Crossroad Traffic Simulation – Project CA

Modelling Simulation and Optimisation (H9MSO)

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Abstract—**The following document serves the purpose of outlining a simulation study which looks at crossroad junction traffic in two states. The following simulation are conducted using Python's Simpy module. The study considers multiple variables such as speed, traffic volume and inter-arrival time.**

Keywords—Simpy, Inter-Arrival Time (IAT), optimal traffic flow, MATSim, VISSIM, traffic modelling, simulation.

I. Introduction

The aim of this simulation study is to evaluate multiple traffic models for a rural crossing junction involving a main and local road. The motivation behind this work is to gain an understanding to how the traffic on rural crossing from the local road behaves under the various constraint of the main road. The behaviour is studied under two conditions:

1. Baseline model where the rural crossing operates with no traffic lights controlling the flow of traffic.
2. Traffic light model where the rural crossing operates under traffic lights controlling the flow of traffic.

Throughout this research the study aims to answer the following:

1. What is the maximum traffic flow on the main road which still allows for the required traffic flow on the local road?
2. What is the average wait time for the cars on the local road?
3. What is the optimal green, yellow, and red sequence to facilitate the maximum traffic flow on the main road?
4. What is the average wait time for all when controlled by traffic lights?

A few additional questions will be considered and reported on.

II. Literature Review

With the rise in urbanization and increase in vehicle ownership, it is to no surprise that traffic congestion has become a popular concern. The use of simulation is widely used to address various traffic congestions issues, from the prediction of travel times to the evaluation of new intersections.

The proposed research takes its inspiration for the modelling of the simulation following the evaluation of the following studies:

- "Modeling Crossroads in MATSim: the Case of Traffic-Signaled Intersections" [1]
- "Design and evaluation of a new intersection model to minimize congestions using VISSIM software" [2]

With the numerous simulation software available, the proposed research looks to apply some of the tested methods through the aid of the programming language Python and its simulation package Simpy.

III. Methodology

The proposed research has been developed using the provided code from the Modeling, Simulation and Optimisation lecture delivered by Prof. Christian Horn [3][4]. The provided code material allowed for the base modeling of the simulations and was enhanced with the appropriate parameters needed to derive the best results for the given state.

Table 1 outlines all the proposed simulations undertaken to evaluate and derive the results.

TABLE I. Simulation Outline

Case	Simulation Outline				
	Type	**Run-Time(s)**	***Inter-Arrival Time(s)***	***Speed***	***Traffic Sequence***
1	Rush Period – Main & Local	900	North: 18 South: 12 West/East: 18	Main: 65km/h Local: 50km/h	N/A
2	Reverse Rush Period – Main	3600	North: 12 South: 18 West/East: 360	Main: 65km/h Local: 50km/h	N/A
3	Daytime Driving	3600	North/South: 36 West/East: 360	Main: 65km/h Local: 50km/h	N/A
4	Traffic Light – Setting 1	900	North/East: 18 South/West: 12	Main: 100km/h Local: 80km/h	MG:25 | LG:20 MY:5 | LY:5 MR:25 | LR:30
5	Traffic Light – Setting 2	600	North: 16 South: 24 East: 21 West: 12	Main: 100km/h Local: 80km/h	G: 15 Y: 5 R: 20
6	Traffic Light – Setting 3	600	North: 10 South: 16 East: 48 West: 21	Main: 100km/h Local: 80km/h	MG:30 | LG:25 MY:5 | LY:5 MR:30 | LR:35

Table 1: Simulation Outline

IV. The Simulation Model

The proposed simulation models utilises the Python simulation library Simpy to simulate traffic flow of a rural crossing between a main and local road. As outlined earlier, the simulation models evaluate the rural crossing based on two states. The overall code base uses object-oriented programming alongside computational mathematics to facilitate a multi-agent simulation. This allows for vehicles to be simulated following an exponential distribution. Different mechanics such as velocity, road network and inter-arrival time play a role in the evaluation of the simulation results.

These results are captured and stored using a programmed recorder.

A. Model of the Street Crossing

A simple crossroad infrastructure is used within the study. For both states of the crossroad junction the roads consist of two lanes flowing in either direction of North, South, West, and East. The key differential point between the two states within the study is the traffic light control, which when not invoked yields priority to the main road. Following the traffic light testing all roads share equal crossing which is control by the said traffic lights.

