Science, Engineering and Technology Vol. 3, No. 1, pp. 9-21
www.setjournal.com https://doi.org/10.54327/set2023/v3.i1.56

Traffic Signal Controller Optimization Through VISSIM to Minimize Traffic Congestion, CO and NOx Emissions, and Fuel Consumption

Dinakara Gunarathne[1], Niranga Amarasingha[1], Vasantha Wickramasinghe[2]

[1]Sri Lanka Institute of Information Technology, New Kandy Rd, Malabe 10115, Sri Lanka
[2]University of Peradeniya, Galaha Rd, Peradeniya 20400, Sri Lanka

Abstract

In developing countries with heterogeneous traffic, such as Sri Lanka, it is possible to observe severe traffic congestion at intersections and traffic corridors. The main objective of this study was to demonstrate the optimization of traffic signal controllers using VISSIM microsimulation software. It aimed to minimize traffic congestion, emissions, and fuel consumption. This study focused on developing a traffic signal controller optimization program for a congested traffic corridor which consisted of a three-legged signalized intersection, a four-legged unsignalized intersection, and a three-legged unsignalized intersection. The entire corridor was modeled here, and the already signalized three-legged intersection was optimized. Traffic signal controller optimization was done separately through the built-in optimization features in VISSIM and Webster's Method. The results showed that emissions and fuel consumption were reduced by 14.89 % in VISSIM optimization and 14.11% in optimization using Webster's Method. Through the comparison between the VISSIM optimized signal timing and manually calculated signal timing, it was found that the signal timing optimization provides much more improved results than the manual signal timing calculations. Using the proposed methodology, the traffic signal controllers can be optimized within a short duration in very few steps without any iterations compared to the existing traffic signal controller optimization techniques. Therefore, the proposed methodology is a good alternative method to optimize the traffic signal controllers.

Keywords: *signal optimization, VISSIM, traffic congestion, traffic microsimulation*

1. Introduction

Transportation scenarios in developing countries are fundamentally different from those in developed countries. Heterogenous or mixed traffic conditions are mostly observed in developing countries such as Sri Lanka. These traffic conditions consist of various types of motorized and non-motorized vehicles. The homogeneous traffic is composed of passenger cars. The heterogenous is composed of vehicle types with various static and dynamic characteristics that occupy the same right of way [1]. The movement of the vehicle becomes asynchronous. Another distinguishing feature of this traffic is the lack of lane discipline due to the large differences in vehicle size and maneuverability. These differences lead to several phenomena, such as vehicle creeping that do not exist in uniform traffic. It is crucial to comprehend the traffic flow in order to understand what mixed traffic exactly means. The interaction of the various elements of traffic, including land use, road infrastructure, and automobiles, results in traffic flow. A few reasons for the heterogeneous traffic conditions are the lack of lane markings and the lack of lane discipline of the drivers.

In Sri Lanka and many other developing countries, the relevant road development authorities and researchers have been using various microsimulations to model real-world traffic conditions. And had come up with suitable traffic management solutions to reduce traffic congestion before implementing them in the real world. In the past

Corresponding author: Dinakara Gunarathne *(dinakaragunarathne@gmail.com)*
Received: *30 December 2022;* Revised: *6 April 2023;* Accepted: *10 April 2023;* Published: *12 April 2023*

years, there have been several microsimulation software, such as VISSIM, PARAMICS, and AIMSUN, developed to simulate various traffic conditions [2]. Out of those, the most popular and most commonly used software is the VISSIM microsimulation software. VISSIM microsimulation software was used for this study mainly due to the features available within the software (i.e., traffic signal optimization), effectiveness in modeling interactions, and the user-friendly interface compared to the other microsimulation software.

PTV VISSIM is a multi-modal microscopic traffic flow simulation software created by PTV in Karlsruhe, Germany [3]. Traffic engineering, public transport, urban planning, fire safety, and 3D visualization for illustrative and public communication are among the applications. From the point of origin to the point of destination, VISSIM has the capacity to change driver behavior, vehicle behavior, and so on. VISSIM can simulate and interact with several modes of traffic, including cars, buses, and trucks, as well as public transportation, cycles, pedestrians, and rickshaws. Vehicle conflict points could be modeled in VISSIM using priority rules, conflict areas, and signal heads. Signals can be modeled using fixed-time schedules or on-demand signals. Other types of control and synchronization can be modeled using Vehicle Actuated Programming (VAP).

