TTC values than the predefined threshold get their PET values computed and compared against the predefined PET threshold. Therefore, events with PET values lower than the PET threshold but TTC values higher than the TTC threshold will not be identified (Pu & Joshi, 2008). As

mentioned earlier, real conflicts obtained for this research were identified using PET only. Using SSAM in this research to identify conflicts might have left events with PET lower than 3 seconds unidentified because of that limitation. Thus, SSAM was not used to identify conflicts in this research. Nonetheless, SSAM was used to convert the binary trajectories files of all the conducted runs to text files. Converting the files was necessary to analyze them and identify the simulated conflicts.

3.3.3 Areas of Potential Collisions

The bound considered in each modelled intersection contained an area of potential collisions. In each considered bound, the area of potential collisions was defined as the area in which the paths of any through cyclist and right-turning vehicle will intersect. Two polygons were used to represent the area of potential collisions in each model. The coordinates of the two polygons were chosen so that each of them covers one of the two paths cyclists can take in the segregated bike lane. The width of each polygon was defined as the width of the segregated bike lane minus the defined cyclist width in VISSIM. This allowed capturing the interaction between a vehicle and a cyclist based on what path of the lane the cyclist was taking. Furthermore, the coordinates were chosen so that each polygon contains the entire width of any passenger vehicle as it is making the right turn. More specifically, the length of each polygon was equal to the width of a passenger vehicle.

3.3.4 Simulated Conflicts Algorithm

An algorithm implemented in Python was developed to identify conflicts between right-turning vehicles and through cyclists. This algorithm used the trajectories files output from VISSIM to identify this type of conflicts. The steps used in this algorithm to identify conflicts in each trajectories file are shown in Figure 3.18 and explained as following:

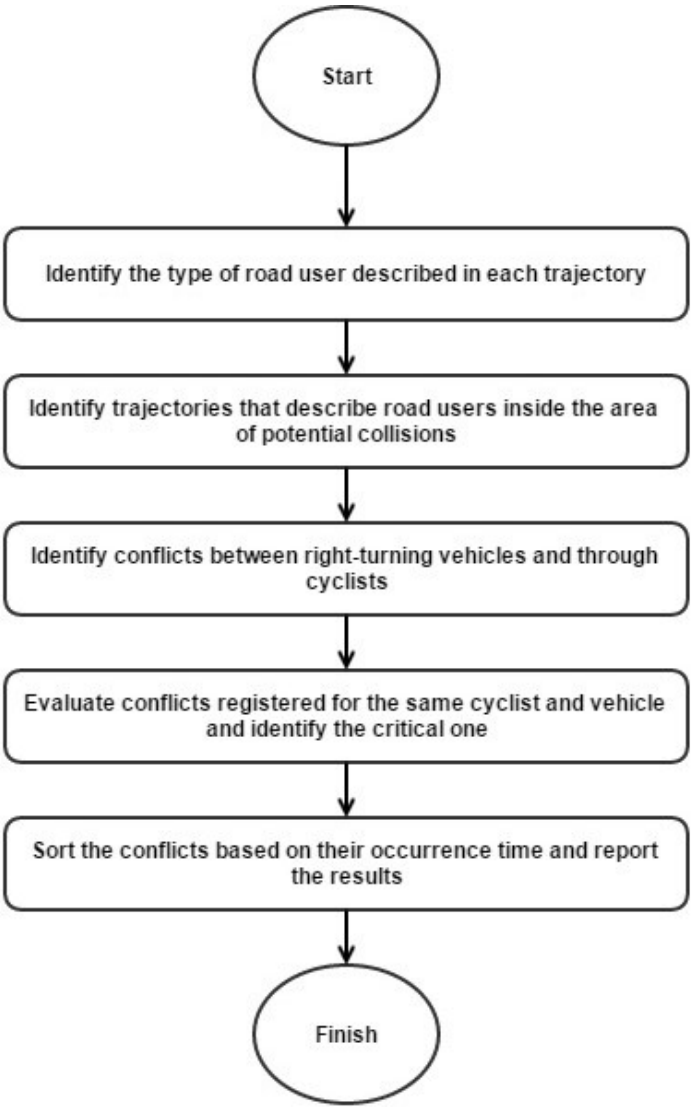


Figure 3.18: Steps of the Algorithm developed to Identify Simulated Conflicts

1) Identify the type of road user described in each trajectory:

In each trajectories file, trajectories of different road users (*i.e.,* vehicles, cyclists) are listed at each time step. However, the type of road user to which each trajectory belongs is not among the information available in the trajectories files. Since this piece of information is crucial to calculate PET and identify conflicts, it had to be obtained. To do that, the width recorded in each trajectory was used. To illustrate, all road users with a width of less or equal to 0.8 were identified by the algorithm as cyclists. On the other hand, road users with a width of greater than 1.7 were identified as vehicles. These two values were used after reviewing the predefined widths of vehicles and cyclists in PTV VISSIM.

