Exploiting Witness for Traffic Simulation

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ABSTRACT: Traffic congestion in urban cities is an increasing problem. Not only does it lead to an increase in pollution, but the time spent waiting in traffic queues wastes valuable time in addition to causing frustration. A system that can control and manage traffic efficiently is one way that this issue can be reduced.

A specific road traffic intersection in South Manchester, UK, was selected for investigation as it experiences high levels of traffic flow through it during the evening peak time. This has led to large queues and long waiting times due to the fixed timings of the traffic lights. This paper explores strategies to better control the traffic flow through it.

A model of the selected traffic junction has been built using Witness simulation software. Data for this junction has been obtained partially from observations and mostly from traffic surveys enabling a simulation of the traffic flow. Analysing the results allowed two alternative scenarios to be developed and simulated. Results from one of the scenarios showed noticeable reductions in the average queue waiting times at the traffic junction.

Keywords: Traffic Simulation; Discrete Event Simulation; Witness Modelling

1. INTRODUCTION

As a continually expanding population, being mobile is a fundamental part of society. It is vital that a well organised and efficient infrastructure is present to allow a convenient and safe method of travel. The most popular method of travel involves the use of roads and increases in traffic volume results in congestion which is an increasing problem [1]. Since most cities rely on traffic signals to control the flow of traffic, it is important to have a system that allows congestion to be managed, especially during peak traffic hours [2].

Traffic lights are responsible for controlling the flow of traffic at junctions and can influence the amount of congestion around a certain section of road leading to aggravation for passengers [3]. It is not only frustrating waiting for an extended period of time for a light to change, but being in a queue wastes precious time. It is therefore important to implement a system that takes into consideration peak times, when congestion is high, as well as explore alternative methods to reduce the waiting time of motorists.

Unfortunately, it is not possible to simply approach a junction and begin to alter traffic signals as this is both unreasonable and would have disastrous effects. Secondly it is very difficult to model road traffic flow through analytical methods [4]. The alternative to this is to use computer modelling and simulation which is generally a well understood field [5]. This approach allows a real world scenario to be modelled safely and answers domain-specific set of questions [6]. Changes can also be made instantly with the added benefit of speeding up and slowing down time - something that is not possible to do otherwise [7]. The proposed approach is to use a discrete-event queue-based model as it has some advantages over other methods [8].

WITNESS is an industry-standard software program that was selected as it has the ability to model a wide range of process and operation tasks [9]. By utilising it, a traffic simulation model can be built and tested eliminating the need to physically carry out tests on the road. The model can then be modified and adapted in a number of ways in order to reach a favourable outcome. In this case it would be to reduce congestion and queue wait times for a specific road junction by improving the timings of the traffic signals [10].

1.1 Specific Problem and its Issues

Traffic growth is increasing each year on UK roads and Manchester is no exception. As a major city in the North West with an estimated population of 503,000, congestion is prevalent in most boroughs. These impacts the journey time for all road users whether they are using their own means of transportation, or are using public services such as buses. The junction selected for investigation is one which experiences congestion during the peak hours of the day and it imposes a significant burden in lost time, uncertainty, and aggravation for road users.

1.2 The Junction

The chosen junction is an intersection at Moss lane/ Alexandra Rd in South Manchester, UK. Essentially the intersection is secondary link route enabling motorists travelling in and out of the centre of Manchester. This is a common route motorists will take to travel to their place of work and is shared by a number of popular bus routes. Whilst there are queues present in the morning, the evening peak time has shown to have a greater flow of traffic through the junction. This has also been confirmed by the traffic data collected. Therefore, only the evening time period will be considered.

This particular junction's traffic signals run on a fixed timing rather than an adaptive system. This means the signals cannot intelligently change to give priority to queues with a larger quantity of vehicles. By allowing signals to control the flow of traffic, depending on the volume, it could help reduce congestion on busier sections of the junction.

The main issue caused by the congestion around this junction is an increased journey time, which is a result of longer queuing periods. This in itself can have its own impact on an individual such as a loss of valuable time and frustration from waiting in a traffic queue.

