A SIMULATION MODEL OF ROAD USER BEHAVIOUR
AND TRAFFIC CONFLICTS AT UNSIGNALIZED INTERSECTIONS

by

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ABSTRACT

This thesis describes a visual microscopic traffic conflicts simulation model for both T and 4-leg unsignalized intersections. The objective of the model is to study traffic conflicts as critical traffic situations and understand the driver's behaviour at these situations. The Author rejected the use of pure gap acceptance criteria to describe driver's behaviour at unsignalized intersections. As an alternative, a combination of some aspects of the gap acceptance criteria and the effect of several parameters including driver's characteristics such as age and sex and the waiting time are used to describe that behaviour. The model also investigates the effect of different traffic parameters such as volume and speed on the number and severity of traffic conflicts. The model is unique in so far as it stores the traffic conflicts that occur during the simulation for latter study. A graphical animation display is used to show how the conflict occurred and the value of critical variables at this time. The model results were hypothetically validated against previous work in the literature and externally validated using field observations from two unsignalized intersections. In both cases the validation process proved successful.
# TABLE OF CONTENTS

ABSTRACT ........................................................................................................ ii

TABLE OF CONTENTS .................................................................................. iii

LIST OF FIGURES ............................................................................................ vii

LIST OF TABLES ............................................................................................... ix

ACKNOWLEDGMENT ....................................................................................... x

1. INTRODUCTION .............................................................................................. 1
   1.1 The Problem ................................................................................................ 1
   1.2 Simulation of traffic conflicts at unsignalized intersections ..................... 2
   1.3 Visual Simulation Models .......................................................................... 3

2. LITERATURE REVIEW .................................................................................. 6
   2.1 Traffic conflict techniques and road user behaviour. .............................. 6
       2.1.2 Measures of traffic conflicts ............................................................. 7
       2.1.3 The validity of traffic conflict techniques ....................................... 9
3.2.5.3 Conflict resolution ........................................... 45
3.2.6 Model output .................................................. 46
3.2.7 Some aspects of programming in GPSS/H ................... 46
3.3 Model Visualization .............................................. 47
3.3.1 Generation of the animation files ............................ 48

4- MODEL VALIDATION .................................................. 52
4.1 Face validity ...................................................... 52
4.2 External validity .................................................. 53
  4.2.1 Site selection ................................................ 53
  4.2.2 Intersection geometry and traffic control ............... 57
  4.2.3 Traffic conflicts observation ............................. 62
  4.2.4 Observation methodology ................................. 62
  4.2.5 Comparing results ......................................... 64

5- FINDINGS .............................................................. 68
5.1 Relation between conflicts and traffic parameters .......... 68
  5.1.1 Volume - Conflicts relation ............................... 68
  5.1.2 Speed - Conflicts ........................................ 73
  5.1.3 Speed - severity of conflicts. ........................... 77
5.2 Conflicts and driver type ....................................... 80
LIST OF FIGURES

Figure 2.1 Flowchart of the procedural elements of simulation models ........................ 18
Figure 2.2 Step gap acceptance function ...................................................................... 26
Figure 2.3 Shifted exponential gap acceptance function .................................................. 27
Figure 3.1 Delay modification function .......................................................................... 43
Figure 3.2 Gap acceptance function ............................................................................. 44
Figure 3.3 A sample screen of the animation for a T-intersection ................................. 50
Figure 3.4 A sample screen of the animation for a 4leg-intersection ............................... 51
Figure 4.1 Site location of 156th Street and 20th Avenue intersection ................................ 55
Figure 4.2 Site location of Holdom Avenue and Broadway intersection .......................... 56
Figure 4.3 156th Street and 20th Avenue intersection geometry ...................................... 58
Figure 4.4 Holdom Avenue and Broadway intersection geometry ................................. 59
Figure 4.5 Peak hour vehicle traffic volumes 156th Street and 20th Avenue intersection .... 60
Figure 4.6 Peak hour vehicle traffic volumes Holdom Avenue and Broadway intersection .... 61
Figure 5.1 Relation between crossing conflicts and traffic volume for a T-intersection ......... 70
Figure 5.2 Relation between crossing conflicts and traffic volume for a T-intersection ......... 71
Figure 5.3 Relation between crossing conflicts and traffic volume for a 4-leg intersection ................................................................. 72

Figure 5.4 Relation between conflicts and approaching speed at Stop-controlled T-intersection .............................................................. 74

Figure 5.5 Relation between conflicts and approaching speed at Yield-controlled T-intersection ............................................................ 75

Figure 5.6 Relation between conflicts and approaching speed at Stop-controlled 4leg-intersection ............................................................. 76

Figure 5.7 Effect of approach speed on conflicts severity for a Stop-controlled T-intersection ................................................................. 78

Figure 5.8 Effect of approach speed on conflicts severity for a Yield-controlled T-intersection ................................................................. 79
LIST OF TABLES

Table 2.1 Mean and standard deviation of crossing times for different drivers . . . 30
Table 3.1 Mean and Standard deviation of the gap acceptance function ........... 39
Table 4.1 Conflict observation schedule ................................................. 63
Table 4.2 Time to collision and risk to collision scores ............................... 63
Table 4.3 Observed and predicted conflicts distribution 156th Street and 20th
Avenue intersection ........................................................................... 65
Table 4.3 Observed and predicted conflicts distribution Holdom Avenue and
Broadway intersection ........................................................................ 66
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1. INTRODUCTION

1.1 The Problem

Traffic engineering problems are becoming more computationally intensive due to both the greater complexity of the problems and an improved understanding of the mechanism of the problems. This has led engineers to employ any promising advances in either mathematical techniques or computer hardware. Three main areas seem to be emerged. The first is simulation and rule based systems which are gaining importance as computers hardware capabilities increase. The second is studying extreme values (congestion or conflicts and accidents) and failure analysis as engineers gain better understanding of the engineering mechanism and the mathematical techniques required to solve such problems. The third is graphical visualization of events to improve ones understanding of the extreme values and to ease communicating results with others. A more complete discussion is given by Navin (1991).

This thesis studies traffic conflicts (extreme events) at unsignalized intersections. The thesis’ objective is to gain a better understanding of the drivers’ behaviour and the factors affecting the occurrence of conflicts. Simulation is employed to study the problem for two reasons. The first is the uncertainty associated with human behaviour. The second is the great difficulty in considering all different aspects of that behaviour and the system
Chapter 1. Introduction

operation through using conventional methods.

The model is unique in so far as it stores the traffic conflicts that occur during the simulation for latter study. A graphical animation display is then used to show how the conflict occurred and the value of the critical variables at this time.

1.2 Simulation of traffic conflicts at unsignalized intersections

There is a considerable literature on simulation models for unsignalized intersections. However, most of these models only considered the capacity of the intersections and how traffic volume affects the level of service and delay for the intersection. Only a few authors such as Cooper et al. (1976) and McDowell et al. (1983), considered simulating traffic conflicts at unsignalized intersections. This is surprising since it is known that about half of all reported injury accidents take place at or within a few meters of intersections. The models that did consider traffic conflicts at intersections neglected to deal with driver’s behaviour in depth; instead they adopted the gap acceptance criteria to describe how drivers based their decision, and neglected some of the important aspects of driver’s behaviour such as the effect of the stopped delay on the driver’s aggression.

The Author’s model rejected the use of a pure gap acceptance criteria to describe driver’s behaviour. As an alternative, a combination of some aspects of the gap acceptance criteria
and the effect of several other parameters are used to describe that behaviour.

In practise, observing traffic conflicts requires skilled and trained people which is expensive. An alternative to direct observation is to first utilize the results provided by a simulation modelling technique to understand the traffic situation. These models offer a way of estimating traffic conflicts and also provides an in depth study of conflicts as critical traffic events. The results of the simulation may eventually reduce the need for direct observation of all except the most complex intersections.

1.3 Visual Simulation Models

An old saying "A picture is worth a thousand words". A difficult problem associated with traffic simulation models is gaining confidence in the model output. If the model is to be used for decision making, the decision makers need to be confident that the model is sufficiently accurate. Moreover, non-experts often experience difficulties understanding the model results through the printed tabular output and the complicated statistics.