2) Identify trajectories that describe road users inside the area of potential collisions:

In this step, all trajectories that describe road users' movements inside the area of potential collisions were identified and registered in two new lists. Two lists were used to represent the two polygons that describe the area of potential collisions. A road user trajectory was identified whenever its front or rear point was within any of the two polygons. Then, that trajectory was registered in the list of the polygon that contained its front or rear point. For example, the list of Polygon 2 contained trajectories of cyclists on the right side of their lane and inside the area of potential collisions. On the other hand, cyclists biking on the left side of their lane and inside the area of potential collisions were registered in the list of Polygon 1. Similarly, vehicles' trajectories identified inside Polygon 1 and Polygon 2 were registered in their two respective lists.

3) Identify conflicts between right-turning vehicles and through cyclists:

For each polygon list, the algorithm checked each vehicle trajectory against the trajectories of all cyclists. This was done to identify events where a pair of vehicle and cyclist trajectories passed each other within 3 seconds. The algorithm calculated the PET for each pair of vehicle and cyclist trajectories to identify these events. For each pair of trajectories, the PET was calculated by finding the absolute difference of the time steps at which the two trajectories occurred. Since trajectories were recorded each 0.25 seconds, the simulated PET values were calculated to a precision of 0.5 seconds. Finally, each event with a PET equal or less than 3 seconds was identified as a conflict and registered in a new conflicts list in the following format:

[PET value, vehicle ID1, vehicle ID2, vehicle1 type, vehicle2 type, conflict time]

4) Evaluate conflicts registered for the same cyclist and vehicle and identify the critical one:

Since trajectories were recorded at each time step, the movements of a road user inside the area of potential collisions were described by multiple trajectories. This means it is likely that multiple trajectories in each polygon list belonged to the same road user. Therefore, different pairs of trajectories for the same cyclist and vehicle might have a PET less than or equal to 3 seconds. In other words, the algorithm might register multiple conflicts for the same vehicle and cyclist. For instance, multiple conflicts in each conflicts list might have the same *vehicle ID1* and *vehicle ID2* but different *PET value* and *conflict time.* In this step, the critical conflict among the multiple ones registered for the same vehicle and cyclist in each conflicts list was identified. The critical conflict was the one with the least PET value. If one conflict only was registered for a cyclist and vehicle, it was considered the critical conflict. From this point onwards, the critical conflicts will be referred to as simulated conflicts.

5) Sort the conflicts based on their occurrence time and report the results:

Since the real conflicts were reported in 3 or 4 time intervals, the simulated conflicts of each model had to be reported in accordance with that. Thus, the simulated conflicts obtained from each trajectories file were sorted by the time interval. Then, the number of simulated conflicts of each trajectories file was reported per time interval. For example, the simulated conflicts obtained from the first four models' trajectories files (Metcalfe → Kent) were reported in 3 equal intervals. The ones obtained from Lyon model's trajectories files were reported in 4 unequal intervals. As mentioned earlier, each model produced 100 trajectories files based on default parameters and another 100 based on calibrated parameters. Each trajectories file was analyzed to identify simulated conflicts that occurred in that run. Finally, the average number of simulated conflicts per time interval was calculated for each 100.

Finally, the number of simulated conflicts from a random run was manually identified to verify that the numbers reported by the algorithm reflect all conflicts simulated in that run. The three hours simulation period was observed time-step by time-step to track when a vehicle or a cyclist entered either one of the polygons discussed earlier. When a vehicle or a cyclist was visually observed entering or leaving any of the two polygons, the trajectories of that road user at that time-step were pulled from the trajectories file. These trajectories were used to verify that the front point or the rear point was actually inside the occupied polygon. If a road user was observed entering a polygon 3 seconds or less (15 time-steps or less) after a different type of road user was observed leaving the same polygon, a conflict was recorded. The number of manually- identified simulated conflicts was sorted per hour for comparison with the hourly numbers reported by the algorithm. The number of simulated conflicts identified in each polygon by the observer matched the one reported by the algorithm in each of the three hours.