Due to the congestion at a signalized intersection, crashes between the emergency vehicle and other vehicles are common in the world. This is one of the major problems at signalized intersections which occurs mainly due to the driver's behavior and improper signal timing. Another issue that could be observed is the improper allocation of green time which leads to a long delay for the passengers. It will also generate longer queues which eventually cause environmental pollution due to Carbon Oxides (CO) and Nitrogen Oxides (NOx) emissions. Accurate green timing is required at signalized intersections to minimize congestion, delays, and environmental pollution. Therefore, traffic signal controllers must be optimized in order to determine the most suitable timing for the red and green phases.

The optimization of signal timing synchronizes groups of traffic lights so that vehicles traveling on the main road can pass multiple traffic lights without stopping. It can also cut vehicle wait times at individual junctions by altering green light durations to fit demand. Signal timing optimization benefits the general public since it allows them to go through several traffic signals without stopping. When new optimized timings are implemented on previously uncoordinated corridors or key routes, dramatic improvements in congestion can occur. Signal timing optimization cuts down on latency, travel time, and fuel consumption. The benefit-to-cost ratio of traffic signal optimization is frequently high [4]. Because it just requires some engineering and technician work and can be finished in a few months. The cost of designing, implementing, and fine-tuning new signal timings is inexpensive when compared to significant construction projects.

The objective of this study was to suggest a methodology to minimize traffic congestion, CO and NOx emissions, and fuel consumption using VISSIM under heterogeneous traffic conditions in Sri Lanka. Mainly for signalized intersections and corridors with signalized intersections, the traffic congestion, CO, and NOx emissions could be reduced through signal timing optimization. In Sri Lanka, CO emissions in 2021 from transportation were observed to be nine metric tons which have rose by seven metric tons growing at an average annual rate of 3.81% compared to 1972 [5].

2. Literature Review

The usage of restricted lefts/through U-turns at key crossings was investigated by ElAzzony et al. [6]. In Cairo, a simulation model was created for an urban corridor with two intersecting crossings. The PARAMICS program was used to model three scenarios. Scenario 1, current condition with restricted lefts/throughs U-turns. Scenario 2, restricted left U-turns with two-phase traffic control at the intersection. Scenario 3, no limitation of direct movements at the intersection with complete signal control. SIDRA Intersection 4.0 was used to create the best signal control designs. For scenario 2, the signal control plan for both intersections were created in two phases. Scenario 3 looks at a four-phase traffic signal situation. To compare different intersection improvements, the peak hour demand of automobiles was used as a measure of effectiveness. The 4-phase signal control was the most superior, with 41 percent of peak hour demand reaching the destination. Providing a downstream U-turn as a replacement for directing left and/or through traffic movement was found to be useless during the analysis. The results revealed that the U-turn is not the best solution for the case study, with the signal control demonstrating superior performance.

Labib et al. [7] investigated the use of data mining and microsimulation modeling to reduce traffic congestion. The goal of this study was to construct a three-part system that uses fixed time intervals to provide efficient varying signal timing profiles. The study focused on jammed intersections in Dhaka. Scenario 1 was modeled with a total of 145-second cycle length and 75 seconds of green time. It showed a 38 percent (131m to 81m) decrease in queue length on all the legs of the intersection. Scenario 2 was modeled with a 165-second cycle length and 100 seconds of green time. It resulted in a 42.7 percent (131m to 75m) reduction in queue length in all the legs. Therefore, Scenario 2 was recognized as the most suitable signal timing profile. According to the findings of the study, varied traffic signal timing profiles resulted in a 40% reduction in line duration. It also resulted in a 40% rise in average vehicle travel speed, reducing traffic congestion. The research showed that signal timing optimization with an integrated data collection system could be used in real-world traffic situations in a high-traffic metropolitan setting. It was recommended to reduce traffic congestion using low-cost hardware (such as CCTV), simulation software, and minimal expert inputs.

Roy et al. [8] investigated the feasibility of traffic operation alternatives at signalized crossings in Dhaka, Bangladesh. The study's goal was to evaluate and improve traffic operations at the Science Laboratory-Elephant Road signalized four-leg crossroads. It had a large volume of traffic and had more delays and traffic congestion than other crossings in the city. The intersection was modeled using VISSIM, with the intersection being treated as a single signalized intersection. Average speed, average delay, and average queue length were used to determine the efficiency of the study. Four methods were suggested to solve the traffic congestion. The first option was to prohibit right turns on all approaches. The second option was to improve the existing traffic signals. The third option was to build an overpass from New Market to the Kalabagan approach. Alternative 4 planned to build two overpasses in two directions. One for the New Market to Kalabagan approach and the other for the Elephant Road to Dhanmondi approach. Alternatives 1 and 2 were shown to be unable to significantly enhance the Level of Service (LOS). However, alternatives 3 and 4 showed a considerable improvement in LOS with a short delay time. Alternative 2 indicated that traffic signal optimization increased speed by 17.32 percent and reduced delay by 61.82 percent. The queue length was decreased by 26.31 percent. The third alternative was chosen as it was the most cost-effective and adequate solution to the intersection's traffic congestion problem. Alternative 3 resulted in a 250.6 percent increase in average traffic speed and a 92.91 % reduction in average wait length. The average delay was reduced by 100 %. The findings showed that building a thorough overpass from New Market to Kalabagan will reduce traffic congestion at the signalized intersection, especially during peak hours. It led to lower travel costs, improved road network efficiency, increased safety, improved traffic flow, and traffic operations, and reduce air pollution.

