Traffic Simulation for a Road Intersection Crossing across a National Road

Modelling, Simulation and Optimisation
M.Sc. Data Analytics

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***Abstract*—Real estate planning and construction takes a lot of considerations of not only present scenarios but also future possible scenarios that may arise due to the ongoing current developments. Road traffic is one such feature that can change due to developments in nearby areas owing to the increased area population and commuters travel intensity at specific times of the day depending upon the local estate and road infrastructure. Constructing without proper study may lead to heavy losses due to future problems, one of which is huge traffic congestion that may lead to public disorder and finally rework. Road traffic simulation is one of the most useful applications under the umbrella study of simulation and optimization that provides a direct practical influence of statistics and probability in the real-world scenarios, and helps with determining the relevant parameters for the proposed scenarios. This project aims at simulating the road traffic across an intersection between a national road and a village crossing, and evaluate various scenarios along with the proposed developments by the roads, and its effects on the Queue Length, Waiting Time and Travel Time.**

Keywords—Queue Length, Waiting Time, Travel Time, Baseline Simulation, Phase 1 Simulation, Phase 2 Simulation

I. Introduction

Road traffic simulation study includes simulating for various scenarios by evaluating the effects of change in parameters such as driver behaviour, traffic flow, road traffic priority, availability of traffic signals, speed limits, rush hour timings and inter-arrival times, on the selected variables i.e., waiting time, queue length and travel time [5] in order to gauge the possible effects of simulation scenarios when compared with the Baseline.

As a part of this project, we have been designated to provide an extensive traffic simulation study and investigation for an urban area traffic crossing (without traffic lights) on a commuter belt of a national highway.

A two-lane national road going in the North-South direction is intersected by a two-lane crossing road that goes in the West-East direction. The Crossing Road connects a village on the west with a school on the east side 1 km apart, and intersects the main National Road at 700 m (metres) from the village. The school-bound commuters (50 cars) have to travel across the intersection in the mornings on time so as to not miss the 9:00 am school time. Over the years, the South-bound traffic flow in the morning, on the national road has increased from 200veh/h to 300 veh/h (vehicles per hour), however, the North-bound traffic remains static at 120 veh/h. This didn't affect much the average travel time of under 2 minutes but the maximum travel time increased from 3 to 4 minutes for school-bound commuters.

Furthermore, it is suggested that in the future, the completion of Phase 1 and Phase 2 of the estate planned in the north of the village will boost the morning rush hour traffic on the national road to 400 veh/h and 600 veh/h respectively, which makes the school-bound commuters unsure of the estimated morning traffic congestion. Therefore, this project studies the proposed simulations and investigates the various scenarios to identify if there is any significant change in the queue lengths, waiting times and travel times for the school-bound commuters.

The project utilizes Python3 as programming language and Jupyter Notebook as the code editor. Python libraries such as Pandas, Matplotlib, Math, Numpy, Random, PIL and Simpy are utilized for data manipulation, plotting, animations and simulation, whereas, Scipy library for statistical tests and evaluation.

The project report delves into various sections of the study scenarios in the following sequence:

Section 2: Literature Study

Section 3: Methodology

Section 4: Results and Conclusions

Section 5: Future Work

II. Literature Review

Study of the existing literature on the topic of road traffic simulation yielded the review of the past studies conducted on the specific use case and its impacts on various scenarios.

The authors in [1] proposed a computationally feasible and realistic simulation by employing a 2-stage multi-objective calibration technique for microscopic traffic simulation study by performing a sensitivity analysis of the high contribution parameters and then utilizing a multi-objective genetic algorithm optimization to produce optimal solutions from the influential parameters. Microscopic traffic parameters including driver behaviour models such as EIDM and MOBIL were also evaluated to capture real driver attention and aggression.

The study [2] provides an extensive traffic simulation and optimization analysis of traffic congestion in an eco-neighbourhood in Nancy, France for reconfiguration aimed at reducing peak hour congestions by utilizing a 3D mesoscopic simulation model and evolutionary algorithms for multi-objective optimization for better traffic management to support engineering decision-making and sustainable development.