All vehicles begin travel from the same point in the respective direction, being the edge of the road network map. The proposed road network proposes a stretch of 1km in all directions. The 'Intersection' class object represents the center point of the rural crossing followed by the 'Road Segment' class object which proposes a measurable road segment to facilitate the gathering of data. Ultimately the proposed study is interested in gathering the travel time and throughput experienced on the road of interest.

For simplicity reasons the code base follows the same structure regarding the class objects between the two states with the class object 'Traffic Light' being the additional code to allow for the two different states.

The mechanics behind the capture of the data at interest follows a queueing system for the local road and later for both the main and local road.

B. Model Vehicle and Driver Behaviour

The vehicle and driver behaviour model follows a very simple structure. All generated vehicles follow the same parameters for emergency braking, coasting, and acceleration as well as all vehicles are of the same length and width. For differentiation purposes the math behind the calculation of the braking rate is further enhanced on to allow for the consideration of different speeds followed on both the main and local road when approaching an intersection controlled by traffic lights.

Various computational mechanics such as positional tracking and stopping/crossing of/at the intersection are encoded to ensure the simulation operate as realistically as possible.

Behavioural driving factors such as distance evaluation between two vehicles and the evaluation of plausible crossing is considered in the simulations to ensure vehicle collision is avoided.

C. Traffic Generation

Traffic generation follows an exponential distribution following a Poisson point process. Essentially all traffic flow events from either possible direction has been set to a constant average rate of occurrence. This is determined using the Inter-Arrival-Time which has been split into each direction being North, South, West and East and is further calibrated using the set speed and running-time of the simulation itself.

D. Data Collection

The class object 'Recorder' from the code material provides multiple tools to gather and store important statistics from the. To address the outlined research questions the 'Recorder' gathers statistics on parameters such as traffic volume, density, speed, travel time, wait time and queue lengths.

To ensure that the information is distinguished between the rural crossing the 'Recorder' is split based on the road type and direction flow. At the end of each outlined simulation plots are produced to report in a visual aspect. Further work to aggregate the findings from the outlined simulation models is conducted outside the provided code material.

V. RESULTS AND INTERPRETATION

The proposed research evaluates the simulation models based on two conditional states, the results are derived and reported on per a given simulation. Ultimately the end goal of each simulation is to determine maximum traffic flow on the main road which facilitates the required flow for the local road for the baseline models, alongside the identification of the optimal sequence of the traffic lights which allows for maximum flow on main road whilst facilitating maximum flow on the local road.

A. Baseline Simulation - Case 1:

As outlined by Table 1, the baseline simulation has been tested based on three different configurations. The aim of Case 1 was to understand the impact of the main road on the local road under the conditions of experiencing a rush period mutually. A total of 15 minutes was allowed for simulation 1 as the local road only experiences a 15-minute rush period in the morning between 8:45am an 9am.

As expected, the average wait time for vehicles travelling on the local road is quite high, with the West-bound traffic experiencing on average a wait time of 3 minutes and East-bound totaling at around 2 minutes as per Table 2, in addition to this the local road accumulates a maximum of 70 vehicles cumulatively.

This can be assumed is a direct consequence due to the high volume of traffic coming through from the main road. Based on the inputted IAT's of N:18, S:12 and W/E:18 as per Table 1 - Case 1, the simulation accounted for additional vehicles being generated on the main road which unfortunately causes the local road to underperform in respects to the expected flow for the local road as shown by Fig.1.

```
N-bound Flow:  230.1veh/h  expected flow:  200.0veh/h
S-bound Flow:  346.3veh/h  expected flow:  300.0veh/h
E-bound Flow:  166.4veh/h  expected flow:  200.0veh/h
W-bound Flow:  152.3veh/h  expected flow:  200.0veh/h
```

Fig. 1. Rush Period – Main & Local: Actuals vs Expected

Alternatively, to determine the maximum flow for the main road which would facilitate the required flow on the local road, the Inter-Arrival-Time for the main road for both North and South directions is significantly increased thus, ultimately reducing the traffic volume of the main road. It was determined that the optimal IAT's of N:72 and S:72 (roughly 50veh/h) facilitate the required flow on the local road with East-bound traffic not quite reaching the required flow of 200veh/h either direction as shown by Fig.2. However, the study notes that such volumes may not be possible in the real world and the implementation of traffic light control may elevate some of the discovered pain point.

```
N-bound Flow:   69.8veh/h  expected flow:   50.0veh/h
S-bound Flow:   74.0veh/h  expected flow:   50.0veh/h
E-bound Flow:  173.5veh/h  expected flow:  200.0veh/h
W-bound Flow:  202.7veh/h  expected flow:  200.0veh/h
```