Sariri et al. [9] investigated the use of VISSIM software to simulate traffic at a three-way intersection. The main goal of their research was to determine the traffic performance at the 3-way intersection in Makassar City. There were two signalized legs with three phases of movement and one unsignalized leg at the junction. The VISSIM software is used to simulate the model, and Traffic Signer Tool is used to optimize the signals. The queue length was used as a performance indicator. Practically in every approach, there was a long queue. The longest was 338.06 meters. Two methods of optimization were proposed. One method was to change the phase time, and the other method was to increase the cycle time. It was recommended to adopt cycle time and phase time optimization to alleviate traffic congestion at intersections. The second alternative produced better performance results because the first alternative increased the queue length in one leg. The cycle time was optimized by increasing it from 105 to 120 seconds, which resulted in greater traffic performance than before. The average queue length was cut in half, from 233.93 meters to 222.26 meters. It was discovered during the research that traffic performance might be improved by optimizing cycle times.

Valencia et al. [10] used microsimulation to figure out a long-term solution to traffic congestion. The goal was to offer a simulation model for creating and evaluating action plans to alleviate traffic congestion and the resulting conflicts. The case study was conducted at a junction in Chile with a high volume of traffic. The VISSIM software was used to model the microsimulation.

The queue length and the average speed were used as the performance measure. There were two simulation models created. One of the simulation models that worked to alleviate traffic congestion included programming the traffic signal from 120 seconds to 90 seconds. Through that model, it was proposed to use short bus lanes for public transport. This strategy resulted in a 14 percent increase in speed and an 18 percent decrease in queue length. Private transportation reduced the trip time by 24%, while public transportation reduced travel time by 42%. CO_2 emissions were cut by 54.3 percent (from 1263 to 686 gCO_2/km). The proposed strategy was able to achieve the research goal of reducing traffic congestion and resulting conflicts. Through the proposed strategy, CO_2 emissions, fuel consumption, delays, and intersection pauses were reduced. It was also suggested that this paradigm could be used in other scenarios.

Gokce et al. [11] used Particle Swarm Optimization (PSO) to improve the traffic signals of a major signalized roundabout in Izmir, Turkey. The major goal of their research was to reduce traffic signal wait times by using a simulation-optimization methodology to optimize signal timings. In the simulation and optimization, 12 signals were considered out of a total of 28 traffic signals. VISSIM software was used to create the intersection model, and MATLAB was used to create the PSO. The effectiveness was measured by the average delay and the total number of vehicles passing. PSO was used to look for traffic signal timings that would reduce the average travel time through the roundabout. The results obtained from PSO were simulated in VISSIM to assess the results of the intersection. The model was run for several cycle time values starting at 149s, then 70s, and gradually to 5s at 5s intervals. It was done to discover the most suitable signal cycle time. Initially, the cycle time was 92s. The average number of vehicles was 1997, with a cycle time of 45 seconds. The average delay was 36.98 seconds. The average delay was decreased by 55.9%. The number of cars moving through the roundabout increased by 9.3% as a result of signal light optimization.

In China, Wu et al. [12] investigated the development of a traffic signal cycle optimization model for signalized crossings. In Xi'an City, traffic data was collected from 50 signalized crossings. During the optimization, it was discovered that the model considers vehicle delay time, pedestrian crossing time, and driver anxiety. Three of the 50 crossings were chosen for simulation to test the optimization signal cycle length model (NEW Model). The three intersections represented three different traffic flows. Low traffic flow was at intersection I. Medium traffic flow was at intersection II. Heavy traffic flow was at intersection III. At each intersection, two distinct traffic signal programs were examined. The variation in delay time and queue length between the two models was tested using the T-test. The mean delay durations for the selected junctions using the TRRL model program were 3.64s, 34.51s, and 50.13s, respectively. The average delay times using the NEW model program were 4.27s, 31.08s, and 42.58s. The mean queue lengths for the selected junctions according to the TRRL model program were 2.74m, 8.12m, and 15.98m, respectively. The average queue lengths, according to the NEW model program, were 3.24m, 6.04m, and 10.02m. Optimizing traffic signal cycle length was found to be the best solution for reducing delays and queue length in Xi'an City.