3.4 Summary

This chapter highlighted the research methods followed to obtain the results needed to achieve the objective of this research. The work was organized in three main phases. The first phase was collecting the data needed in this research. The data collected in the first phase was used to complete the second and third phase in this research. The second phase dealt with building a model of the selected site selected in VISSIM and calibrating it for travel time. Finally, the third phase focused on identifying the conflicts simulated by VISSIM. The output data obtained from the third phase was used to address the question that motivated this research.

CHAPTER 4: RESULTS AND DISCUSSION

This chapter highlights the results obtained from the implemented methodology that was explained in the previous chapter. The results presented in this chapter are categorized into two sections. The first section discusses the simulated conflicts results obtained from the conflicts detection algorithm. As for the second section, it explains the statistical tests conducted on these results and reports the findings of this research.

4.1 Simulated Conflicts Results

An algorithm was developed using Python language to identify conflicts between right-turning vehicles and through cyclists. For each modelled intersection, this algorithm used its trajectories files output to identify conflicts of such type that occurred during simulation. As mentioned earlier, each model produced 100 trajectories files based on default parameters and another 100 based on calibrated parameters. Each trajectories file was analyzed to identify simulated conflicts that occurred in that run. Then, the number of simulated conflicts of each trajectories file was reported per time interval. Finally, the average number of simulated conflicts per time interval was calculated for each 100 runs. Table 4.1 shows the average number of simulated conflicts in each intersection per time interval for both default and calibrated parameters. These results were used to achieve the objectives of this research.

Table 4.1: Average Number of Simulated Conflicts per Time Interval

Intersection	Time		# Real Conflicts	Average Number of Simulated Conflicts	
	From	To		Default Parameters	Calibrated Parameters
Metcalfe St	3:00 pm	4:00 pm	6	8	8
Metcalfe St	4:00 pm	5:00 pm	12	16	15
Metcalfe St	5:00 pm	6:00 pm	11	18	16
O'Connor St	3:00 pm	4:00 pm	9	27	22
O'Connor St	4:00 pm	5:00 pm	14	37	26
O'Connor St	5:00 pm	6:00 pm	13	45	34
Bank St	3:00 pm	4:00 pm	13	6	6
Bank St	4:00 pm	5:00 pm	23	15	14
Bank St	5:00 pm	6:00 pm	20	18	18
Kent St	3:00 pm	4:00 pm	25	14	13
Kent St	4:00 pm	5:00 pm	23	23	22
Kent St	5:00 pm	6:00 pm	33	25	24
Lyon St	3:00 pm	3:45 pm	0	0	0
Lyon St	3:45 pm	4:30 pm	1	1	1
Lyon St	4:30 pm	5:20 pm	0	0	0
Lyon St	5:20 pm	6:00 pm	0	0	0

4.2 Statistical Tests

Several statistical tests were performed on the results of the implemented methodology using SPSS statistical package (SPSS, 2013). Pearson correlation coefficient (r) was used to evaluate the strength of the relationship between real conflicts and simulated conflicts. Indeed, two coefficients were obtained for the relationship between real conflicts and simulated conflicts of the default models and calibrated ones, respectively. The value of r that describes the relationship between real conflicts and default models' simulated conflicts was found to be 0.525. This value indicates a moderate correlation between real conflicts and simulated conflicts of the default models. A stronger correlation was found between real conflicts and calibrated models' simulated conflicts with a value of r equal to 0.618. This suggests that travel time calibration improved VISSIM's conflicts' prediction accuracy. One of the objectives of this research was to investigate the significance of travel time calibration on VISSIM's accuracy in predicting the traffic conflicts

of interest. A One-way ANOVA test at 95% confidence interval was conducted with the following null and alternative hypotheses:

$$H_0 = \mu_{Default\ Simulated\ Conflicts} = \mu_{Calibrated\ Simulated\ Conflicts}$$

$$H_1 = \mu_{Default\ Simulated\ Conflicts} \neq \mu_{Calibrated\ Simulated\ Conflicts}$$

The p-value obtained from the one-way ANOVA test was found to be 0.575 ($p > 0.05$); therefore, the null hypothesis was accepted. As mentioned earlier, a moderate correlation was found between real conflicts and simulated conflicts of the default models ($r = 0.525$). A stronger correlation was found between real conflicts and calibrated models' simulated conflicts ($r = 0.618$). These results suggest that travel time calibration improved VISSIM's conflicts' prediction accuracy. However, the one-way ANOVA test results indicate that this improvement was not significant. In other words, travel time calibration did not significantly affect VISSIM's accuracy in predicting the traffic conflicts of interest.