Fig. 2. Optimal Main Road Flow: Actuals vs Expected

With the main road flow significantly reduced the average wait time for the local road reduces to roughly 2 minutes for West-bound traffic, with similar results for East-bound traffic as per Table 2. This is followed with a reduction in the maximum queue length on the local road. Lastly, with the reduction we can witness a greater coverage of distance for vehicles travelling on the local road as illustrated by Fig.3. and Fig.4.

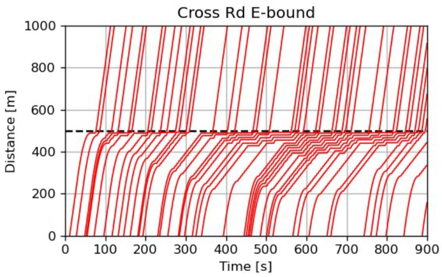

Fig. 3. Distance/Time: Rush Period – Main and Local Road

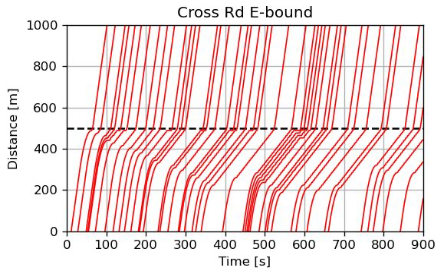

Fig. 4. Distance/Time: Local Flow accommodated.

B. *Baseline Simulation – Case 2:*

Case 2 observed the behavior of the main road on the local road when the main road continues to experience a rush period in a reversed manner. Surprisingly, the high traffic flow doesn't impact the local road excessively. Looking at the actual vs expected figures of the simulation which operated for a total of an hour, illustrated by Fig.5. the original traffic flow of the main road still allows for the required flow of the local road.

```
N-bound Flow:  286.5veh/h expected flow:  300.0veh/h
S-bound Flow:  213.5veh/h  expected flow:  200.0veh/h
E-bound Flow:   12.4veh/h  expected flow:   10.0veh/h
W-bound Flow:    9.5veh/h  expected flow:   10.0veh/h
```

Fig. 5. Rush Period – Main Road: Actuals vs Expected.

On average vehicles travelling the local road experienced a wait time of a minute for West-bound and roughly a minute and a half for East-bound traffic as per Table 2. Fig.6. illustrates the average wait distributed across the local road. In comparison to case 1, the maximum queue length experienced on the local road reduces significantly, dropping to a total of 3 vehicles cumulatively.

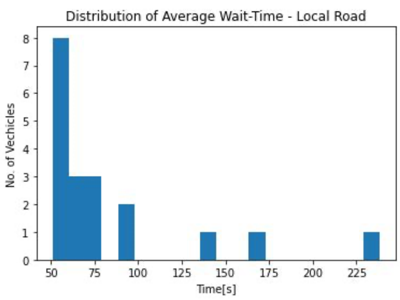

Fig. 6. Distribution of Average Wait Time for the Local Road.

It stands to reasons that the main road has little impact on the local road outside the 15-minute rush period experienced by the local road. It can be assumed that the implementation of traffic light control outside the rush period may cause an increase in the wait time. This is further discussed on in the results of the Traffic Light Settings 1 simulation.

C. *Baseline Simulation – Case 3:*

Case 3 on the other hand observes a much quieter period between the main and local road. A few noteworthy, though not surprising results to report on. As expected, the simulation performed well, accounting for the expected volumes.

The main road had minimal impact on the local road with the simulation generation an additional 2 vehicles for the local road from the East-bound direction. Reviewing the wait time, both West-bound and East-bound traffic experienced an average wait time of just shy a minute as per Table 2, being the lowest wait time, the local road has experienced compared to Case 1 and Case 2.

Overall, the local road appears to perform well against the main road volumes with Fig.7. outlining the distribution of average wait time. Thus, the study further suggest that the implementation of traffic light control may increase the overall average wait times.