Salvo and Sanfilippo [13] used a microsimulation model and mathematical calculations to investigate traffic management. The major goal of the study was to show the importance of a synchronized traffic light cycle for high-traffic crossroads like Palermo. The research is being carried out between the junctions of piazza Don Bosco and piazza Leoni. The current scenario (with uncoordinated traffic signal cycles) and the proposed scenario (with coordinated traffic light cycles) were both microstimulated. The piazza Don Bosco intersection has a three-phase articulated signal with a signal period of 142 seconds. The piazza Leoni intersection has a two-phase signal with a signal time of 86 seconds. An additional lane was created to reduce the load of vehicles arriving from the access roads. An equation was used to determine the minimum cycle time, which was 133 seconds. In each signal phase, the green signal periods were discovered to be 40 seconds, 42 seconds, and 30 seconds. The offset time between the cycles of the two junctions was determined to be 32 seconds. It allowed the current priority vehicles to proceed beyond the first traffic lights, avoiding additional pauses and maintaining a constant speed of 40 km/h. The maximum, minimum, and average travel times were utilized as performance measurements in the simulations for the two situations. It was discovered that the additional lane eliminates the left turn onto via dell'Artigliere for vehicles coming from piazza Leoni. Through simulations, it was discovered that all destinations with origins have reduced throughput times. The proposed solution reduced mean travel times by 20%

and 10% on the viale del Fante and via Di Giorgio, respectively. The mean travel times were reduced by 7% in the viale Artigliere and via Diana. There were decreases in mean travel time ranging from 8 to 38 percent for the path that began in Piazza Don Bosco. The installation of an extra lane, the viale Imperator Federico, resulted in a 55 percent decrease in mean travel time.

Ping and Qun [14] investigated the use of a Genetic Algorithm (GA) to optimize traffic signals at a busy crossroads. GA was utilized to discover the best signal timing because its objective function was based on the concept of minimizing average delay. The GA's improved timings were compared to those computed using Synchro using microsimulation for the same junction. GA produced a reduced average delay and the average number of stops in congested settings than Synchro.

Imran and Nayyer [15] investigated the use of microsimulation to evaluate corridor improvements. The major goal of their research was to make modifications to the study corridor in order to minimize traffic congestion. The chosen corridor ran from the Kazipet railway station junction to the Nakkalagutta junction, including two unsignalized and three signalized intersections. The modeling was done with VISSIM software. Signal coordination in the corridor was used to analyze the corridor. Three signal schemes were tested and assessed on the corridor based on queue length, travel duration, and intersection delay. Signal plan 1 exhibited a 20% reduction in average travel time due to simultaneous coordination. Here, all signals along a given street continually displayed the same indication to the same traffic stream at the same time. The average delay time was shortened by 22%. Signal plan two was simple progressive coordination. Here, various signals along a street are displayed green in such a way that platoons of vehicles can operate continuously along the street. It resulted in a 17.4 percent reduction in average travel time and a 20.6 % decrease in average delay time. The third signal design, alternate signal coordination, showed a 26.92 percent decrease in average travel time for the entire corridor. It also reduced the queue length at each intersection by 41.27 percent and the average wait time by 34.90 percent. The average speed was increased by 13.42 percent with the alternate signal scheme, according to the conducted spot speed assessments. According to the findings of the study, alternative signal coordination was the best method for reducing traffic congestion along the corridor. It reduces queue lengths, average travel time, and average delay time, and it also helps to boost average speed.

Singh et al. [16] used a genetic algorithm to optimize the signal timing of traffic signal control. Their goal was to develop a traffic adaptive control technique that recognizes the real-time traffic scenario in small steps (surveillance interval). And also to provide appropriate green time extensions. They created the model using a MATLAB-based genetic algorithm. To correspond to changeable traffic conditions, a JAVA traffic emulator was constructed. They discovered that when comparing a real-time-based system to a fixed-time-based system, the real-time-based system outperformed the fixed-time-based system by 21.9 percent.

Zhang et al. [17] studied a multi-objective optimization of metropolitan traffic signal timing, which required a sensible signal timing factor. Only the traffic volume, latency, and emissions from the junction were considered. First, based on traffic volume as the basic data, a multi-objective model of the signal timing problem was developed. Second, the target model was solved and tested by the genetic algorithm of the unclassified classifier framework. It was identified that the traffic index set of the Pareto solution obtained by NSGAIII has a larger domain. Lastly, the search mechanism of the evolutionary algorithm was unrestricted. The real traffic signal timing issue was constrained by the traffic environment. To obtain an improved signal timing scheme, the method of combining a hybrid binding strategy and NSGAIII framework, abbreviated as HCNSGAIII, was introduced. Simulation experiments were performed based on the same target model. The simulation results were compared with the real diagram and the synchronization diagram found in the recent study. The results showed that the traffic volume, latency, and emission indicators obtained by the suggested method have more evident advantages.