2. DATA COLLECTION

It is important to obtain accurate and reliable data. Multiple methods are needed to be combined when collecting data to ensure the model runs as close to the real world scenario that is being modelled. The required traffic flow data must include the amount of cars arriving at the peak time, where they were arriving from and the direction in which they travelled. The chosen junction is a simple intersection allowing all vehicles from any direction to carry on straight ahead, turn left or to turn right. The second piece of information that was needed was the traffic signal timings for the junction. Data collection was achieved by conducting both field observations at the traffic junction, in addition to collecting specific traffic data and signal timings from the Greater Manchester Urban Traffic Control Unit (GMUTCU).

2.1 Field Observations

In order to validate the obtained data some field observations at the junction were conducted. This was carried out at the peak times for each road at the junction over several days. Traffic data was observed for the peak time period which was from 16:00 to 17:45 hours in 15-minute intervals over a series of several consecutive days.

The traffic light timings were also observed and were recorded. Average queue times and queue length at the traffic lights were also noted as reliable and accurate data is needed to build a realistic model. Traffic data obtained from GMUTCU was verified by field observations. The observations closely matched the official data without any reasons for concern.

2.2 Data Collected

When modelling a specific problem using simulation several types of data is required. The data needs to be accurate to produce a valid model and it should be obtainable without having to go to excessive means to collect it. In this case, most of the data required to drive the model correctly had been obtained however, it required manipulation to be appropriate for modelling purposes. For simplicity the four roads forming the intersection are described as Arms 1..4 in the directions North, South, East and West.

The data displayed in tables 1,2,3,4 is an extract from the collected data. These tables depict the number of vehicles that have passed through the junction, the direction they have come from and the destination direction they have proceeded to.

From the data shown in tables 1-4, it was necessary to determine the destination percentage of vehicles in each time slot. The viable directions were either left, straight ahead or right. The destination percentage showed some variation over the PM peak period. This was deemed necessary to enable the model to behave as realistically as possible.

Table 1: Traffic entering junction from North

P.M Peak	**Entry Arm 1, from North to arm:**			
	2	**3**	**4**	**Total**
16.00	5	124	51	**179**
16.15	2	97	60	**159**
16.30	8	142	90	**240**
16.45	4	110	66	**179**
17.00	5	153	74	**232**
17.15	5	166	93	**264**
17.30	4	176	65	**244**
17.45	5	164	76	**244**

Table 2: Traffic entering junction from East

P.M Peak	Entry Arm 2, from East to arm: 3	4	1	Total
16.00	31	124	4	**158**
16.15	11	103	2	**116**
16.30	14	114	5	**133**
16.45	31	96	2	**129**
17.00	20	120	5	**145**
17.15	30	106	2	**138**
17.30	35	125	13	**173**
17.45	27	107	4	**138**

Table 3: Traffic entering junction from South

P.M Peak	Entry Arm 3, from South to arm: 4	1	2	Total
16.00	26	98	24	**148**
16.15	44	94	11	**149**
16.30	20	73	9	**103**
16.45	32	63	8	**103**
17.00	19	84	5	**107**
17.15	28	71	11	**110**
17.30	15	55	7	**78**
17.45	17	85	12	**113**

Table 4: Traffic entering junction from West

P.M Peak	Entry Arm 4, from West to arm: 1	2	3	Total
16.00	51	106	20	**177**
16.15	52	105	18	**175**
16.30	45	99	15	**159**
16.45	45	99	25	**169**
17.00	41	120	30	**191**
17.15	46	77	12	**135**
17.30	41	84	20	**145**
17.45	35	78	26	**139**

3. MODELLING THE SYSTEM

The layout of the model follows the general shape of a traffic junction. It features four roads from the North, East, South and West directions meeting to form an intersection. Traffic signals are situated at the boundaries of each junction and vehicles will queue just before the traffic lights.

To build a functioning model the necessary simulation elements need to be setup. Witness uses a variety of these elements to represent different aspects of a model. These are detailed next:

Entity: Represents physical items in a model, for example these include (but is not limited to) vehicles.