The benefits of simulation models may be maximized if the users fully understand what the model represents and how it behaves. The best way of doing this is by a graphical animation. This graphical animation display is not only important for the model users but it is probably even more important to the programmer. There is no better way to find
programming and logic mistakes than to observe the model behaviour on the screen. This is particularly true for large and complex systems where finding mistakes is very difficult.

Another important feature of visual simulation models is the ability to display the value of different variables which affect the model behaviour while the simulation is running. This provides the user or the decision maker with knowledge of how these variables affect the model behaviour and further changes of the variables could lead to the model best possible performance.

The benefits of visual simulation models were summarized by Bell et al. (1987) and they include:

1. "Situations may arise that... the decision maker may never have envisaged" (Brown 1978). A certain situation can be easily observed through visualization; whereas, the situation can be lost in the aggregate output from the ordinary simulation.

2. The pictures gives the user "The freedom to shift attention" (Rubens 1979) between different parts of the simulation.

3. The picture has a "wide appeal" (Brown 1978). Users enjoy seeing a visual display of the system.

Ellson and Cox (1988) concluded that 'an animation is worth a million graphs'.

Chapter 1. Introduction
Chapter 1. Introduction

These observations were in part the motivation behind developing a visual display of a traffic situation. The second motivation was to integrate more human factors into the actual interaction simulation.
2. LITERATURE REVIEW

2.1 Traffic conflict techniques and road user behaviour.

2.1.1 History and Definition.

The idea of near misses by vehicles or traffic conflict techniques has had a long history in traffic safety research. Near accidents studies have been undertaken in the 1950s by Mcfarland and Moseley (1954) and Forbars (1957). The actual establishment of the Traffic Conflict Techniques (TCT) was proposed by the General Motors team of Perkins and Harris (1967). Their objective was to define a technique to study events which occur frequently, can be clearly observed, and are related to accidents rather than depending on accident data which, in many cases, is scarce, unavailable or unsatisfactory. They defined the term traffic conflict as any potential accident situation, leading to the occurrence of evasive actions such as braking and swerving.

This definition has always been questionable and there has been a continuous debate about it since the definition only associates conflicts with evasive actions. Researchers noted that many accidents were not accompanied by an evasive action therefore the conflict definition should consider these kind of situations. This has led to another debate about whether a conflict is an event or a situation. Although the early literature about
traffic conflicts regarded conflicts as a potential accident situation, the definition equates conflicts with evasive actions. Eventually, Older and Spicer (1976) suggested that a traffic conflict be defined as "a situation involving one or more vehicles where there is an imminent danger of collision if vehicles movements remain unchanged". The most internationally accepted definition of traffic conflict is by Amundson and Hyden (1977) "a conflict is 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".

2.1.2 Measures of traffic conflicts.

There is a variety of observation methods developed to evaluate traffic conflicts. In general, these methods can be classified into two categories: subjective methods and objective methods.

1- Subjective methods:
In the subjective methods one can find subjective terms such as "evasive action" or "sudden behaviour" as a part of the definition. These methods include considerable amount of judgement by the observer and were highly criticised by many researchers such as Hauer (1978) and Allen et al. (1977) as the grading of severity of the evasive action used a subjective element, which varies from one observer to another.
2- Objective methods:

These methods adopted more objective measures to evaluate traffic conflicts. Hayward (1972) defined the time to collision (TTC) measure as "the time for two vehicles to collide if they continue at their present speed and on the same path". The value of TTC is infinite if the vehicles are not on a collision course. On the other hand, if the vehicles are on collision course the value of TTC is finite and is decreasing with time. The minimum TTC as reached during the vehicles approach on the collision course is taken as an indicator for the conflict severity. According to this measure, a traffic conflict can be redefined as a situation with a minimum TTC less than a certain threshold value.

Hayward suggested a minimum TTC value of 1.0 second. This was criticised by Van der Horst (1983) who concluded that "the threshold value of 1.0 second is an arbitrary choice and can depend on the type of interaction (car-car or car-cyclist) or on different speed classes". Van der Horst (1984) used a threshold value of 1.5 sec as the minimum TTC value for defining a conflict between a car and a cyclist.

The International Committee on Traffic Conflict Techniques (ICTCT) at a meeting in Malmo, Sweden (1983), had different teams from ten countries made observations at three local intersections. The TTC measure had a good performance as a conflict severity measure.
Another objective measure, the Post-Encroachment-Time (PET), was defined by Allen et al. (1977) as "the time difference between the moment an offending vehicle passes out of the area of potential collision and the moment of arrival at the potential collision point by the conflicting vehicle". In the first ICTCT calibration study, the PET measure had a poor performance. This poor performance of PET according to Oppe (1986) refers only to urban areas with mixed traffic. In a second ICTCT calibration study at a rural signalized intersection at Trautenfels, Austria, the PET measure had a better performance.

2.1.3 The validity of traffic conflict techniques

There has been a continuous debate about the validity of traffic conflict techniques in traffic safety. The main question is whether conflicts can predict accidents and whether counting conflicts can be a substitution for accidents counts. Validation of conflict techniques with regard to the number of accidents will probably always be difficult. Hauer (1975, 1978) stated that conflicts can not predict the exact number of accidents because of the accidents random nature, but they can demonstrate the expected number of accidents through the product of the expected number of conflicts and the conditional probability of an accident given a conflict. Work by Garder (1985) and Glauz and Bauer (1985) showed that conflicts are generally as good as accidents in predicting the expected number of accidents. Hauer and Garder (1986) also stated that "a technique for the estimation of safety is valid if it produces unbiased estimates of the variance, which is
Hyden (1987) introduced the term "process validity" of traffic conflict techniques. Using detailed accidents reconstruction data, he compared the processes that leads to both conflicts and accidents. He concluded that there are similarities between the events and behaviours of these processes.

The validity debate only considers the limited use of traffic conflicts as surrogates for accidents. This narrow view, according to Grayson and Hakkert (1987), has been both an incentive to work at practical level (through attracting more researchers because of the short term goal) and an obstacle to advance at theoretical level (because of the narrow view as accidents surrogates). If more attention is given to the validity issue of traffic conflict techniques regarding to their contribution to the study of unsafe traffic behaviour, the question of whether conflicts can be a substitution for accidents will be less important.

2.1.4 Possible application of traffic conflict techniques.

As mentioned earlier, accident data is often scarce, unsatisfactory, and in many cases unavailable. Traffic conflicts offer a rich source of data and a way of better understanding of how safety measures work. A summary of some of the important application of traffic conflicts are:
- a complement to accident data to help solving some safety problems, or to design new countermeasures.

- a research tool for studying road users' behaviour and as an educational tool to improve driver's performance.

- for before and after studies and short term evaluation studies where accident data is not appropriate.

- to improve countermeasure design and get a better understanding of how these countermeasures work and how they influence road user's behaviour.

It can be concluded that traffic conflicts techniques have a considerable potential in safety research which will not be fully realized until the limited view of conflicts as a substitution for accidents is changed.
2.2 Traffic simulation models

2.2.1 History and definitions

The word computer simulation means different things to different people according to their use and objectives, but it can be generally defined as "a numerical technique for conducting experiments on a digital computer, which includes certain types of mathematical and logical models to describe the behaviour of the system over extended periods of time" Shannon (1975).

Digital Computer simulation modelling has a short history. The first work on digital computers began in the 1930-s and was first used for simulation modelling in the 1940-s. The early simulation models dealt with problems which were expensive and dangerous to be experimentally solved such as ballistic trajectories and nuclear shielding. In 1954 the first commercial digital computer became available and researchers in different areas could build simulation models.

Traffic simulation models were first developed in the mid 1950-s by researchers who found that traffic simulation models can represent stochastic situations which are too complex to be represented by reasonable mathematical models. The earliest computer
simulation work in highway transportation was by Hillier et al. (1951) for intersections. This was followed by other simulation models such as Gerlough (1954) for freeway operations and Webster (1958) for traffic signals phasing. Webester’s traffic signal model is probably one of the most influential models in traffic engineering as it is the foundation for most signalized traffic delay models. The development of traffic simulation models grew rapidly during the 1960-s and 1970-s. During the 1980-s, more attention was given to model improvements. These improvements included conversion to personal computers, adding optimization submodels, additional measures of effectiveness, integration of simulation models, and using computer graphics for the model output.