Khang et al. [18] investigated the capability of a Genetic Algorithm (GA) in optimizing traffic light plans. GA was applied using the Python coding language. In addition, SUMO, a traffic simulation package, was used to simulate the traffic scenario of the average loss time calculation solution. The GA efficacy survey showed that a selectivity rate of 0.8 and a mutation rate of 0.75 were more effective. Using these numbers, GA was used to find the traffic light plane for low, medium, and high traffic demand levels. The results were compared with the algorithm based on Webster's formula, which showed that it was outperformed by GA. Additionally, GA performed best at high traffic demand with 38.46% lower losses. Followed by 37.41% lower and 3.48% lower traffic levels, low and medium, respectively.

Lee et al. [19] studied adaptive real-time signal optimization using GAs. The algorithm was evaluated using micro-simulation for online evaluation and compared with fixed-term plans generated from TRANSYT7F 9.7, which includes genetic optimization. The developed signaling system consisted of three main elements. A GA optimization module, an internal traffic simulation module, and a database management system work together collaboratively to optimize signal timing. Using a pseudo-online simulation platform, three test scenarios for high, medium, and low levels of traffic demand were performed. It was aimed at evaluating some important characteristics of the suggested adaptive signal control. Experimental results indicate that real-time genetic control outperforms fixed-signal timing schemes in all situations based on whole-vehicle delay. The previous research conducted to optimize traffic signal timing mainly consisted of developing optimization programs. For example, Genetic Algorithm (GA), PSO and Webster Delay Model, Analytical Fuel Consumption Model (AFCM), and Mathematical models can be found. The summary of the entire literature review is tabulated in Table 1.

Table 1. Literature review summary.

Study	Intersection Evaluation Criteria	Applied Method	Achieved Results
ElAzzony et al. [6]	Peak Hour Vehicle Demand	SIDRA Intersection 4.0	4-phase signal control was the most superior
Labib et al. [7]	Vehicle Queue Length	Manual	Varied traffic signal timing profiles reduced traffic congestion
Roy et al. [8]	Average speed, average delay, and average queue length	Manual	Building a through overpass will reduce traffic congestion at the signalized intersection
Sariri et al. [9]	Queue Length	Traffic Signer Tool	Traffic performance improved by optimizing cycle times
Valencia et al. [10]	Queue length and the average speed	Manual	The proposed strategy reduced CO_2 emissions, fuel consumption, delays, and intersection pause.
Gökçe et al. [11]	Average delay and the total number of vehicles passing	Particle Swarm Optimization	The average delay was decreased, and the number of cars moving through the roundabout increased by signal light optimization
Wu et al. [12]	Average Delay and Queue Length	Optimization signal cycle length model	Optimizing traffic signal cycle length was found to be the best solution for reducing delays and queue length in Xi'an City
Salvo and Sanfilippo [13]	Maximum, minimum, and average travel time	Mathematical calculations	The proposed solution reduced mean travel times
Ping and Qun [14]	Average Delay	GA optimization and Synchro	GA produced a reduced average delay and the average number of stops in congested settings than Synchro.
Imran and Nayyer [15]	Queue length, travel duration, and intersection delay	Manual	Alternative signal coordination was the best method for reducing traffic congestion along the corridor
Singh et al. [16]	Total number of vehicles on the road	MATLAB-based genetic algorithm	Real-time-based signal control system outperformed the fixed-time-based signal control system
Zhang et al. [17]	Traffic volume, latency, and emission	HCNSGAIII	The suggested method has more evident advantages on traffic volume, latency, and emission
Khang et al. [18]	Average loss time	GA optimization and Webster's Formula	Webster's Model was outperformed by GA.
Lee et al. [19]	Vehicle Delay	GA optimization	Real-time genetic control outperforms fixed-signal timing schemes

However, none of the research studies were done based on the traffic signal timing optimization directly through the VISSIM software. The direct signal optimization feature in the VISSIM software reduces the time spent developing signal optimization programs manually. After signal timing optimization through VISSIM, it will directly show the results on how the road network was affected by signal optimization. VISSIM optimization will provide a directly optimized signal timing. But optimization programs will provide several optimized signal timings, which should then be manually input to the VISSIM to get the results. This study focuses on optimizing traffic signal timings of signalized intersections through VISSIM to minimize traffic congestion, CO and NOx emissions, and fuel consumption. To optimize the traffic signals, it is difficult to manually vary the green time or the cycle time. Therefore, signal timing optimization will help to determine the optimum green times and cycle times that suit the intersection or a traffic corridor. There are various techniques used for signal optimization, such as GA optimization, mathematical models, etc. In the proposed methodology, the signal controller timing optimization will be done in VISSIM itself without using any additional tools or programs. In contrast, other signal controller timing optimization methods require separate programs, coding, calculations, etc., which consumes time.