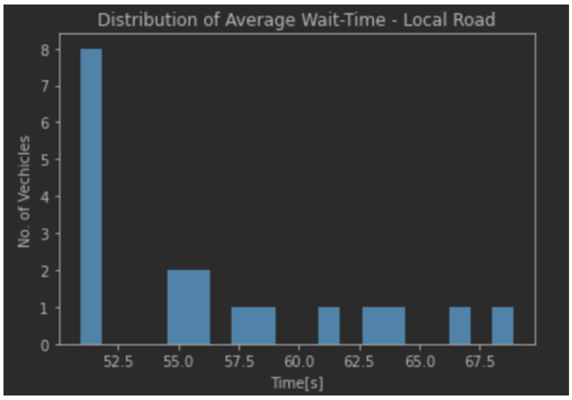

Fig. 7. Distribution of Average Wait Time: Daytime Driving.

D. *Traffic Light - Setting 1:*

With the introduction of traffic light control due to the newly developed residential estate, the research looked to evaluate the same conditions as undertaken in Case 1. It was noted in Case 2 and Case 3 that the introduction of said control may increase pain points in the form of large queues and wait time.

A total of 15 minutes run-time was allowed for setting 1, with a sequence of [G:25, Y:5, R:25] for the main road and [G:20, Y:5, R:30] for the local road. As expected, possibly due to the road network constraints of a 1km stretch a few issues were encountered.

The study notes that if said constraints were to be expanded on the simulation may not have encountered such restraints however, the capability of one's machine to undergo testing may not be favorable to facilitate said expansions. Thus, the research understands that the results may not be overly accurate, and this is something that has the potential of further analysis using more appropriate software's.

We can witness a few of the issues encountered by setting 1, such as extensive congestion forming due to emergency braking (illustrated by red circles) both for the main and local road as illustrated by Fig.8. and Fig.9.

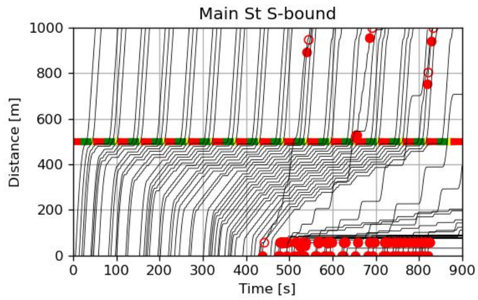

Fig. 8. Distance over Time: North bound

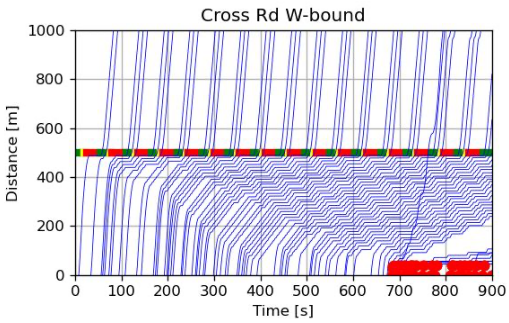

Fig. 9. Distance over Time: West bound

We can see that around the 400 second mark both roads start to experience a buildup of vehicles, covering a short distance as the simulation progresses and introduces new vehicles. These poor results are further supported by the excessive wait times with vehicles waiting up to 6 and a half minutes on the main road and 7 minutes on the local road as per Table 2.

In comparison to Case 1 from the Baseline simulation the local road wait time increases by 4 minutes, with the queue lengths decreasing to 38 vehicles cumulatively. This is an interesting observation, as the following simulation undertook the same conditions as from Case 1 with two differences implement, being a speed limit increase for both and traffic light control.

The research considers that the decrease in queue lengths could be directly because of the speed limit for both roads as shown in Table 1. Further to expand on the findings from setting 1, the simulation underperformed in respects to the expected and actual results of vehicles generated, with the simulation only accounting for roughly two thirds of the expected 300veh/h for traffic being South and East bound.

E. Traffic Lights – Setting 2:

Setting 2 looks at a different configuration of the traffic light sequence as well as a reduction in flow for the crossroad to manage. To no surprise with the reduction setting 2 performs more favorably in comparison to setting 1. The sequence is set as [G:15, Y:5, R:20] for the main road and [G:15, Y:5, R:20] for the local road. Though, these results may be biased as the overall simulation run-time is reduced to optimise machine performance.

Fig.10. illustrates that congestion still occurs for the local road for West-bound traffic, though this is to no surprise as the parameters account to produce 300veh/h.