For the general use of traffic engineers, many macroscopic and microscopic simulation models are currently available for different traffic environments. Some of them include: TRARR and TWOPAZ for rural highways, TEXAS and SIGSIM for signalized intersections, TRANSYT and SSTOP for arterial networks, and FREQ and INTRAS for freeway corridors. Apart from these available simulation models, there is a great opportunity for the traffic engineer to develop specific models necessary to solve a unique set of problems which face in daily practice.

Traffic simulation models can be categorized into two main groups; microscopic and macroscopic. Microscopic models represent each vehicle by a set of variables such as vehicle type, speed, acceleration and position then update these variables at a fixed or
variable time interval. Macroscopic models handle vehicles in groups and represent traffic in terms of overall factors such as traffic volume, density, and speed.

Microscopic models are often more precise than their macroscopic correspondence, largely due to the fact that they make fewer assumptions. However, microscopic models do require more computer resources, but with the current advances in computer hardware, these resources are easily obtainable.

2.2.2 Rational of simulation models

Simulation models can be very powerful analytical procedures for many complex transportation problems. A summary of the main advantages of using simulation modelling in traffic research are:

- Mathematical alternatives are often unavailable or limited in scope as they incorporate simplifying assumptions which compromise the realism of the results.
- Simulation models are effective in describing complex and stochastic processes.
- Using simulation, a system can be studied in real time, compressed time, or expanded time.
- Unsafe experiments can be undertaken without risk to the system users.
Chapter 2. Literature Review

- When new components are introduced into a system, simulation can be used to help foresee bottlenecks and other problems that may arise in the operation of the system.
- Traffic simulation can yield valuable insight by identifying critical variables in the system and illustrating how these variables interact.

The main reservations about using traffic simulation models are:

- Traffic simulation models may require some input characteristics which are difficult to obtain.
- Some users may apply simulation models as "black boxes" without fully understanding what these models represent.
- To apply solutions offered by simulation models, a lot of time and effort should be taken to ensure that these models have been fully calibrated and validated.

However, the majority of the reservation on using traffic simulation models can be eliminated through better understanding of their rule and where they should be applied.

In conclusion, traffic simulation is not a solution for all traffic problems but can be a very useful technique especially in stochastic, time varying, and complex cases where sometimes it might be the only solution to a problem.
2.2.3 Steps in developing Simulation models

A flow chart of the procedural elements in building simulation models is shown in Figure (1.1). The Ten elements identified by Shannon (1975) are briefly explained in the following paragraphs.

1. Problem Formulation  The definition of the problem to be studied including a statement of the problem-solving objective.
2. Model Building  The abstraction of the system into mathematical-logical relationships in accordance with the problem formulation.
3. Data Acquisition  The identification, specification and collection of data.
4. Model Translation  The preparation of the model for computer processing.
5. Verification  The process of establishing that the computer program executes as intended.
6. Validation  The process of establishing that a desired accuracy of correspondence exists between the simulation model and the real system.
7. Strategic and Tactical  The process of establishing the experimental conditions Planning for using the model.
8. Experimentation  The execution of the simulation model to obtain results.
9. Analysis of Results  The process of analyzing the simulation output to draw inferences and make recommendation for problem
10. Implementation and Documentation

The process of implementing decisions resulting from the simulation and documenting the model and its use.

Shannon (1975) presents more details on each of the previous steps.
Figure 2.1 Flowchart of the procedural elements of simulation models.

Source: Shannon (1975).
2.3 Unsignalized intersections.

The unsignalized intersection is the most common type in road networks. Vehicles movements at an unsignalized intersection are controlled either by regulatory signs (Yield or Stop) or by rules of the roads (such as first come first served). Models used to describe traffic operation at these intersections usually have three main parts: the arrival of vehicles, the gap acceptance criteria of the minor road vehicle, and the method of combining these two parts into the model. A review of the terminology is useful before elaborating on the parts of the unsignalized intersection simulation model.

2.3.1 Terminology.

The essential terms needed to understand the operation of an unsignalized intersection are the following:

A gap is the elapsed time between arrival of successive major road vehicles at a specific reference point in the intersection area.

A lag is that portion of a current gap remaining when a minor road vehicle arrives or in other words the elapsed time between arrival of a minor road vehicle and the arrival of the next major road vehicle.

A lag is accepted by the minor road vehicle if this vehicle enters or crosses the major road before the arrival of the first major road vehicle.
A gap is accepted by the minor road vehicle if this vehicle crosses or enters between two major road vehicles compromising a gap.

Stopped delay is the time that a minor road vehicle spends waiting in the queue before being able to cross or join the major road stream.

A considerable amount of research has been undertaken to investigate the statistical difference between the acceptance distributions of gaps and lags such as Wagner et al. (1965) and Polus (1983). However, no definite conclusion for that has been obtained and in the majority of the models dealing with gap acceptance criteria this statistical difference is ignored.

2.3.2 The vehicles arrival.

The arrival process includes choosing the traffic headway distribution which may be either deterministic or probabilistic in nature. The choice of the headway distribution for a certain road mainly depends on the flow condition of that road. Some of the applicable distributions are; negative exponential, shifted negative exponential and Erlang. Gerlough and Harber (1978) has a more complete description of these distributions. The following is a brief discussion of the basic elements of these distributions.

1- Negative exponential distribution.

This distribution, which follows the Poisson process, assumes a random arrival rate of
vehicles. If \( \lambda \) is the arrival rate, the cumulative distribution function of the negative exponential distribution may be written as:

\[
P(h \leq t) = 1 - e^{-\lambda t} = 1 - e^{-\bar{t}t}
\]

with the probability density function

\[
f(t) = \lambda e^{-\lambda t}
\]

with mean and variance equal to

\[
\bar{t} = \frac{1}{\lambda}
\]

\[
\sigma^2 = \frac{1}{\lambda^2}
\]

The negative exponential distribution can only be applied to situations with low traffic flow and where the vehicles speeds are independent. This implies that there is the capability of overtaking.

2- Shifted negative exponential distribution.

As small time headways are very unlikely to occur, a situation possible with the negative exponential distribution. It might be more realistic to introduce some minimum allowable headway to the negative exponential distribution. This can be achieved by shifting the negative exponential distribution by a fixed time interval \( c \). The cumulative distribution function of the shifted exponential distribution may be written as:

\[
P(h \leq t) = 1 - e^{-[(t-c)(\bar{t}-c)]} \quad \text{for } t \geq c
\]
with the probability density function

\[
f(t) = \begin{cases} 
0 & t < c \\
\frac{1}{t-c} e^{-\frac{t-c}{\bar{t}-c}} & t \geq c
\end{cases}
\]

and with mean and variance equal to

\[
\bar{t} = \frac{1}{\lambda} \\
\sigma^2 = (\bar{t}-c)^2
\]

3- Erlang distribution.

In the shifted exponential distribution the probability of headways less than c is equal to zero. The Erlang distribution gives a low probability for small headways but not zero. The cumulative distribution function of the Erlang distribution can be written as:

\[
P(h \leq t) = 1 - e^{-\lambda t} \sum_{n=0}^{k-1} \frac{(\lambda t)^n}{n!}
\]

The probability density function of the Erlang distribution can be written as

\[
f(t) = \lambda \ e^{-\lambda t} \frac{(\lambda t)^{k-1}}{(k-1)!}
\]
Chapter 2. Literature Review

If \( k=1 \) yields the negative exponential distribution.

Both the shifted exponential distribution and the Erlang distribution can be used for representing medium flow conditions, but when there is a significant amount of vehicles interaction then the vehicles should be generated in bunches (almost constant headways).

2.3.3 Gap acceptance criteria.

The gap acceptance criteria is used to describe how minor road drivers decide to join or cross the major road traffic at unsignalized intersections. A number of gap acceptance models have been developed. These models assume that drivers at the minor road decide whether or not to join or cross the major road according to the size of the gaps (lags). The size of the gap (lag) can be expressed in either distance or time measures. Various studies [such as Cooper et al. 1976] have indicated that drivers base their decision on time gaps rather than distance gaps. Three main gap acceptance models were used to describe that gap acceptance behavioral of drivers. These models are: fixed critical gap, consistent behaviour and inconsistent behaviour. The following is a brief discussion of the models.