Queue: Allow entities to line up and wait until they can be processed and then moved to a specified location. For this model, a queue is situated at the start of each junction so the arriving entities (vehicles) can queue up ready to move when the traffic signal is switched to green.

Activity: Allows entities to be processed and then moved to a new area of the model. Activities for this model will mainly represent the traffic lights, which will pull entities from a queue.

Path: Allows entities to be transported from one element to another. They can be used to represent the length and physical route that the entities can take. Roads will be modelled using paths for this specific model.

Variable: Is used to display information for a specific area of a model. For example, this model will have a variable that displays the stage the traffic light sequencer is on.

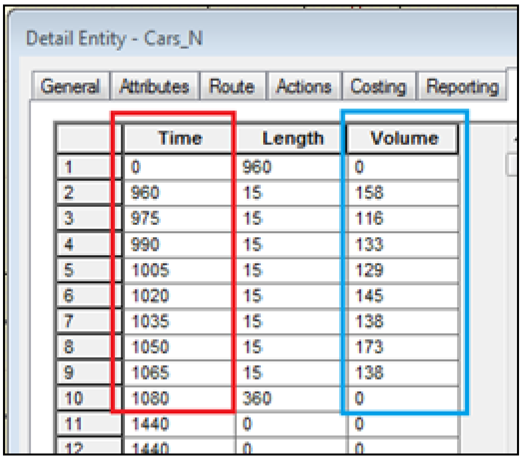
3.1 Junction Layout

The chosen junction has been modelled using paths to represent each of the four roads. Each road also has two separate paths, which represent the two lanes and their respective direction of traffic flow. The quantity of vehicles allowed on the path can be set to emulate the actual capacity that the length of road being modelled can hold. This will allow the simulation to produce a more accurate result, as it will ensure that the traffic can build up just as it would in real life.

3.2 Vehicles

Vehicles arrive from each of the four roads. Entities have been used to model the arriving vehicles. An arrival profile has been used to setup vehicles entering the junction for each of the four directions. Since the traffic data is recorded in 15-minute time intervals, the amount of vehicles arriving differs for each time slot, figure 1 illustrates an arrival profile for vehicles designated as Cars_N.

Note: the base time units is in minutes of simulation.


Detail Entity - Cars_N

General | Attributes | Route | Actions | Costing | Reporting

	Time	Length	Volume
1	0	960	0
2	960	15	158
3	975	15	116
4	990	15	133
5	1005	15	129
6	1020	15	145
7	1035	15	138
8	1050	15	173
9	1065	15	138
10	1080	360	0
11	1440	0	0
12	1440	0	0

Figure 1. Arrival profile of vehicles

The data collected is for the P.M. peak time (16:00-17:45 hours), therefore the vehicles will only arrive within this time period. The time column shown in Fig. 1. is the arrival time in minutes. The first batch of vehicles arrives at 16:00 hours, which is the equivalent of 960 minutes of simulation. The volume column in fig 1 represents the quantity of arriving vehicles, so for this case at 4.00 P.M. 158 vehicles will arrive.

As the vehicles (entities) enter the model, they will travel along a path where they can either queue up or proceed past the junction. This will depend on whether the traffic light signal is on green or on red. A queue has been added to the end of each road, just before the junction, to allow this to happen.

3.3 Traffic Lights

Traffic lights have been modelled as an activity and are situated at each point of the junction. They are placed after the queues ready to process the arriving cars and send them to their destination. The traffic lights rely on a sequencer, which is responsible for the light timings. Vehicles will queue up when the signal is red and move across the junction when green. The model also includes an animated set of traffic lights labelled as L1..L6 (fig 2), which provides a visual display indicating the status of the traffic signal (i.e. red, amber or green). The traffic light sequencer is responsible for controlling the colour changes of the animated lights.