3. Methodology

3.1. Study area

The Pittugala – Malabe corridor (Figure 1) is located close to Malabe town in Sri Lanka. Pittugala – Malabe corridor consists of a three-legged unsignalized intersection (Y- intersection) (Figure 2), a four-legged unsignalized intersection (Truncated T-Intersection) (Figure 3), and a three-legged signalized intersection (Figure 4). The rest of the roads, which are connected to the Pittugala – Malabe corridor, were not considered during the study due to the low traffic flow compared to the considered connections. The Pittugala – Malabe corridor has a heavy traffic volume and must be improved. This corridor consists of a two-lane road (one lane each direction) within the entire corridor with a lane width of 5m. Kahanthota road and CINEC road has a lane of 3.5m and 2.5m, respectively.

Figure 1. Pittugala – Malabe Corridor (Ariel View).

Figure 2. Pittugala Intersection.

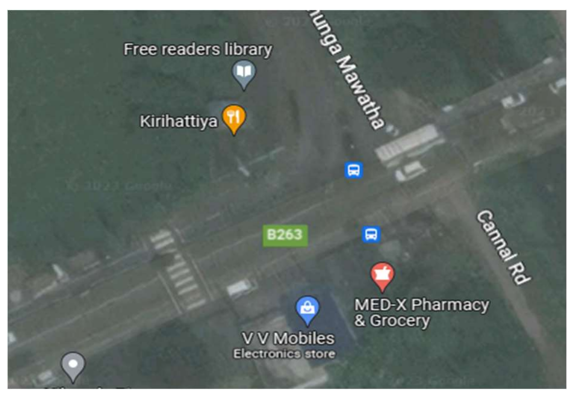

Figure 3. CINEC Intersection.

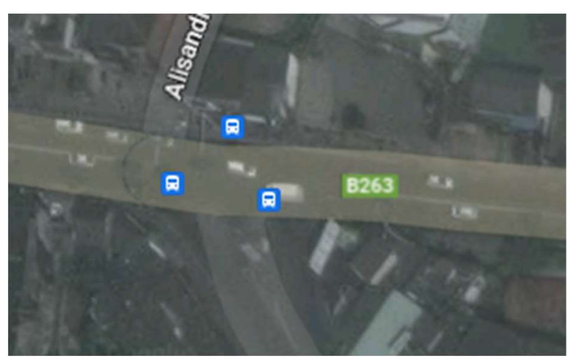

Figure 4. Malabe Intersection.

3.2. Data collection and analysis

The data collection of the Pittugala – Malabe corridor was done during the off-peak time (9.00 am to 11.30 am and 2.00 pm to 4.00 pm) [20]. Geometric data were collected through field measurements using a measuring wheel as well as by using the Google Earth Pro software. The measurements from the Google Earth Pro software were validated using the field measurements. The travel time data was collected by using two test vehicles in which each vehicle traveled in all the possible routes in the corridor. The test vehicles traveled each route four times, and the average travel time was calculated. Vehicle volumes and vehicle turning movements (Figure 5) were obtained by analyzing the videos collected by the video recorders placed at each intersection of the corridor. The signal timings, signal phasing, and signal cycle time were collected by conducting observations at the signalized intersections. Pittugala – Malabe corridor is a highly congested corridor. The congestion is mainly observed at the CINEC intersection and the Malabe intersection. Due to the high traffic flow, the existing signal timings don't allow a reasonable number of vehicles to pass during one cycle, which leads to long delays and queues. A high volume of vehicles passing through the CINEC intersection causes long delays and queues.