1- Fixed critical gap:

The fixed critical gap concept assumes that there is a minimum (critical) gap (lag) acceptable to all drivers at all times. Drivers accept gaps (lags) greater than or equal to this critical gap and reject all others.
2- Consistent behaviour:

The consistent behaviour model assumes that there is a minimum gap (lag) acceptable to a driver at all times. All gaps (lags) smaller than this critical gap (lag) will be rejected and all gaps (lags) larger than this critical gap (lag) will be accepted. This critical gap (lag) is considered fixed for a given individual and has a distribution over the population. [Ashworth 1968,1970; Ramsey 1973].

If C is the driver critical gap, the gap acceptance function, α(t) for this kind of behaviour can be expressed as:

\[
\alpha(t) = \begin{cases} 
0 & t \leq C \\
1 & t > C 
\end{cases}
\]

Where \(\alpha(t)\) is the probability of accepting a gap of size t.

The graphical representation of this function is shown in Figure 2.2.

3- Inconsistent behaviour:

The Inconsistent behaviour model assumes that each driver has a variable critical gap (lag). The driver might accept a certain gap (lag) on certain occasions and reject the same gap (lag) size on other occasions. This might lead to the driver accepting a gap (lag) shorter than one he had previously rejected. This variable critical gap (lag) can be described by some distribution (usually normal or log-normal) such that the same distribution can be applied to each driver. [Ashworth 1975,1977]
Chapter 2. Literature Review

An example of a gap acceptance function, $\alpha(t)$ describing this kind of behaviour is:

$$
\alpha(t) = \begin{cases} 
0 & \text{if } t \leq T \\
1 - \exp[-\beta(1-T)] & \text{if } t > T 
\end{cases}
$$

where $\beta$ and $T$ are constants for a given driver and which vary over a population of drivers. According to this function the probability of accepting gaps (lags) less than the threshold value $T$ is zero and this probability is increasing as $t$ increases beyond $T$. The graphical representation of this function is shown in Figure 2.3.

It is apparent that the real drivers behaviour is somewhere between the last two models. The second model considered the variability between individuals, which is a well known aspect of all human behaviour. The third model considered the variability within individuals which may refer to the degree of concentration and the driver mode at the decision time. However, it is known that the variability between drivers is much higher than the variability within a driver. Therefore, the second model seems to be more adoptable. A more complete discussion is given by Ashworth and Bottom (1975,1977).

2.3.4 Factors affecting a driver's critical gap value.

Many factors have been found to affect the driver's critical gap value including the type of traffic control (Yield or Stop), the approaching speed, and the driver characteristics.
Figure 2.2 Step gap acceptance function

(Consistent driver behaviour)
Figure 2.3 Shifted exponential gap acceptance function

(Inconsistent driver behaviour)

Source: Ashworth et al. (1975)
The type of control is important in drivers’ decision. At Stop controlled intersections, drivers usually start from a stop condition, while at Yield controlled intersections some vehicles start from a low speed. It will obviously take the drivers starting from stop condition longer to complete their manoeuvre. This leads to drivers accepting shorter gaps (lags) at Yield controlled intersections than those accepted at Stop controlled intersections.

The approaching speed has an important effect as well. Drivers accept a gap (lag) according to its size and their confidence that this gap (lag) will remain stable during executing their manoeuvre. As the approaching speed increases, the drivers confidence about the stability of the gap (lag) decreases and consequently they become more conservative in their accepting decision. Cooper (1976) indicated that the gap size which would be accepted by a driver is related to the approach speed. He also suggested that there are errors of judgment associated with vehicles travelling with speeds different from the mean speed.

The driver’s characteristics such as age and sex have a significant effect on the gap acceptance behaviour. The data reviewed by Cooper (1976) indicated that younger drivers generally accepted shorter gaps and are more consistent in their driving behaviour than older drivers. Cooper also indicated that female drivers are often more cautious than male drivers in most traffic situations.
Darzentas et al. (1980) analyzed an unpublished data by Traffic Engineering and Control on crossing times of different drivers. The mean and standard deviation of this data are given in Table 2.1.

The values in Table 2.1 indicate that young male drivers have the shortest crossing times. Both young male and female drivers have much smaller standard deviation than old drivers of the same sex. This means that young drivers are often more consistent in their driving behaviour than old drivers. Darzentas et al. (1980) also found that female drivers were involved in fewer conflict situations than male drivers.

Wennel et al. (1981) studied the gap acceptance behaviour of men and women drivers at four unsignalized intersections. They found that the median accepted gap for women drivers are longer than that for male drivers in all situations. They also found that women drivers were less involved in traffic conflict situations than male drivers.
### Table 2.1 Mean and standard deviation of crossing times for different drivers.

(Source Darzentas et al. 1980)

<table>
<thead>
<tr>
<th>Class</th>
<th>Mean (seconds)</th>
<th>Variance (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young males</td>
<td>2.48</td>
<td>0.035</td>
</tr>
<tr>
<td>Old males</td>
<td>3.10</td>
<td>0.254</td>
</tr>
<tr>
<td>Young females</td>
<td>3.42</td>
<td>0.065</td>
</tr>
<tr>
<td>Old females</td>
<td>3.38</td>
<td>0.121</td>
</tr>
</tbody>
</table>
2.3.5 The effect of the stopped delay

The value of the stopped delay significantly modifies the driver's gap acceptance behaviour. Wagner (1965) introduced the term "pressure of traffic demand" which may refer to the pressure that the driver is exposed to after suffering delay. He found that this traffic demand had a very significant effect on drivers' behaviour. Ashworth (1977) divided the gaps presented to drivers into two categories: those gaps which were presented to drivers who had been waiting at the head of the queue for less than 8 seconds; and those presented to drivers who had been waiting at the head of the queue for more than 8 seconds. He found that the proportion of gaps accepted increased with increased waiting time. Another study by Adebisi et al. (1989), concluded that drivers showed significant changes in their gap acceptance behaviour when their stopped delay time exceeded the range of 25-30 seconds, as they began to accept shorter than normal gaps.

This can be explained by the fact that drivers are more relaxed and less sensitive to gaps when they suffer minimal delay, while they are more alert and more sensitive to gaps when they suffer higher delay. The result is that drivers tend to accept shorter gaps as their waiting time increases.
Chapter 3. The Simulation Model

3- THE SIMULATION MODEL.

3.1 Introduction

A traffic conflict simulation model was built for both T and 4-leg unsignalized intersections. A personal computer version of the discrete event simulation language GPSS/H was used. GPSS/H is an enhanced version of the IBM mainframe computer simulation language GPSS (General Purpose Simulation System).

GPSS/H was preferred to procedural languages (such as PASCAL and FORTRAN) in building the model. Most of the simulation models built in procedural languages use the so-called fixed-time-step method (update all the variables in the system after each time unit) rather than the discrete event method (updating the simulation clock to the next event time). Hogeweg (1978) has shown that discrete-event models are clearer and easier to develop than fixed time step models, particularly when using a capable simulation language. For example the automatic maintenance of the built-in floating point simulated clock enables the programmer to deal with very close events which might differ in time by only a small fraction of a second without needing a very small time step.

The basic elements of GPSS/H models are blocks and transactions. Transactions are dynamic entities which move from one block to another. Blocks can be considered as actions or events that affect the transactions and other system entities. In addition to
transactions, there are other classes of entities such as statistical, computational and resource entities. A full description of these elements is found in Schriber (1974).

For example, a transaction can represent a vehicle which arrives to the model through the "GENERATE" block, joins a queue of cars through the "QUEUE" block, and departs the model through the "TERMINATE" block. While transactions are moving through the model, statistical entities (e.g. queues and tables) may be used to collect statistical information, computational entities (e.g. variables and functions) can be used to perform certain computations, and resource entities can be used to represent limited capacity resources.

3.2 Overview of the simulation model

The simulation model developed for this work differs from the other simulation models of unsignalized intersections. Most of these models only considered the capacity of the intersection and how traffic volume affects the level of service and delay for the intersection. The main objective of the current model is to study traffic conflicts as critical traffic situations and understand the driver’s behaviour at these situations. The model also investigates the effect of different traffic parameters on the number and severity of traffic conflicts.

The model is microscopic (vehicle by vehicle simulation model) since it deals with the
individual vehicles as they approach, go through and depart the intersection. Events for vehicles in the model include:

1. Vehicles generation
2. Approaching the intersection
3. Entering the intersection
4. Conflict resolution and departure

Before proceeding to the discussion of each event, the model’s main assumptions and input parameters are introduced.