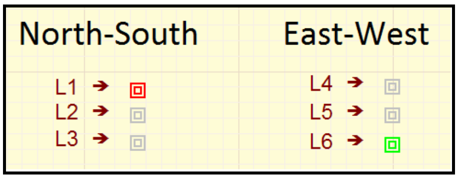


Figure 2. Traffic lights

3.4 Traffic Light Sequencer

The traffic light sequencer is effectively the controller for the traffic light signals. The timings for each stage of the traffic light cycle are input into this. The sequencer is modelled as an activity, which uses multiple stages for each stage of the traffic light cycle. Since traffic lights work in sync for opposite directions, the North-South lights will share the same timings and the East-West lights will share the same timings.

As the sequencer progresses through each stage it will also control the colour that the two sets of lights (L1-L6 in fig 2) will display. The colour displayed has been set up in relation to how each pair of traffic lights behave when run simultaneously, and act just as you would expect from a real life system. The colour of the lights displayed at each stage is shown in table 5.

Table 5.Stages of the traffic lights

Stage	North	South	East	West
1	Red	Red	Red	Red
2	Amber	Amber	Red	Red
3	Green	Green	Red	Red
4	Amber	Amber	Red	Red
5	Red	Red	Red	Red
6	Red	Red	Amber	Amber
7	Red	Red	Green	Green
8	Red	Red	Amber	Amber

A variable (traffic_stage) has been used to identify the stage the traffic lights are at. Whilst this is good as a visual indicator, it serves a much more important function. This variable is used in the coding of the model to ensure that the traffic can only move across the junction when the traffic light signal is on green. Clearly the assumption is that vehicles do not cross the junction during the amber stage.

3.5 Dummy Activities

To enable extending the output rules for the Witness modelling elements, some dummy activities have been utilised. The dummy activities act as a placeholder that will accept an entity, process it, and then send it off to its next destination. The duration of these dummy activities is zero so it will not impact the results of the simulation in anyway; it is just a means to allow the model to perform tasks simultaneously.

One example of using dummy activities has been to push a percentage of the arriving vehicles to the appropriate road. The percentages used in the model are extracted from tables 1..4

3.6 Variables

The use of variables is an important aspect of modelling with Witness. Variables can provide useful statistics related to the simulation model, which can be seen in real time whilst the model is running. In addition to this, variables can also be used in the model's coding to change its behaviour.

For this simulation a few important variables have been created to display useful statistics from the simulation. These include:

- The current stage of the traffic sequencer.
- The number of vehicles that have entered and exited the model.
- The current size of the queue for each road.
- The largest queue size reached for each road.
- The current queue wait time for each road and the total average wait time for the entire junction.
- The maximum wait time reached for each queue.

Not only does the value from these variables aid with the validation process, they also provide a starting point for the experimental work.

The model constructed is displayed in fig 3, representing the layout of the actual junction.

4. VERIFICATION AND VALIDATION

To produce an accurate and reliable simulation model, which behaves in a representative manner it is necessary to verify and validate it. These steps are important as it ensures the model is correctly structured and has the appropriate behaviour subsequently leading to realistic and credible results