3.3. Model development and evaluation

VISSIM microsimulation software was used to develop the model of the selected corridor. Average travel time was used as the measure of effectiveness. The queue length was considered as the performance measure in the early part of the study for calibrating and validating the software at the intersection level. Other performance measures were not considered due to the time and resource limitations of the research study. In order to evaluate the performance of the traffic signal optimization the total average travel time, CO emissions, NOx emissions, fuel consumption, average stop delay, and average vehicle delay were considered. The base model was calibrated to the local conditions by using the calibration parameters developed for three-legged signalized, three-legged unsignalized, and four-legged unsignalized in the early part of the research [21, 22]. The most sensitive calibration parameters which were identified were the average standstill distance, additive part of safety distance, multiplicative part of safety distance, look ahead distance, distance standing, and distance driving. The calibration parameter values were determined for each type of intersection by developing separate optimization programs for each intersection type considering the identified sensitive calibration parameters. The calibration of the three-legged signalized showed an error of 7.82 %. Three-legged unsignalized showed an error of 10.09 %. Four-legged unsignalized showed an error of 13.35 %. The obtained errors were within the acceptable range of 0 – 15 %. The validation process was done with several other intersections, which also provided errors within the acceptable range. It showed that the calibrated parameters were acceptable. Those calibration parameter values were used while developing the model of the current study, which showed an error of 13.45 %. The vehicle volume, vehicle composition, vehicle turning movement, and signal timing data were input to the VISSIM software while developing the model.

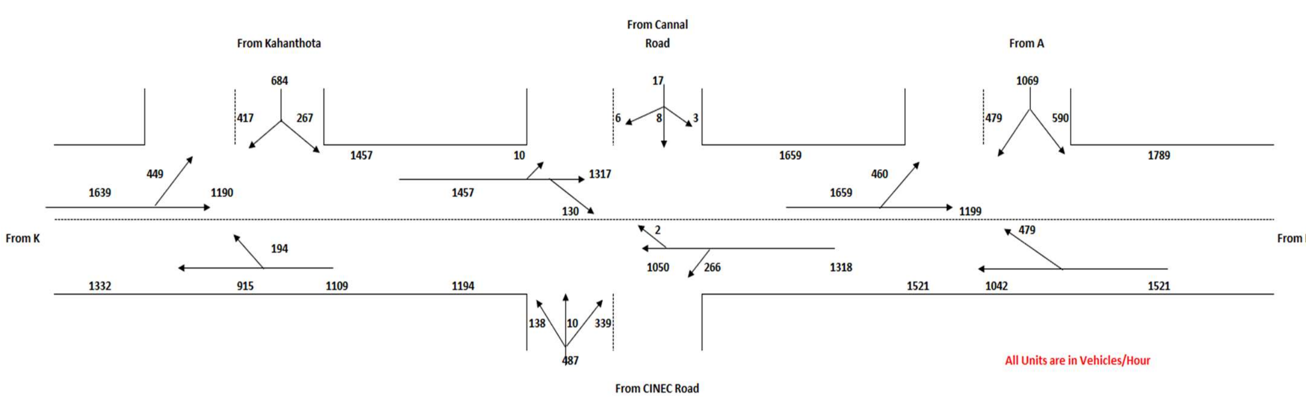

Figure 5. Average Vehicle Volume and Vehicle Turning Movements Per Hour at the Pittugala – Malabe Corridor.

The base model of the corridor was developed using the collected and analyzed data and the predetermined calibration parameter values. In the Pittugala – Malabe corridor, the Malabe intersection was the only signalized intersection, and it had an existing cycle time of 124 s. Malabe intersection was a fully signalized and heavily congested three-legged intersection. The existing signal program of the Malabe intersection is shown in Figure 6. With the existing signal plan, only a few numbers of vehicles were able to pass the intersection from each direction during their respective green times. It resulted in heavy traffic congestion with high traffic flow in each direction.

3.4. Traffic signal optimization

The traffic signal optimization was done using the VISSIM software itself. A new signal program was created as a stage-based signal controller along with priority rules. Afterward, the signal timing optimization was run to find the optimum traffic signal controller timings. Additionally, manual signal timing calculations were done using Webster's Method to identify the suitable traffic signal timings. The results from the manual calculations were compared with the results obtained through the optimization done in VISSIM.

4. Results and Discussion

The simulation of the Pittugala – Malabe corridor base model was done through VISSIM software. The simulation results of the base model are tabulated in Table 2.

Table 2. Simulation Results of the Base Model of the Pittugala. – Malabe Corridor

Parameters	Simulation Results
Total Average Travel Time	5420.46 sec/hour
Average Vehicle Delay	66.65 seconds
Average Stop Delay	35.41 seconds
Total CO Emissions	21630.90 grams/hour
Total NOx Emissions	4208.59 grams/hour
Total Fuel Consumption	309.46 gallons/hour

The Malabe intersection of the Pittugala – Malabe corridor was modified with priority rules where there will be a continuous, thorough movement of the vehicles approaching from Battaramulla (B) towards Kaduwela (K) and when vehicles approach from Athurugiriya (A) towards Kaduwela, the vehicles traveling from B to K should give the priority for the vehicles traveling from A to K. A continuous movement of vehicles is modeled from K to A, and when the vehicles approaching from B to A, the vehicles approaching from K to A will give priority for vehicles approaching from B to A. Also, a continuous movement of vehicles is modeled from A to B, and when the vehicles approach from K to B, the vehicles approaching from A to B will give priority to vehicles approaching from K to B.