3.2.1 Assumptions

The basic assumptions of the model are listed below:

- No overtaking or lane changing is allowed at the intersection.
- An isolated intersection (the effect of nearby intersections is not considered).
- All drivers have an unobstructed view of the intersection.
- There is no pedestrian interference.
- All drivers must maintain at least a minimum headway between their vehicle and the vehicle in front.
- All drivers looking for an acceptable gap have perfect knowledge about the movement of vehicles having higher priority, and fully understand the
rules of the road.

### 3.2.2 Input parameters

The important input parameters to the model include:

- Traffic volumes of all traffic streams.
- Percentage of heavy vehicle traffic in relation to the total traffic volume.
- Type of the intersection control (Yield or Stop).
- Speed limit on the major road.
- Percentage of each driver type in the drivers population.
- Number of lanes in both major and minor roads.
- Total simulation time.

Several other input parameters such as: move-up time, minimum allowable headway, turning speed of vehicles, and maximum queue lengths are held constants in the model. It is possible to change the values of these parameters between simulation runs.

### 3.2.3 Vehicle generation

This sections explains how vehicles are introduced to the simulation model. A negative exponential distribution is used to generate vehicle headway about the average headway calculated from the traffic volume. A value of 2.0 seconds is used as a minimum
allowable headway between vehicles in the same lane. If the generated headway is less than the minimum allowable headway, it is set to the minimum. In this case, the vehicle is considered a member of a platoon. The model uses a random number generator and a shifted exponential function to produce the required headway. Due to the variability of the random number generator, the actual flow rate generated by the model may differ from the required one. This is solved by calculating the flow rate generated by the model each four minutes. The difference between this flow rate and the required one is calculated and then used to adjust the average headway used in the GENERATE block of the model.

Each vehicle transaction has a number of parameters used to hold the necessary information associated with the vehicle such as the vehicle type, the vehicle direction and the driver type. This is achieved by using a random number generator to test a discrete function containing the different function values and their corresponding cumulative frequencies. Some parameters are also used for programming purposes; such as keeping the instantaneous speed of the vehicle, the driver’s critical gap, and the stopped delay value.

3.2.4 The approaching process

After the vehicles are generated, a lane selection process is used to ensure that vehicles will reach their desired destination. After a lane is selected, vehicles try to proceed and enter the intersection. The minor road consists of two sections; the approaching section
Chapter 3. The Simulation Model

and the queuing (decelerating) section. At the approaching section vehicles have smaller speed than the desired speed, as they are preparing to what is called "negotiating the intersection". The queuing section is the location in which vehicles decelerate and in some cases have to stop according to the number of vehicles in the queue and the type of intersection control. Vehicles on the major road are either free movers or a platoon member. Free mover vehicles can have their desired speed (controlled by the speed limit). The speed of all platoon members is the same as the speed of the platoon leader.

3.2.5 Entering the intersection

Major road vehicles are assumed to be unaffected by minor road vehicles, so they can proceed and enter the intersection directly without any speed change. In some situations vehicles on the major road have to decelerate or stop as other major road vehicles in the same lane are attempting to turn into the minor road.

Minor road vehicles have to find a suitable gap (lag) to join or cross the major road. If the intersection is Stop-controlled, vehicles have to come to a complete stop before looking for a suitable gap (lag). In the case of a Yield-controlled intersection, minor road vehicles may proceed and directly enter the intersection if they can find a suitable gap (lag). The minor road driver decision whether the gap (lag) is suitable or not depends on its size compared with his critical gap.
3.2.5.1 Factors affecting driver’s critical gap value

1. The driver type

As discussed before, drivers’ characteristics such as age and sex have a remarkable effect on driver behaviour. Female drivers tend to accept longer gaps than male drivers. They are also less involved in traffic conflicts situations than male drivers. Young drivers are often more consistent in their driving behaviour than old drivers.

The model considers four types of drivers: young males, young females, old males, and old females. The model uses a truncated normal distribution gap acceptance function. Based on the work by Darzentas et al. (1980) and Polus (1983), the values in Table (3.1) were chosen for the mean and standard deviation of the gap acceptance function for each group. The model allows these values to be changed with any other input values.

The higher the mean of the gap acceptance function the more cautious the driver group is. The higher the standard deviation of the gap acceptance function the less consistent the driver group is. The value of mean and standard deviation of the gap acceptance function is considered to be equal for both merging and single lane crossing manoeuvres.
### Chapter 3. The Simulation Model

<table>
<thead>
<tr>
<th>Group</th>
<th>Yield Control</th>
<th>Stop Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (seconds)</td>
<td>Std. Dev. (seconds)</td>
</tr>
<tr>
<td>Young males</td>
<td>4.0</td>
<td>0.75</td>
</tr>
<tr>
<td>Old males</td>
<td>4.5</td>
<td>0.85</td>
</tr>
<tr>
<td>Young females</td>
<td>5.5</td>
<td>1.00</td>
</tr>
<tr>
<td>Old females</td>
<td>6.0</td>
<td>1.25</td>
</tr>
</tbody>
</table>

*Table 3.1 Mean and Standard deviation of the gap acceptance function*
Chapter 3. The Simulation Model

2. Number of lanes being crossed

Number of lanes or traffic streams being crossed in the manoeuvre affects the critical value of drivers. Based on the gap acceptance values provided by the Highway Capacity Manual, a correction factor of 0.25 second is added to the critical gap value for each extra lane being crossed.

3. The vehicle type

Heavy vehicles require about 30% larger critical gaps than cars because they accelerate and decelerate at slower rates than passenger cars.

4. The Stopped delay

Several researchers, Wagner (1965), Ashworth et al. (1977) and Adebisi et al. (1989), have indicated that drivers accept shorter gaps as their stopped delay time increases. Based on information from those authors the following stopped delay modification factor is used to alter the driver critical gap value:

\[
\Theta_D = \frac{DL}{Q_D + DL} + C
\]
Where

\[ \Theta_D = \text{stopped delay modification factor} \]
\[ DL = \text{the delay value after which driver behaviour begin to change.} \]
\[ Q_D = \text{the stopped delay value (seconds)} \]
\[ C = \text{constant value.} \]

The value of DL and C were chosen 27, 0.5 respectively. These values were obtained after examining the data presented by Adebisi et al. (1989). Tudge et al. (1988) suggested a similar function. They used a value of 8 seconds for the delay value after which drivers begin to accept shorter gaps based on the observations reported by Ashworth (1977). However, Ashworth only considered the time drivers wait as the head of the queue and not the total delay. Adebisi (1989) suggested a total delay value of 25-30 seconds after which drivers begin accepting shorter than normal gaps, this idea was used in the simulation model. The Function is shown in Figure 3.1.

### 3.2.5.2 The gap acceptance process

This process takes place when a vehicle has to cross or merge with other traffic streams. Different traffic streams have different priority levels according to the rules of the roads. Generally, major road vehicles have a higher priority than minor road vehicles. Straight ahead major road vehicles also have a higher priority than turning left or right major road vehicles. Each vehicle is assigned a primary critical gap value by testing the
gap acceptance function according to the driver type and the intersection type of control. The primary critical gap value is modified according to the vehicle type and the number of lanes to be crossed. Vehicles trying to cross or merge wait for a gap in the conflicting traffic stream (streams) greater than or equal to their critical gap. The critical gap value is obtained by multiplying the primary critical gap with the delay modification factor $\Theta_D$. The delay modification factor has an initial value of 1.5 when the vehicle faces no delay and this value decreases as the vehicle’s stopped delay increases with a minimum theoretical value of 0.5 when the vehicle faces infinite delay (Figure 3.2). The model assumes that no driver will accept a gap that he/she thinks will certainly lead to a collision. Therefore, a minimum acceptable gap ($G_{cmin}$) is used. If the critical gap value is less than the minimum acceptable gap, it is set to the minimum. A value of 2.5 seconds is used as a minimum allowable critical gap value based on the data provided by Wennel et al. (1981).