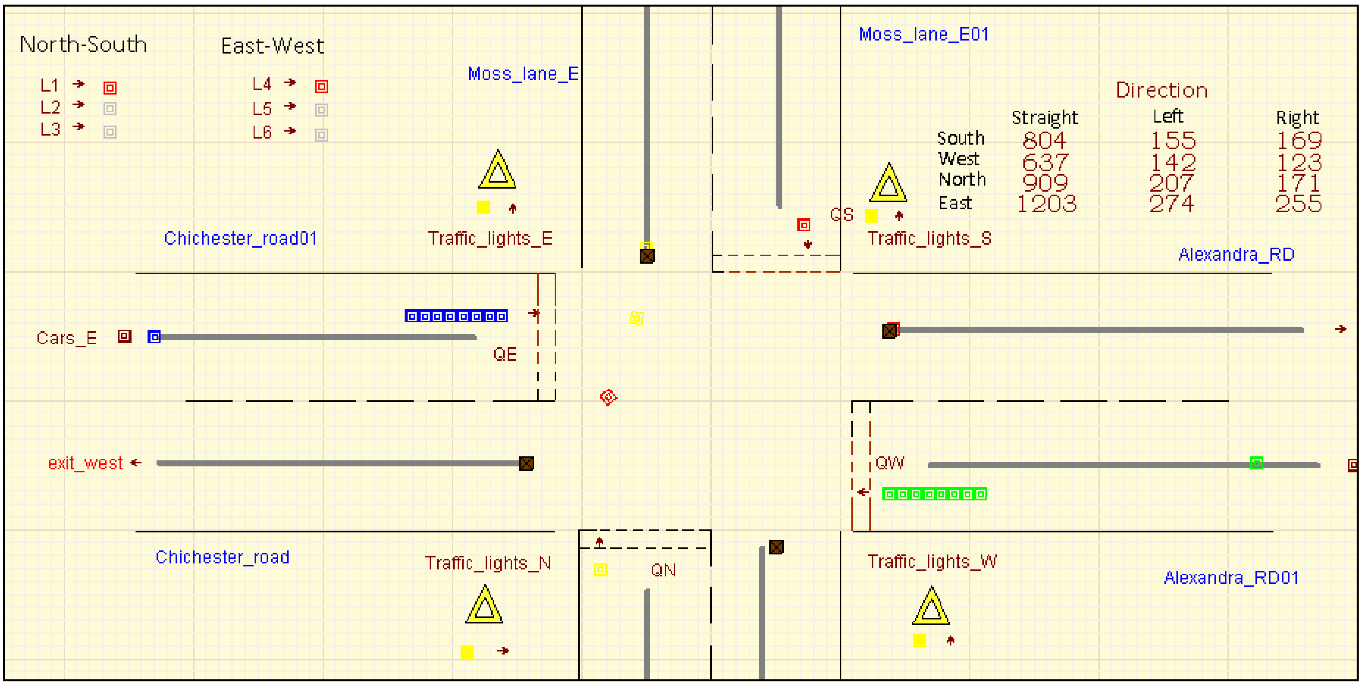


Figure 3. Simulation Model

4.1 Verification

Verification involves checking the model to make sure each element behaves in manner that you would expect. Since real world elements are being modelled using the obtained data it is important to ensure that they behave in a way that is representative of this data. By verifying each section of the model, possible faults can be detected and rectified before they have an impact on other sections of the system. This not only saves time; it also provides additional confidence that the final model will run correctly.

For the model that has been built a few areas were tested during verification. These include:

- The timings for the model such as the arrival times for each direction, the sequencer timings for the traffic lights and the visual sequence of lights L1-L6.
- The flow of entities and the route they can take.
- The coding of the model that ensure vehicles only proceed across a junction when the signal is green, and the distribution of cars travelling straight, turning left or turning right.

In order to then validate these areas a few methods were used together. A visual check was conducted, in addition to checking over the coding of the model as well as looking at the statistics for each area that required verification. The statistics captured during the simulation were dynamically displayed. These could be used for verification such as the quantities of elements output, timings etc.

4.2 Checking The Code

The coding that the model relies on to run properly needs to be checked for each stage of the model. This includes the rules that will pull entities from a queue as well as push them to the correct destination. The coding has been checked at each stage that the entities go through from the moment they arrive. Checks have been made to make sure the code allows entities to travel along a fixed path and then proceed to a queue. From this point, the code allows vehicles to only proceed past the queue when the signal is green. The percentage rule that directs the vehicles to their destination has been checked to make sure it uses the correct values from the data. Witness also incorporates a visual system that displays the flow of an entity. This is used when applying visual checks, which is the next method of verification.

4.3 Visual Checks

By using the tools available in Witness the speed that the model runs at can be slowed done, in order to see how it behaves. This allows the model to be visually checked with relative ease. Visual checks have been done to ensure that the visual display of the traffic light signals is representative of the sequencer stage. The flow of the elements, which represent the vehicles, and the various directions they can take, has also been observed visually. By setting a specific colour for the vehicles arriving from each direction (North, East, South and West), their routes can easily be checked. Each direction has also been checked to ensure the elements can take one of the three directions, and that they are travelling along their respective paths.