Two scatter plots were constructed for the default models' conflicts and calibrated models' conflicts against the real conflicts. These scatter plots are shown in Figure 4.1 and Figure 4.2, respectively.

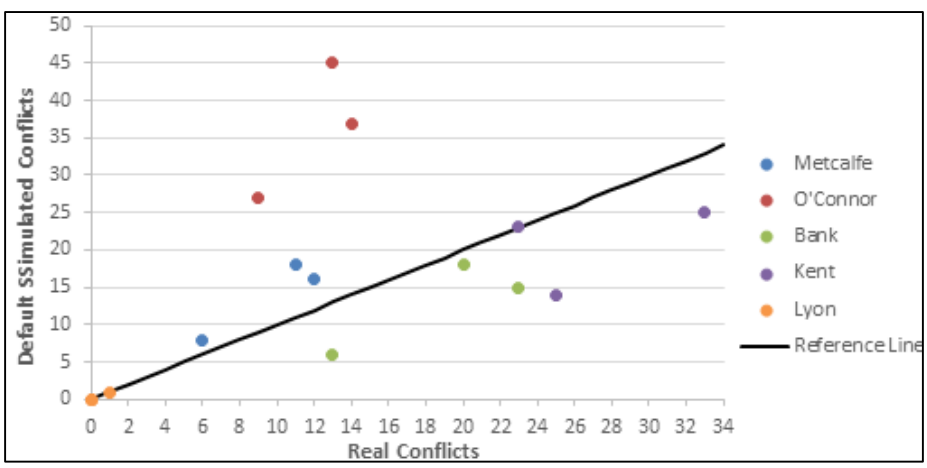


Figure 4.1: Scatter Plot of Default Models' Simulated Conflicts against Real Conflicts

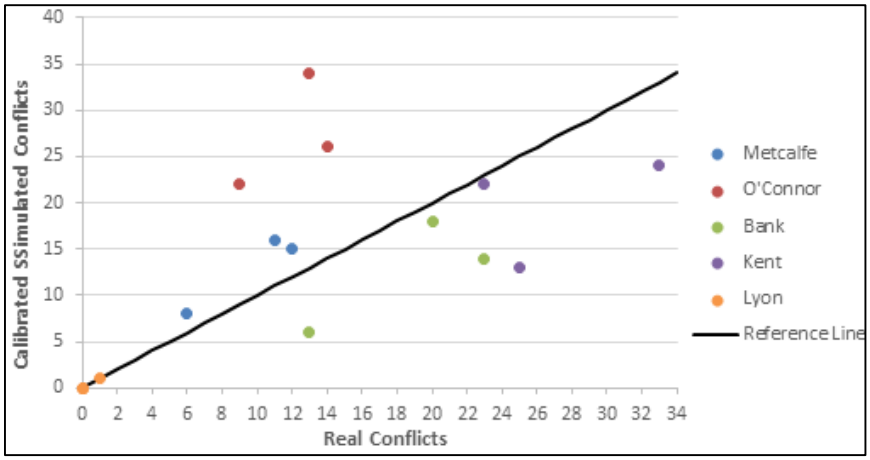


Figure 4.2: Scatter Plot of Calibrated Models' Simulated Conflicts against Real Conflicts

It can be seen that all the points of O'Connor St are very deviant from the reference line in both figures. The real-time volumes in Table 3.2 were visually inspected to explore any obvious patterns with the simulated conflicts. It was found that the intersection at O'Connor St witnessed the highest volume of cyclists among the other five intersections in each considered time interval. This motivated the author to explore if a monotonic relationship exists between the accuracy of the simulated conflicts and the real-time volumes. Absolute difference between simulated and real conflicts was used to describe how accurate the simulated conflicts are. A list of absolute difference values for each time interval is shown in