Vehicle drivers who decide to enter the intersection are assigned a single lane manoeuvre time. This time is sampled from a truncated normal distribution function. The mean and standard deviation of the function depend on the driver type (Darzentas et al. 1980). The sampled manoeuvre time is then corrected according to the number of lanes to be crossed and the vehicle type.
Chapter 3. The Simulation Model

Figure 3.1 Delay modification function
Figure 3.2 Gap acceptance function
3.2.5.3 Conflict resolution

A conflict occurs when a driver decides to execute a manoeuvre which put him/her in risk of collision with another vehicle. Conflicts in this model are classified into two groups:

- Within the intersection conflicts, which result from conflicting vehicles entering the intersection at close times and can mainly be divided into crossing and merging conflicts.

- Rear-end conflicts which result from conflicting vehicles leaving the intersection through the same lane at close times intervals.

The model uses the time to collision (TTC) as a measure of traffic conflicts. The TTC is defined as "the time for two vehicles to collide if they continue at their present speeds and on the same path". The model first estimates whether the vehicles are on collision course or not. If the vehicles are on collision course, the TTC value is calculated and compared with the threshold value of 1.5 seconds. If TTC is less than or equal to the threshold value the model records the conflict, its type, location, and the TTC value. There are basically three conflict types: crossing; merging and rear-end conflicts. The location defines the two conflicting traffic streams from where the vehicles originated. The TTC value represents the conflict severity. The smaller the TTC value the more
severe the conflict. Conflicts with TTC value less than 1 second are usually considered to be severe conflicts.

3.2.6 Model output

The main output statistics of the model is included in the file "OUTPUT.LIS" which is produced with each simulation run. These statistics include:

1- The input and generated traffic volumes for each direction.
2- The average vehicle delay for each queue along with the average and maximum queue contents.
3- The total number of conflicts, their locations and the TTC values.

A sample of the file "OUTPUT.LIS" is given in appendix A.

3.2.7 Some aspects of programming in GPSS/H

Although using GPSS/H has several advantages because of the many well tested built-in capabilities, it does not provide a very important feature which is the interprocess communication (parameters of one transaction is not readily available to other transactions). This feature is very important for traffic simulation models to allow for vehicles interaction. Two methods can be used to overcome this problem. The first is using global variables to hold data belonging to a certain transaction. This method is not efficient from a programming point of view, especially in large models where many
global variables would be needed. The second is using the technique provided by Atkins (1980) which he referred to as "Atkins chain". In this technique, vehicles transactions are split (a copy of the transaction is obtained with the same parameters values) to be inserted into a user chain. Other vehicle transactions can check the parameters values of the split transaction through the Boolean-variable operand in the "UNLINK" block. The last method is used in the model.

Many other programming ideas in GPSS/H were developed in the model such as calculating the gap (lag), adjusting the generated flow rate, handling acceleration and deceleration and identifying conflict situations.

### 3.3 Model Visualization

The visualization process is a very important part of this model. Its objective is to show how the model is behaving at extreme values, that is during traffic conflicts. This view gives a better understanding of these critical situations and the parameters affecting their occurrence without having to view many average events.

A general purpose system animation software for the IBM PC called "PROOF" is used to provide this graphical representation of the simulation events. PROOF is general purpose for two reasons. First, it is independent of any simulation or programming language. Second, the flexibility of its animation command set allows animation of a wide
variety of systems in many different ways.

Two files are needed to run a PROOF animation. The first is the animation trace file which contains the sequence of timing information and other commands that make the animation happen. The second is the layout file which contains all the background text and graphics for an animation. The animation trace file is generally written directly by an executing model or program designed to generate syntactically correct PROOF commands. The layout file is created either by the graphical tool provided by PROOF (as the case of the current model) or other programs such as CAD programs.

3.3.1 Generation of the animation files

In addition to the "OUTPUT.LIS" file, two other files are produced during the simulation run. The first is the animation trace file (*.ATF) which contains the animation commands for the whole simulation time. The second is the presentation file (*.PSF) which contains commands for the animation of the times at which traffic conflicts occur.

The animation trace file is generated during the simulation run and its commands are connected with the model simulation blocks. For example, when a transaction which represents a vehicle is generated through the "GENERATE" block, the model writes an animation "CREATE" command to create the object representing the vehicle and the generation time to the animation trace file. The model also writes the values of important
variables affecting drivers’ decision such as; the delay value, the presented gap (lag) size, and the driver critical gap to the animation trace file to be continuously displayed during the animation process.

The presentation file is generated after the simulation run ends. The model stores the times at which traffic conflicts occur and uses these times to write the presentation file. Conflicts are viewed one at a time. The animation lasts one minute for each conflict 30 seconds before the conflict and 30 seconds after. The user is able to jump or go back through these conflicts using the "+" and "-" keys. The following information is shown with each conflict:

- The driver type
- The vehicle type
- The primary critical gap
- The stopped delay value
- The driver critical gap
- The conflict type
- The TTC value

Two sample screens of the animation of both T and 4-leg intersections are shown in Figures 3.3 and 3.4.
Figure 3.3 A sample screen of the animation for a T-intersection
Figure 3.4 A sample screen of the animation for a 4leg-intersection
Validation is an essential part in building any simulation model. Before a model can be applied, it has to be shown that the model is both logically correct and adequately representing the modeled system. An accepted definition of validation is "the process of assessing the extent to which a test or instrument measures what it purports to measure" Grayson and Hakkart (1987).

There are several philosophical views on simulation model validation. After examining many of these views, three approaches were used for the validation process of the current model. The first is called the face validity. This is concerned with whether the model seems to behave correctly. The second is the hypotheses validity, which determines whether the model results agree with other work in the literature. The third is the external validity which looks at the relation between the model results and field observations of the system. Both face and external validity are discussed in this chapter while hypotheses validity is left to the next chapter on findings.

4.1 Face validity.

This type of validation was achieved by observing the model animation. Animation allows observation of the behaviour of individual vehicles at the intersection to decide if the vehicles behaviour is reasonable. Also, different model variables are viewed during
the animation and these show the internal interaction between different model entities.

Researchers such as McCormick et al. (1987) and Thomasma et al. (1991) indicated that the visualization process is a very important part in the model validation. Face validity provides more trust in the model and ensures that the model is logically correct.

4.2 External validity.

This type of validation is achieved through comparing traffic conflicts observed at certain unsignalized intersections with traffic conflicts predicted by the model for these intersections for the same period of time.

A study of traffic conflicts at several intersections in the greater Vancouver area was carried out by G.D. Hamilton & Associates Consulting LTD. The data of traffic conflicts for two intersections were supplied from this study and used with the permission of the City of Vancouver, The City of Burnaby, Road Safety Research of the Insurance Corporation of British Columbia and G.D. Hamilton & Associates Consulting LTD. These data were used to validate the simulation model.

4.2.1 Site selection.

The majority of the unsignalized intersections covered by the local conflict studies
included complex layouts which do not meet two basic intersection types used in this analysis. Only two intersections found to be suitable for the validation process, both are 4-leg intersections. The model limitations were negligible grades, good visibility and simple layout. The site locations intersections are shown in Figures 4.1 and 4.2.
Figure 4.1 Site location of 156th Street and 20th Avenue intersection.

Figure 4.2 Site location of Holdom Avenue and Broadway intersection.

4.2.2 Intersection geometry and traffic control.

The first intersection, 156TH street and 20TH Avenue have four, one lane approaches which intersect at approximately 90 degrees. All four approaches permit left turn, through and right turn movements. Gradients on all approaches are negligible. The eastbound and westbound approaches on 20th Avenue are controlled by STOP signs. Crossing sight distances and stopping sight distances for all traffic movements are adequate. The overall intersection geometry is illustrated in Figure 4.3.

The second intersection, Holdom Avenue and Broadway consists of four approaches with the two roadway intersecting at approximately 75 degrees. The grades are considered negligible on all directions. Sight distances are adequate for all traffic movements. The intersection configuration is shown in Figure 4.4. The northbound approach leg consists of two lanes for left-turn, through and right turn movements. The northbound exit leg consists of a single lane. The southbound approach leg consists of a single lane for left-turn, through and right-turn movements, while the exit leg consists of two lanes. The eastbound and westbound approach traffic movements on broadway are controlled by STOP signs. In addition to the STOP signs on broadway, southbound left-turn movements on Holdom avenue are restricted between 0700 hours and 0900 hours, Monday through Friday. The peak hour traffic volumes of the two intersections are shown in Figures 4.5 and 4.6.
Figure 4.3 156th Street and 20th Avenue intersection geometry.
Figure 4.4 Holdom Avenue and Broadway intersection geometry.
Figure 4.5 Peak hour vehicle traffic volumes
156th Street and 20th Avenue intersection
Figure 4.6 Peak hour vehicle traffic volumes

Holdom Avenue and Broadway intersection
4.2.3 Traffic conflicts observation.