4.4 Checking The Results

The final method of verification involves checking the statistics after running the simulation. By doing this it allows the data to be compared with what the expected results should be. Statistics relating to the various queue times and sizes, as well as how many entities have entered and exited the model, have been evaluated to make sure the model behaves correctly. This has been done for each direction.

Verification for the model was completed successfully and any problems were rectified before proceeding to the next stage of the model.

4.5 Validation

Validation involves making sure the model is an accurate representation of the real system and as a result, fulfils the objectives and aims of the project. The first step of validating the model involved watching the model for a length of time and noting down how the system behaved. It was then compared to how the real world junction behaved at the time when field observations were made. Initially there were some issues with how the cars were behaving as there was excessive queuing at the East and West roads of the model. However after performing a verification relating to the coding of the model, the issue was solved. The next method of validation was demonstrating the model. The simulation was run and shown to a handful of people that were familiar with the traffic junction. Feedback relating to the models behaviour and the results that were output were positive.

5. EXPERIMENTATION, RESULTS & ANALYSIS

The successful completion of the verification and validation stages of the model will allow results to be acquired after running the simulation. By analysing these results, the overall behaviour of the traffic junction can be assessed and the areas that need to be optimised can be addressed. Using a variety of methods, the queue times and quantities will be reduced by manipulating the way the traffic lights behave.

5.1 Results

The model has been run for a specified time period which is the P.M. peak traffic time. This is from 16:00 to 18:00 hours. Using the initial conditions of the model, the results output from the simulation run have been used as a starting point. Improvements related to the reduction of waiting times and queue sizes have been compared with these values.

The timings used, and the results for each queue is shown in tables 6..9. The amber timings are not shown and have not been altered as they are set to run at a fixed time across all traffic junctions. From the red phase switching to green, the amber stage has duration of 2 seconds. The phase moving from green to red; amber has a duration of 3 seconds.

The results have focused on the average queue time, the maximum queue time and the maximum queue size. This has been done for all of the traffic directions over the simulation running period.

Table 6. Timings for the green phase

Model	Green Timing (seconds)	
	North/South	East/West
Model 1	15	16
Model 2	15	25
Model 3	8	25 or 40

Table 7. Average queue times (minutes)

Queue	Model 1	Model 2	Model 3
Q-North	0.35	0.31	0.30
Q-South	0.53	0.30	0.29
Q-East	0.35	0.28	0.15
Q-West	0.59	0.37	0.23

Table 8. Max queue times (minutes)

Queue	Model 1	Model 2	Model 3
Q-North	1.09	1.82	2.15
Q-South	1.09	0.93	1.00
Q-East	1.01	0.78	0.53
Q-West	3.10	1.89	1.64

Table 9. Max queue size (vehicles)

Queue	Model 1	Model 2	Model 3
Q-North	12	11	9
Q-South	16	9	13
Q-East	14	13	11
Q-West	44	28	27

The results obtained for model 1, has shown that the most problematic queue is the Q-West queue in terms of both waiting time and queue size, this is related to volume of traffic travelling in that direction. Another potential problem area is the Q-South queue which is representative of the second highest quantity of vehicle arrivals.

Results for the other traffic directions in model 1 are relatively acceptable and are similar to what is to be expected for the peak traffic time. Experimentation has been conducted in order to explore improvements to these results with the aim of reducing the average wait times, in addition to the quantity of vehicles queuing.

5.2 Experimentation

Model 1 has undergone some experimentation, in order to improve the queue waiting times and queue size.

There are not many variables that can be manipulated to control how traffic will behave when passing through a junction. Control over how many vehicles arrives at a junction, and the frequency that they arrive cannot be altered primarily to maintain consistency of the model. The single most critical parameter that has an effect on the way that traffic behaves, and is practical to change is the duration of the green light signal. Two variations were devised these are displayed in table 6 and are denoted as models 2 and 3. In model 2, the East-West green duration has been increased from 16 seconds to 25 seconds.