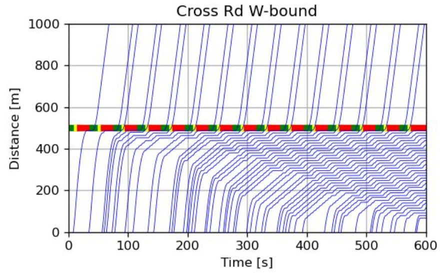

Fig. 10. Distance over Time: West-bound

In comparison to setting 1, setting 2 performs more optimally with the proposed traffic light sequence. We can support this statement by witnessing a reduction in wait time from 6 and a half minutes to 2 and a half for the main road and 7 minutes to roughly 5 for the local road. Considerably, this is a significant reduction in maximum cumulative time for both roads.

F. Traffic Light – Setting3:

Setting 3 like the prior setting proposes a different configuration of traffic light sequence as well as a reduction of flow for some directions for the crossroad to manage. A sequence of [G:30, Y:5, R:30] for the main road and [G:25, Y:5, R:35] for the local road is introduced and performs more or so the same as setting 2. In comparison to setting 2 the congestion buildup occurs on the main road with North-bound traffic, this is of no surprise as the research deliberately increases and decreases the traffic volumes to test the behaviour of the crossroad. Increase in traffic is inevitable with the introduction of residential estates with Fig.11. illustrating the congestion buildup. This result is more realistic as the new residential estates are being developed North side of the crossroad.

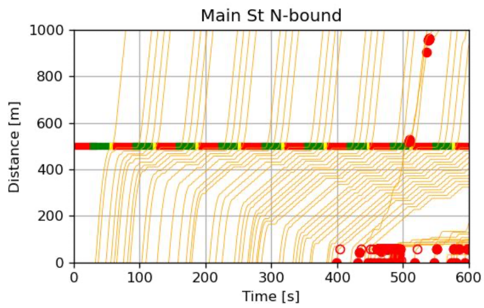

Fig. 11. Distance over Time: North-bound

Overall setting 3 is quite like setting 2 with the key difference being a flip in the congestion buildup between the two. The average and maximum wait time for both roads remain relatively close to that of setting 1 as per Table 2.

G. Conclusion:

In conclusion, the reported results for all simulations can be subjective as shown by Table 2. Multiple simulations can be drafted, each testing and running various parameters and yielding different results for interpretation. Staying within the confines of the proposed research, the study suggests that with the introduction of a traffic light control to the rural crossing, the best optimal choice for the sequence of the lights would be setting 3. This is supported by the outlined simulation results as per Table 2.

However, the study refers to the points highlighted in both Case 1 and Case 2 of the Baseline model. The implementation of traffic light control for the rural crossing poses a large increase for all aspects as outlined by Table 2 should this control be implemented.

TABLE II. SIMULATION RESULTS

Case	Simulation Results									
	Average Wait Time (s)		*Max Wait Time*		*Average Travel Time*		*Average Speed*		**Max Queue Length**	
	Main	*Local*	*Main*	*Local*	*Main*	*Local*	*Main*	*Local*	*Main*	*Local*
1	N/A	378.28	N/A	N/A	60.0	163.4	60.0	22.03	N/A	60
2	N/A	164.47	N/A	N/A	59.81	122.73	60.19	29.33	N/A	3
3	N/A	112.45	N/A	N/A	59.96	96.5	60.04	37.31	N/A	3
4	159.02	162.83	397.58	427.49	180.05	183.45	19.99	19.62	38	39
5	79.55	114.7	158.34	297.63	97.26	139.7	37.01	25.77	20	35
6	120.37	68.82	246.25	152.22	134.05	89.3	26.86	40.31	38	16

Table 2: Simulation Results

VI. REFLECTIONS AND FUTURE WORK

This proposed study has simulated various models in the context of understanding how the local road behaves following the influence of the main roads. Various traffic volume combinations were modelled as a Poisson distribution and performance metrics gathered

The rural crossing at the Baseline model performed strongly in comparison to the Traffic Light Model. The introduction of traffic light control imposed longer wait times and additional queue formations with the main road becoming of equal importance with the local road.

The throughput of this research was significant and holds high potentials for further study. The use of traffic simulation software such as PTV VISSIM can yield interesting and greater results if applied to the outlined models or if explored with new parameters. In addition to this, the outlined study would further be interested in exploring an alternative control to traffic light, a roundabout as part of future work.

VII. REFERENCES

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