Traffic conflicts were recorded at both intersections by observers trained in the traffic conflict observation technique. A total of 32 man-hours of conflicts survey data was collected for each intersection. The traffic conflict survey schedule is summarised in Table 4.1.

4.2.4 Observation methodology.

Conflicts were observed and recorded for both intersections using the TTC (Time To Collision) measure. TTC is the time for two vehicles to collide if they continue at their present speed and on the same path. The severity of traffic conflicts is determined by the sum of two scores: the TTC score and the "Risk of Collision" or ROC score. The ROC score is a subjective measure of the risk of collision and is dependent on the perceived control that the driver has over the conflict situation.

The scale used to determine the TTC and ROC scores is shown in Table 4.2. The summation of the TTC and ROC scores gives the overall severity score which range between two and six. Results of studies performed by Brown (1986) at the University of British Columbia indicate that conflicts which have been assigned an overall severity score of 4.0 or higher exhibit a correlation to accidents and are therefore indicative of a satisfactory significant accident risk.
<table>
<thead>
<tr>
<th>DAY</th>
<th>Time of day (Hours)</th>
<th>Number of Observers</th>
<th>Number of Man-Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>First day</td>
<td>0700 - 1000</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1100 - 1300</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1500 - 1800</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Second day</td>
<td>0700 - 1000</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1100 - 1300</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1500 - 1800</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>32</strong></td>
</tr>
</tbody>
</table>

*Table 4.1 Conflict observation schedule*

*Source: G.D. Hamilton & Associates Consulting LTD. conflict study report*

<table>
<thead>
<tr>
<th>TTC and ROC Scores</th>
<th>Time To Collision (TTC)</th>
<th>Risk Of Collision (ROC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.6 - 2.0 seconds</td>
<td>Low Risk</td>
</tr>
<tr>
<td>2</td>
<td>1.0 - 1.5 seconds</td>
<td>Moderate Risk</td>
</tr>
<tr>
<td>3</td>
<td>0.0 - 0.9 seconds</td>
<td>High Risk</td>
</tr>
</tbody>
</table>

*Table 4.2 Time to collision and risk to collision scores.*

*Source: G.D. Hamilton & Associates Consulting LTD. conflict study report*
4.2.5 Comparing results

A comparison between the observed conflicts and the predicted conflicts was carried out. The model was modified to allow for the traffic volume changes through the morning, noon and afternoon periods. There was another modification to allow the inclusion of the restricted southbound left-turn movement between 0700 and 0900 hours at Holdom Avenue and Broadway intersection.

Since the simulation model only consider conflicts with TTC values less than or equal to 1.5 seconds, observed conflicts with TTC greater than 1.5 seconds were excluded from the validation data. The speed limit was taken 50 km/hr which is the legal speed limit at both intersections. The comparison are given in Tables 4.3 and 4.4.

In the case of 156th Street and 20th Avenue intersection (Table 4.3), the model predicted 5 conflicts out of 8 observed conflicts with a close distribution of conflicts over the different locations within the intersection. The field study observed that typical vehicles speeds exceed the legal 50 km/hr limit along 156th Street. This may be a factor contributing to the difference in number of conflicts. Increasing the speed limit in the model to 70 km/hr caused the model to predicted 10 conflicts with a very close distribution to the observed conflicts.
Table 4.3 Observed and predicted conflicts distribution 156th Street and 20th Avenue intersection
Table 4.3 Observed and predicted conflicts distribution Holdom Avenue and Broadway intersection

<table>
<thead>
<tr>
<th>Conflict name and description</th>
<th>Observed conflicts</th>
<th>Predicted conflicts 50 km/hr</th>
<th>Predicted conflicts 60 km/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left turn crossing conflicts involving westbound left turning motorists and southbound through motorists.</td>
<td>10</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Left-turn opposing conflicts involving eastbound through motorists and westbound left turning motorists.</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Crossing conflicts involving eastbound through motorists and northbound or southbound through motorists.</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Crossing conflicts involving eastbound through motorists and northbound or southbound through motorists.</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Right turn (merging) conflicts involving westbound right turning motorists and northbound through motorists.</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Rear-end conflicts involving southbound through motorists.</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Left turn opposing conflicts involving southbound through motorists and northbound left turning motorists.</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>19</strong></td>
<td><strong>17</strong></td>
<td><strong>21</strong></td>
</tr>
</tbody>
</table>
Chapter 4. Model Validation

The predicted results may be identical to the observed results if an appropriate approach speed between 50 km/hr and 70 km/hr is selected.

The Holdom Avenue and Broadway intersection model predicted 17 conflicts out of 19 observed conflicts. Increasing the speed to 60 km/hr produced 21 conflicts. In both cases the predicted conflicts distribution was very close to the observed conflicts distribution.

The results of the comparison which is limited to two intersections shows that the model results do correlate very well with the observed field data. The comparison implies a successful external validation process. However, due to the limited number of intersections used in the validation process and the variability of the conflict technique; more work on the validation is recommended.
Chapter 5. Findings

5- FINDINGS

This chapter presents some additional simulation results. A comparison of these results and previous work in the literature is also introduced for the purpose of the hypotheses validity of the model.

5.1 Relation between conflicts and traffic parameters.

5.1.1 Volume - Conflicts relation.

Several researchers indicated that traffic volume has a significant effect on conflicts. Cooper et. al. (1976) suggested that number of conflicts occurring at a certain location is proportional to the product of the two conflicting volumes. The same result were recorded by Hodge et. al. (1978). Spicer et al. (1979) indicated that at relatively low traffic volumes, the total number of observed conflicts is proportional to the square root of the product of the conflicting volumes. Darzentas et. al. (1980) proposed that conflicts linearly increased as a function of the traffic volume. None of the above researchers considered high traffic volumes.

Figures 5.1, 5.2 and 5.3 are examples of the relation between traffic volume and conflicts rate obtained from the simulation model. These figures indicate that over a wide range of traffic volumes including congested conditions, an exponential relation seems to give
a good fit. However, if only low traffic volumes are considered, conflicts seems to be proportional to the square root of the conflicting volumes as suggested by Spicer et. al. (1979). The product of the conflicting volumes is also found to be statistically related to conflicts for a limited range of traffic volumes.

The curves representing conflicts for Yield and Stop controlled intersections, Figures 5.2 and 5.3 were very close at low traffic volumes and the difference begin to increase rapidly as traffic volume increases. This agrees with the volume warrant for the use of Yield sign which specify a volume limit after which Yield signs should not be used to control unsignalized intersections. An example of Yield sign warrants is shown in appendix B.
Chapter 5. Findings

Figure 5.1 Relation between crossing conflicts and traffic volume for a T-intersection

$q_1 = kq \quad k = 0.3$
Approach speed = 60 km/hr
2 lanes for both major and minor roads

Conflicts (10 hours)

Volume (VEH/HR)
Figure 5.2 Relation between crossing conflicts and traffic volume for a T-intersection
Figure 5.3 Relation between crossing conflicts and traffic volume for a 4-leg intersection

$q_1 = kq \quad k = 0.3$

Approach speed = 60 km/hr

1 lane for both major and minor roads
5.1.2 Speed - Conflicts.

Early research by Cooper et. al. (1977) indicated that accidents risk increases as the approach speed of major road vehicles increases. Darzentas et al. (1980) suggested a rapid increase of conflicts rate at a fixed flow as the mean speed on the major road increases.

The relation between the mean approach speed and number of conflicts from the current model is shown in Figures 5.4, 5.5 and 5.6. The figures indicate an increase in the number of conflicts as the mean approach speed increases for a fixed volume. The value of the increase is proportional to the traffic volume. A slight increase was obtained at low traffic volume and a significant increase at high traffic volumes. There was no significant effect of the intersection type of traffic control (Yield - Stop) on the value of this increase.