Table 4.2. In particular, real-time cyclists' volume, right-turning vehicles' volume and the product of both volumes were tested against the absolute difference. Moreover, Spearman's correlation coefficient (r_s) was used to examine the correlation between all possible pairs of variables. The Spearman's correlation coefficient is a non-parametric indicator of statistical dependence between two variables. This coefficient describes how well the relationship between two variables can be described using a monotonic function. Table 4.3 presents the correlation coefficients of all possible pairs. The closer the value of this coefficient is to 1 the better the

relationship between two variables is described by a monotonic function. A Spearman coefficient of 0 indicates that no correlation exists between the tests variables.

Table 4.2: Absolute Difference between Real and Simulated Conflicts

Intersection	Time		# Real Conflicts	Absolute Difference ($\lvert Real - Simulated \rvert$)	
	From	To		Default Parameters	Calibrated Parameters
Metcalfe St	3:00 pm	4:00 pm	6	2	2
Metcalfe St	4:00 pm	5:00 pm	12	4	3
Metcalfe St	5:00 pm	6:00 pm	11	7	5
O'Connor St	3:00 pm	4:00 pm	9	18	13
O'Connor St	4:00 pm	5:00 pm	14	23	12
O'Connor St	5:00 pm	6:00 pm	13	32	21
Bank St	3:00 pm	4:00 pm	13	7	7
Bank St	4:00 pm	5:00 pm	23	8	9
Bank St	5:00 pm	6:00 pm	20	2	2
Kent St	3:00 pm	4:00 pm	25	11	12
Kent St	4:00 pm	5:00 pm	23	0	1
Kent St	5:00 pm	6:00 pm	33	8	9
Lyon St	3:00 pm	3:45 pm	0	0	0
Lyon St	3:45 pm	4:30 pm	1	0	0
Lyon St	4:30 pm	5:20 pm	0	0	0
Lyon St	5:20 pm	6:00 pm	0	0	0

Table 4.3: Results of the Spearman's Correlation Coefficients (r_s)

Variables	Absolute Difference (Default)	Absolute Difference (Calibrated)
Cyclists' Volume	0.753	0.720
Right-Turning Vehicles	0.363	0.459
Cyclists X Vehicles	0.643	0.656

The results in Table 4.3 revealed that there were strong positive correlations between the cyclists' volume and both categories of the absolute difference. These results suggest that an increase in the cyclists' volume is strongly associated with an increase in the absolute difference between real and simulated conflicts. Similarly, strong positive correlations were found between the product of cyclists' and right-turning vehicles' volumes and both categories of the absolute difference. Again, these results suggest that an increase in the product of cyclists' and right-turning vehicles' volumes is strongly associated with an increase in the absolute difference between real and simulated conflicts. Ultimately, all the presented results indicate that VISSIM has the potential to predict

traffic conflicts between right-turning vehicles and through cyclists. However, VISSIM's prediction accuracy is expected to decrease as either the cyclists' volume or the product of cyclists' volume and right-turning vehicles' volume increase. This major finding should motivate future work on high-volume urban streets.

4.3 Summary

This chapter highlighted the results obtained from the methodology implemented in this research. In particular, the first section in this chapter presented the simulated conflicts results obtained from the simulated conflicts algorithm. The second section highlighted the statistical tests that were conducted to evaluate the correlations between real and simulated conflicts, and to examine the significance of the travel time calibration on conflicts prediction accuracy.