Model 2 produced much better results than model 1 as displayed in tables 7,8 and 9. The average waiting time for each of the queues has been reduced with the largest reduction in the south and west queues. The maximum queue time has also been reduced for three of the four queues. Whilst the Q-North queue experienced a slight increase from the initial timings, the maximum queue time for Q-West queue has been reduced to 1.89 minutes from 3.1 minutes, a 39% reduction. In addition to this, the maximum queue size has also been reduced by 36% to 28 vehicles. Overall, model 2 has shown an improvement for the East-West direction which was the main concern of the "as is" model.

The second method of experimentation involved creating a system that allowed the signal timings to adapt to a predefined condition. It was found during experimentation that the largest buildup of queues was experienced in the East-West direction during the period of 17:45-18:00 hours. To resolve this timing of the green phase for the lights would be increased by 60 per cent. This method of adaptive signal timings has been set up by creating a variable. The variable has been called 'Factor EW'. By setting the duration of a stage in the sequencer to be multiplied by the value of this factor, the duration can either be increased or decreased, without interrupting the cycle of the sequencers staging. The increase or decrease of the timings has been set up to only come into effect when a specific simulation time in the model occurs.

In model 3, between 17:40 and 18:05 hours the green signal duration for the East-West direction has been increased by 60% and will have a new duration of 40 seconds. After this time it will revert back to its original value. By using this adaptive system there is greater flexibility when trying to manage the traffic signals.

This adaptive strategy implemented in model 3, displayed in tables 7,8,and 9 has produced the best overall results. The average queue waiting time for every junction has been decreased and as a result, the overall average for the entire junction has also been reduced. The overall average for the junction is now 0.2 minutes, which is the lowest result obtained. Although the maximum queue time for the Q-North queue has increased slightly, the maximum time for the east and west directions have been reduced; with the south direction not showing much of a change. Additionally three of the four directions have shown a further reduction in the maximum queue size recorded.

6. DISCUSSION AND CONCLUSION

After selecting a traffic junction where congestion is known to exist, and building a model in Witness, improvements have been made to the overall system. By adjusting the traffic lights timings and creating an adaptive system by which the green phase is increased for the east-west traffic lights, between the times of 17:40 and 18:05, has led to significant improvements.

The model was constructed and coded in a way that allowed the real life system to be mirrored in the Witness simulation. The real world data from GMUTCU was fed into the simulation in order to produce accurate and realistic results. The time period that was being modelled was between the times of 16:00 and 18:00 hours to reflect peak time traffic.

During the later stages of the models construction some problems were encountered. By performing a further verification on the model these issues were resolved. When the final model was verified and validated, the results from the simulation were used as a base to make improvements on. The initial results showed that the biggest queue, and longest wait time, occurred on Q-West queue. This was expected as this road has the largest traffic flow through it. As a result, this queue had priority when it came to making improvements.

The first method of improvement involved simply altering the timings of the traffic signals. When this was done the results related to the average queue size, maximum wait time and largest queue size were all improved. The specific time period was then identified when the largest queue and wait times were recorded, and a variable was created to lengthen the green signal timing for this time period. By increasing the green signal timing for the east-west traffic lights by 60% for this time period, it improved the results further.

The study has been successful overall, aims and objectives set out at the start have been achieved. The results obtained are realistic and are in line to what one would expect when compared with the real system. However, there are still areas that can be improved. The strategy that produced the best results was achieved when using a combination of altering the signal timings, and setting up a system by which the green times were increased during 17:40 and 18:05 hours.

The model that was built to represent the junction functioned well and produced realistic results. However, there is some additional work that could be done to further improve the problem.

Different strategies could be used to manage how the traffic behaves and how the duration of the timings changes throughout the simulation period. Examples of this could be, allowing the lights to change for other variables such as the quantity of vehicles in a certain queue, rather than just the time of day. Further experimentation with other phases of the signal timings could also be explored. The current model has not taken into account pedestrians' crossing over the roads, so this could be factored in and modelled in future work.

7. ACKNOWLEDGMENTS

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