In this paper [3], the authors presented a realistic traffic simulation model for driving in smog conditions by using a Smog Full Velocity Difference Model and modelled various parameters including psychological forces and body forces on driver behaviour to design a visual verification system that provides optimal solutions even in rougher weather conditions.

This paper [4] explores the latest developments in the fields of intermodal traffic simulations and simulator coupling on an open-source traffic simulator called SUMO. The authors not only evaluated and validated the latest framework but also suggested required enhancements and extensions for the SUMO in order to simulate closer to real-world scenarios for research.

III. METHODOLOGY

The methodology utilized in this study is given by the following steps:

- First, the use case is modelled according to the problem statement by creating roadmaps, intersection and the simulation is visualized using plots and animations.
- Various simulation scenarios are discussed and selected as per the research question and model assumptions finalized.
- Finally, different simulations are evaluated with respect to the Baseline simulation and hypothesis testing is conducted to determine whether there is a statistically significant difference in chosen parameters (QL- Queue Length, WT- Wait Time, TT- Travel Time).

Each of the above steps are implemented and described below in detail.

A. *Modelling Road Network, Crossing and Simulation Assumptions*

Various use-case specific features are mapped and displayed with the help of clearly defined classes and for each class specific behaviour is defined by their methods. Some of the necessary classes and methods encoded are mentioned below:

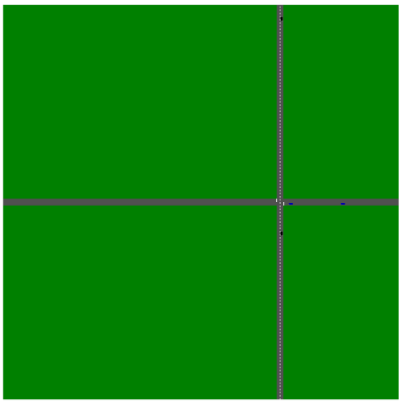

Figure 1: Road Map

- **Class Intersection:** This class consists of attributes to capture road network, directions, queues and spots and has methods to access queue lengths, release, request spots, and stop. It describes the behaviour of vehicles at the crossing while they move across the intersection to the other road segment.
- **Class RoadNetwork:** It contains pre-defined road and map dimensions, different simulations are evaluated with respect to the Baseline simulation and hypothesis testing is conducted to determine whether there is a statistically significant difference in chosen parameters (QL- Queue Length, WT- Wait Time, TT- Travel Time).

Table 1: Road Features

Road Attributes	Value
Lane Width	8m
Keep Clear Line	40m
Time Tolerance	5s

- **Class Vehicle:** It describes the vehicle and driver behaviour considered for the study. It includes colour, acceleration, deceleration, maximum speed, vehicle length, and methods to update actions such as accelerate, wait, exit, cross and stop etc.

Table 2: Vehicle Attributes

Vehicle Attributes	Value
Emergency brake deceleration	$-4m/s^2$
Engine braking	$-0.6m/s^2$
Maximum acceleration	$2.5m/s^2$
Vehicle Width	4m
Vehicle length	10m

- **Class Recorder:** This class records and saves all the necessary parameters and features used in the simulation study, right from the start time, queue data, vehicle data to the generated exponentially distributed inter-arrival times and seed values, for each simulation and makes it available for evaluation
- **Method CrossingThroughRoad:** This method is responsible for compiling all the sub-classes and methods, and simulate the specific scenario with fixed simulation time, maximum speeds, inter-arrival times and specified seed value. This method records the results into a csv file with the help of the Recorder class.
- **Method simulations:** This method is responsible for running multiple iterations of the CrossingThroughRoad method for different seed values in order to evaluate the maximum range of possible simulation runs for a fixed scenario.

B. *Simulation Models (Scenarios)*

According to the problem statement we can identify the Baseline scenario and the proposed simulations for this study which are mentioned below:

- **Pre-Baseline (S0)**: This scenario defines the past south-bound traffic flow of 200 veh/h on the national road and is used for validating simulation with the Baseline (S-flow 300veh/h) model to check if the average travel time is still under 2 mins and the maximum travel time under 4 minutes. Following Parameters were chosen for this scenario:

  N-flow = 120veh/h, S-flow = **200veh/h** with corresponding IATNorth = 30s, IATSouth = 18s;

Cross-flow = 50veh/h, IATCross = 72s; VMaxmain = 100kmph, VMAXcross = 50kmph.