The number of conflicts estimated by the model increased as the dispersion of speeds on the main road increased. This agrees with the published research which indicate that there is a driver’s error of judgement associated with vehicles having speeds different than the mean speed (Brian 1962; Cooper et al. 1976). These results suggest that a decrease in major road vehicles speeds and the dispersion of these speeds can result in decreasing number of conflicts. This may be achieved by police activity at the intersection as reported by Cooper et al. (1977).
Chapter 5. Findings

Figure 5.4 Relation between conflicts and approaching speed

at Stop-controlled T-intersection
Chapter 5. Findings

Figure 5.5 Relation between conflicts and approaching speed
at Yield-controlled T-intersection
Chapter 5. Findings

Figure 5.6 Relation between conflicts and approaching speed

at Stop-controlled 4leg-intersection
5.1.3 Speed - severity of conflicts.

The overall severity of traffic conflicts represented by the average time to collision (TTC) value (the TTC value is inversely proportional to the severity of traffic conflicts) increased as the mean approach speed of the major road vehicles increased, see Figures 5.7 and 5.8. The same results were reported by Copper et al. (1976, 1977) and Darzentas et al. (1980). This indicates that the percentage of injury accidents at unsignalized intersections may increase as the mean major road speed increases.

The overall severity of conflicts was higher in the case of Yield-controlled intersections than Stop-controlled intersections. This may result because of the drivers tendency to accept shorter gaps at Yield-controlled intersections. This increased conflict severity may put a constrain on using Yield sign to control intersections with relatively high major road speeds even though other warranties for using Yield sign such as traffic volume and sight distance are satisfied.
Figure 5.7 effect of approach speed on conflicts severity for a Stop-controlled T-intersection
Chapter 5. Findings

Figure 5.8 effect of approach speed on conflicts severity for a

Yield-controlled T-intersection
5.2 Conflicts and driver type.

The model is based on the consideration of the effect of drivers’ characteristics such as sex and age on the drivers’ behaviour. The model output reflected this consideration. The model output indicate that female drivers were generally less involved in conflict situations than male drivers. It was also noted that older drivers were involved in more conflict situations than younger drivers which indicates that older drivers are less consistent in their driving behaviour.

The number of conflicts can be reduced by increasing the median acceptance gap (i.e. make drivers more cautious). This agrees with Storr et al. 1979 who indicated that police activity near an intersection makes turning drivers from minor road more cautious and consequently decrease number of conflicts.

All these results agree with our expectations and previous research and consequently contribute to both face and hypotheses validity of the model.
6- FURTHER RESEARCH

There are several directions where further development to the model can be undertaken. The first direction is expanding the simulation model to include the effect of some parameters which are not considered in the model. These parameters might include the effect of the surrounding environment such as buildings that obstruct the driver’s view and the weather conditions which are important in determining the driver’s field of vision.

The perceptual and decision making processes can be made more sophisticated in terms of current knowledge about human driving behaviour. For example the decision making process might take into account the driver’s degree of concentration and whether he is familiar with the intersection. Also, the process of estimating gaps which is currently based upon the driver’s estimates of the relative times at which vehicles will arrive at the intersection can be expanded to take into account distance estimates and change in subtended visual angle.

The model at the current stage is only capable of dealing with simple layout intersections. It might be of interest to add the ability of dealing with other layouts such as those with separate turning lanes and corner islands. Another development is to include other types of intersection controls. These controls would include the 4-way Stop, flashing red and traffic lights.
Another important direction in which the model can be expanded is to include user interaction with the model. Through this interaction, the user should be able to alter the values of different parameters and observe the change in the model behaviour. User interaction with the model allow for the integration of more human factors in the model.
7- CONCLUSION

A visual microscopic traffic conflicts simulation model for both T and 4-leg intersections have been developed using GPSS/H. The model considers different aspects of drivers' behaviour and the effect of several parameters on drivers' decision at unsignalized intersections. The visualization process is very important part of the model as it shows how the model behaves at extreme values, that is during traffic conflicts. This view gives a better understanding of these critical situations and the parameters affecting their occurrence. An external validation process was conducted to test whether the model results is indicative of the actual performance. The external validation process showed that the model results correlate well with the field observations.

The significant findings of the model can be summarized in the following:

1. Over a wide range of traffic volumes, including congested conditions, an exponential relation between traffic volumes and conflicts seems to give a good fit.

2. Conflicts rate increases as the mean approach speed increases. The value of the increase is proportional to the traffic volume. This implies that imposing a speed limit especially on intersections with high traffic volumes, can help reduce the number of conflicts.
3. The overall severity of conflicts represented by the average TTC value increases as the mean approach speed increases. This indicates that the percentage of injury accidents may increase with higher approach speeds.

4. The overall severity of conflicts in speed-conflicts relation was higher in case of Yield-controlled intersections than Stop-controlled intersections. This may put a constrain on using Yield sign to control intersections with relatively high major road speeds.

5. Police activities near or at intersections can help in reducing the number of conflicts through increasing the median accepted gap of drivers and decreasing the dispersion of the mean approach speed.

These results agrees with our expectations and previous work in the literature. This indicate that the model has both face and hypotheses validity.

The model can be mainly used for two purposes. The first is assessing the safety and performance of unsignalized intersections. The safety measure can be expressed by the number of conflicts predicted by the model, while the performance can be expressed by the intersection level of service which is a function of the average delay to minor road vehicles. The second is as a tool for investigating how to reduce accidents risk. As several researches emphasized on the value of behavioral studies and drivers education in reducing accidents risk, the model can be a useful tool in identifying the areas at which
these kind of studies should be directed.
References


Bell, P. and O'keefe, R. "Visual interactive simulation- History, recent development, and major issues." Simulation Vol


References


References


References


APPENDIX A SAMPLE MODEL OUTPUT

SIMULATION OUTPUT FILE

TOTAL SIMULATED TIME 10.00 HOURS

INTERSECTION CONTROL TYPE STOP

SPEED LIMIT ON MAJOR ROAD 50.0 KM/HR

1. TRAFFIC CONFLICTS

<table>
<thead>
<tr>
<th>NUMBER</th>
<th>LOCATION</th>
<th>TYPE</th>
<th>TTC (SECONDS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MINOR TURNING RIGHT, MAJOR GOING</td>
<td>MERGING</td>
<td>1.43</td>
</tr>
<tr>
<td>2</td>
<td>MINOR TURNING LEFT, MAJOR GOING</td>
<td>CROSSING</td>
<td>1.41</td>
</tr>
<tr>
<td>3</td>
<td>MINOR TURNING LEFT, MAJOR GOING</td>
<td>CROSSING</td>
<td>1.46</td>
</tr>
<tr>
<td>4</td>
<td>MAJOR TURNING LEFT, MAJOR COMING</td>
<td>CROSSING</td>
<td>1.44</td>
</tr>
<tr>
<td>5</td>
<td>MINOR TURNING LEFT, MAJOR GOING</td>
<td>CROSSING</td>
<td>1.43</td>
</tr>
<tr>
<td>6</td>
<td>MINOR TURNING LEFT, MAJOR GOING</td>
<td>CROSSING</td>
<td>1.43</td>
</tr>
</tbody>
</table>

1- TOTAL VOLUMES

<table>
<thead>
<tr>
<th>DIRECTION</th>
<th>INPUT VOLUME(VPH)</th>
<th>GENERATED VOLUME(VPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRAIGHT AHEAD</td>
<td>400</td>
<td>403</td>
</tr>
<tr>
<td>MAJOR GOING</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Delay (Seconds)</td>
<td>Average Content</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Minor Road</td>
<td>23.47</td>
<td>1.0</td>
</tr>
<tr>
<td>Turning Left</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minor Road</td>
<td>10.86</td>
<td>0.5</td>
</tr>
<tr>
<td>Turning Right</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major Road</td>
<td>6.69</td>
<td>0.2</td>
</tr>
<tr>
<td>Turning Left</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Appendix A. Sample Model Output
APPENDIX B YIELD SIGN WARRANTS

WARRANTS TO BE CONSIDERED FOR INSTALLATION OF YIELD SIGN

1. The sum of the ADT's on the intersecting streets is at least

   \[ \frac{(A + B)}{2} + \frac{(C + D)}{2} = 1500 \text{ to } 5000 \text{ vpd} \]

2. The occurrence of at least two accidents unpreventable by

   less restrictive means in the two latest 12-month periods. The
   accidents should be of the type correctable by Yield signs.

3. The safe stopping sight distance speed must be greater than

   12 mph (triangle distance of about 45 feet).

Source: National Cooperative Highway Research Report 320