A moderate correlation was found between real conflicts and simulated conflicts of the default models ($r = 0.525$). A stronger correlation was found between real conflicts and calibrated models' simulated conflicts ($r = 0.618$). These results suggest that travel time calibration improved VISSIM's conflicts' prediction accuracy. However, a one-way ANOVA test revealed that travel time calibration did not significantly affect VISSIM's accuracy in predicting the traffic conflicts of interest. Furthermore, the cyclists' volume and the product of the cyclists' volume and right-turning vehicles' volume were both found to have a strong positive correlation with the absolute difference between real and simulated conflicts. This indicates that VISSIM has the potential to predict traffic conflicts between right-turning vehicles and through cyclists. However, VISSIM's prediction accuracy is expected to decrease as either the cyclists' volume or the product of cyclists' volume and right-turning vehicles' volume increase.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Traffic collisions have been a major concern to road safety practitioners and government bodies due to their big social and economic cost. However, the random and infrequent nature of many traffic collisions and the incomplete reported traffic collisions information can affect the accuracy of road safety evaluations. Therefore, traffic conflicts have been proposed as an alternative to traffic collisions that can be used in road safety studies. Furthermore, researchers have been questioning if road safety evaluations can be conducted using microscopic traffic simulation tools. Besides that, researchers have been evaluating how accurate traffic microsimulation tools can predict traffic conflicts. However, all studies recorded in the literature attempted to answer this question based on conflicts between vehicles. This thesis examined if microscopic traffic simulation tools have the potential to predict conflicts between right-turning vehicles and through cyclists at signalized intersections. Evaluating the potential of microsimulation tools to predict traffic conflicts between vehicles and cyclists is a novel contribution in this thesis. Moreover, this thesis evaluated if calibrating these models to describe the driving behavioural characteristics at signalized intersections significantly improves the conflicts' prediction.

The methodology implemented in this thesis consisted of three main phases. The first phase was collecting the data needed in this research. The data collected in the first phase was used to complete the second and third phase in this research. The second phase dealt with building a model of the site selected for this research in VISSIM and calibrating it for travel time. Finally, the third phase focused on producing output data that describes the conflicts simulated by VISSIM.

Statistical tests were conducted on the output data obtained from the third phase. The results of the statistical tests were used to address the objective of this research.

5.1 Research Findings

This research was conducted to investigate the potential of traffic microsimulation tools (*e.g.,* VISSIM) to predict conflicts between right-turning vehicles and through cyclists at signalized intersections. Several important findings were drawn from the results of this research. To start with, a moderate correlation was found between real conflicts and simulated conflicts of the default models (r = 0.525). A stronger correlation was found between real conflicts and calibrated models' simulated conflicts (r = 0.618). These results suggest that travel time calibration improved VISSIM's conflicts' prediction accuracy. However, a one-way ANOVA test revealed that the improvement caused by travel time calibration was not significant. Furthermore, the cyclists' volume and the product of the cyclists' volume and right-turning vehicles' volume were both found to have a strong positive correlation with the absolute difference between real and simulated conflicts. This indicates that VISSIM has the potential to predict traffic conflicts between right-turning vehicles and through cyclists. However, VISSIM's prediction accuracy is expected to decrease as either the cyclists' volume or the product of cyclists' volume and right-turning vehicles' volume increase.

The findings of this research can be summarized as following:

- VISSIM has the potential to predict conflicts between right-turning vehicles and through cyclists at signalized intersections.
- Travel time calibration does not significantly affect VISSIM's accuracy in predicting conflicts between right-turning vehicles and through cyclists at signalized intersections.
- VISSIM's conflicts prediction accuracy is expected to decrease as either the cyclists' volume or the product of cyclists' volume and right-turning vehicles' volume increase.

5.2 Recommendations and Future Work

Foremost, the travel time calibration results were not validated due to the unavailability of a different unused dataset to be used. The author acknowledges that this is a limitation in this research. Any future work should take into account modifying the calibration procedure to include a step in which the calibration results get validated using a new dataset. It is important to point out that the transferability of this research's findings to other types of roads was not addressed in this research. Thus, any future work should consider studying different types of roads and check if this research's findings still hold. Additionally, the findings of this research are limited to conflicts simulated in PTV VISSIM 6. The author recommends exploring if these findings still hold when other traffic microsimulation tools are used. Moreover, the findings of this research are limited to conflicts identified using Post-Encroachment Time (PET). Future work should focus on testing if stronger correlations can be found when other surrogate safety indicators are used. Furthermore, the simulated PET values were calculated to a precision of 0.5 seconds. Since parameters selected for travel time calibration were not found to significantly affect the accuracy of traffic conflicts' prediction, the author recommends using a higher simulation resolution value (*i.e.* 10 or more) to improve the precision of simulated PET values. The author also recommends inputting the

volumes of all traffic movements at an intersection when analyzing simulated conflicts as they may affect the simulated conflicts results because of their possible effect on the driver's behaviour. Finally, the author highly recommends that future studies investigate what parameters in traffic microsimulation tools are sensitive to traffic conflicts involving cyclists. Besides that, these future studies should examine if calibrating such parameters using real conflicts datasets can improve the accuracy of conflicts prediction.

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