- **Baseline (S1)**: This is the baseline simulation scenario against which the rest of the scenarios will be studied. Following parameters were fixed:

  N-flow = 120veh/h, S-flow = **300veh/h** with corresponding IATNorth = 30s, IATSouth = 18s;

  Cross-flow = 50veh/h, IATCross = 72s; VMaxmain = **100kmph**, VMAXcross = 50kmph.

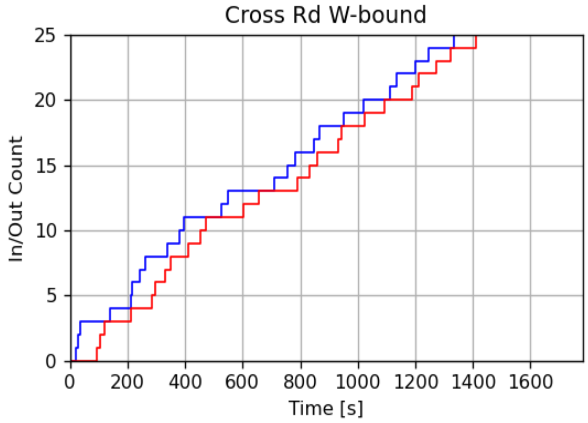

Figure 2: Baseline S1 In/Out plot

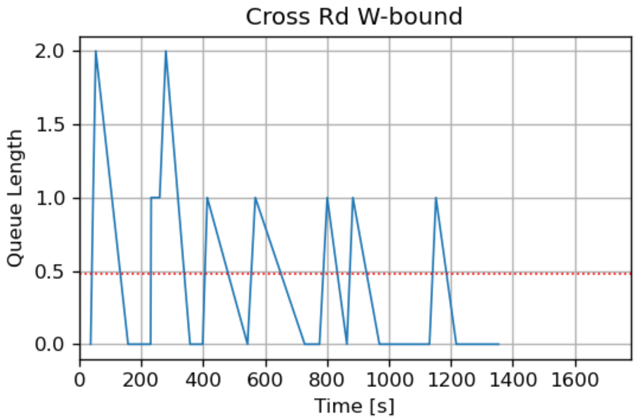

Figure 3: Baseline S1 Queue Length

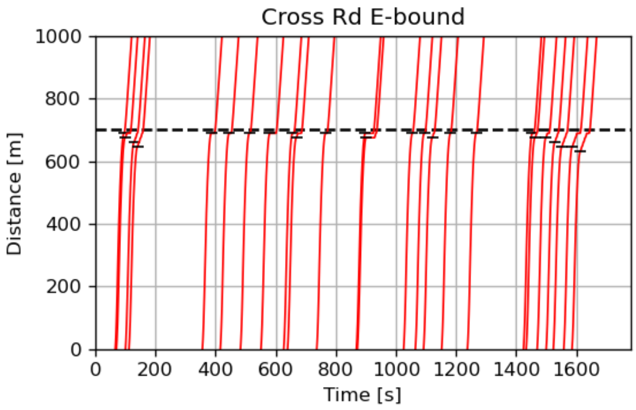

Figure 4: S1 Distance Time plot

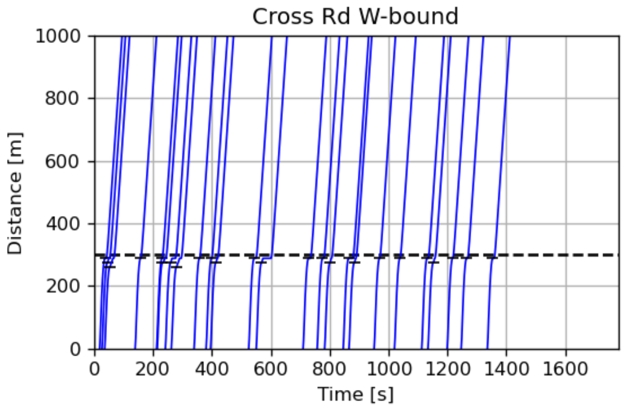

Figure 5: S1 Distance time plot West bound

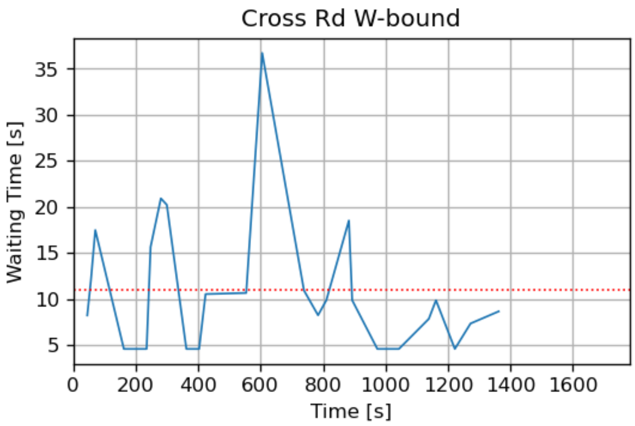

Figure 6: S1 Waiting Time West bound

- **Phase 1 (S2)**: Baseline (S1) parameters along with **S-flow 400 veh/h, VMAXmain = 100kmph**.
- **Phase 2 (S3)**: Baseline (S1) parameters along with **S-flow 600 veh/h, VMAXmain = 100kmph**.
- **Baseline (S4)**: This is the baseline simulation scenario against which the rest of the scenarios will be studied. Following parameters were fixed:

  N-flow = 120veh/h, S-flow = **300veh/h** with corresponding IATNorth = 30s, IATSouth = 18s;

  Cross-flow = 50veh/h, IATCross = 72s; VMaxmain = **60kmph**, VMAXcross = 50kmph.
- **Phase 1 (S5)**: Baseline (S4) parameters along with **S-flow 400 veh/h, VMAXmain = 60kmph**.
- **Phase 2 (S6)**: Baseline (S4) parameters along with **S-flow 600 veh/h, VMAXmain = 60kmph**.
- **Baseline (S7)**: This is the baseline simulation scenario against which the rest of the scenarios will be studied. Following parameters were fixed:

  N-flow = 120veh/h, S-flow = **300veh/h** with corresponding IATNorth = 30s, IATSouth = 18s;

  Cross-flow = 50veh/h, IATCross = 72s; VMaxmain = **80kmph**, VMAXcross = 50kmph.
- **Phase 1 (S8)**: Baseline (S1) parameters along with **S-flow 400 veh/h, VMAXmain = 80kmph**.

- **Phase 2 (S9)**: Baseline (S1) parameters along with **S-flow 600 veh/h, VMAXmain = 80kmph**.

Each of the proposed 9 (S1- S9) simulation models were evaluated for 12 different seed values, against their respective baselines by performing hypothesis testing in the next module and checking the corresponding QL, WT and TT samples.

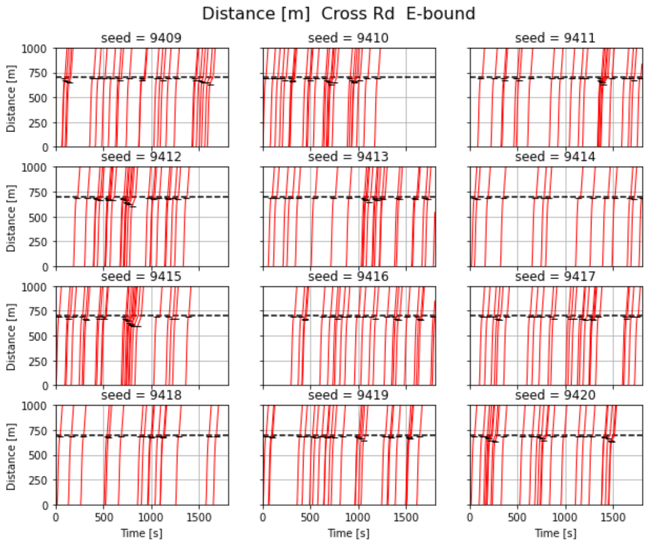

Figure 7: S1 Baseline Simulation for 12 different seed values

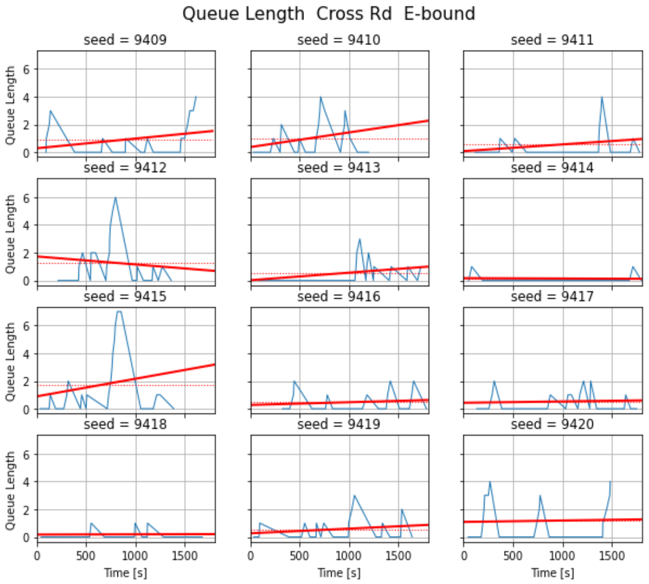

Figure 8 Queue Length for S1 for 12 different seed values

C. Simulation Model Evaluations

In this stage, after performing the model simulations and recording the respective results, we performed One-tailed hypothesis testing (Z-test) and formulated following evaluations:

1. Evaluation A100: For comparing S1 vs. S2
2. Evaluation B100: S1 vs. S3
3. Evaluation A60: S4 vs. S5
4. Evaluation B60: S4 vs. S6
5. Evaluation A80: S7 vs. S8
6. Evaluation B80: S7 vs. S9

The above evaluations were performed separately for each parameter (QL, WT, TT) for the given hypothesis assumptions:

Null Hypothesis, H0: There is no increase in the parameter (Queue Length/ Wait Time/ Travel Time) with increase in S-flow

Alternative Hypothesis, H1: There is a statistically significant increase in parameter with increase in S-flow

The following evaluation results were obtained after hypothesis testing:

1. A100 : Accept the H0 (QL,WT, TT)
2. B100: Accept H0 (QL, TT) and Reject H0 (WT)
3. A60 : Accept the H0 (QL,WT, TT)
4. B60: Accept H0 (QL, TT) and Reject H0 (WT)
5. A80 : Accept the H0 (QL,WT, TT)
6. B80 : Accept H0 (QL, TT) and Reject H0 (WT)

This implies that according to the evaluation results from B100, B60 and B80 hypothesis testing, there is a significant increase in wait times for S3, S6 and S9 simulations.

IV. Results and Conclusions

The comprehensive simulation study for the effects of various parameters on the queue length, wait time and travel time, yielded results for multiple scenarios and the samples for each parameter were tested against their respective baselines models to arrive at a conclusion that it is highly possible that the development of Phase 1 and Phase 2 estate may increase the wait times for the school-going commuters. Although no significant change in travel time or queue length may be noticed.

Following sections address the problem statement (Part and Part2) and provide the results:

A. Baseline Simulation (Part 1)

After performing the simulation study for S0 – Pre-Baseline scenario and S1- Baseline scenario, and related hypothesis tests we can say with evidence that the maximum travel time (S0: 92 s for cross road, S1:104s) remains under 4 minutes and average travel time (S0: 73 s for cross road, S1: 74s) remains under 2 minutes.

B. Simulation Study (Part 2)

As a part of the Part 2 study, the simulations were evaluated for different scenarios and following results were obtained:

1. There seems to be a significant increase in Wait Times for the Phase 2 completion scenario. Travel Times and Queue Length do not show such behaviour.
2. Varying the speed limit of the vehicles on national road doesn't affect the above-mentioned behaviour. The Wait Times still increase when the Phase 2 construction is completed.

V. Future Work

The simulations were run with default vehicle parameters and limited number of simulations were considered for this study owing to the huge computational time associated. In the future, exploring multiple realistic vehicle parameters and exhaustive simulations could result in better performance and expansive results covering many use-cases for road traffic simulation.

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