The existing signal program was removed, and a new stage-based signal controller program with a 110s cycle time was created and optimized. The optimized signal timing is shown in Figure 7. Similar to the VISSIM optimization, the manual signal timing calculations through Webster's method provided a signal cycle timing of 110s. The signal program is shown in Figure 8.

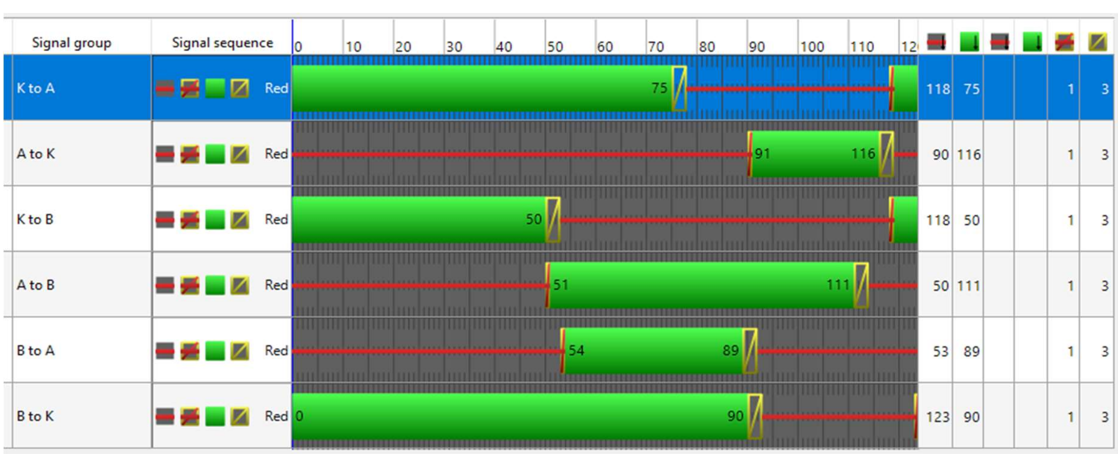

Figure 6: Existing Signal Program of the Malabe Intersection of the Pittugala – Malabe Corridor.

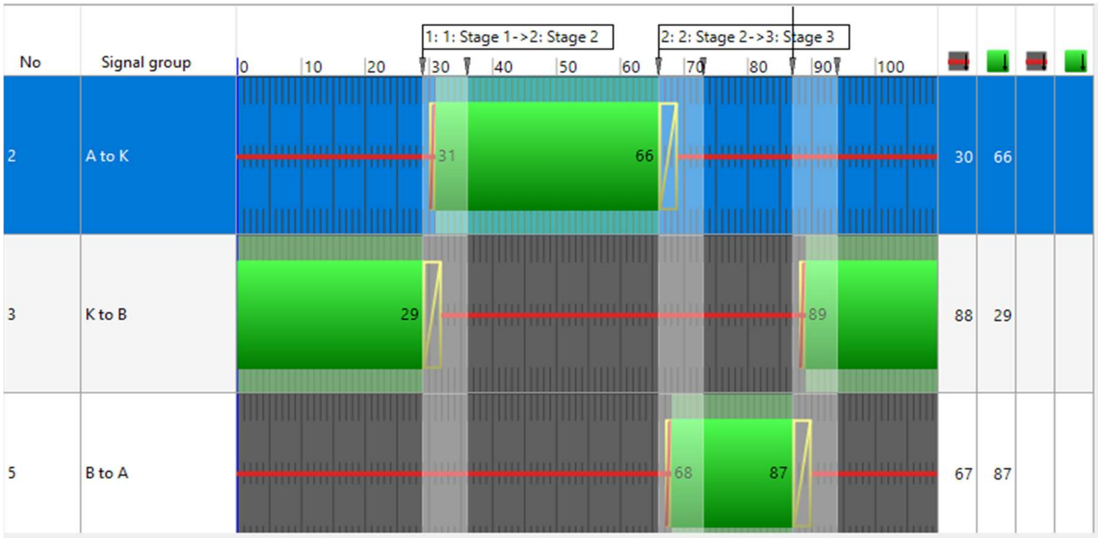

Figure 7: Optimized Signal Program of the Malabe Intersection of the Pittugala – Malabe Corridor.

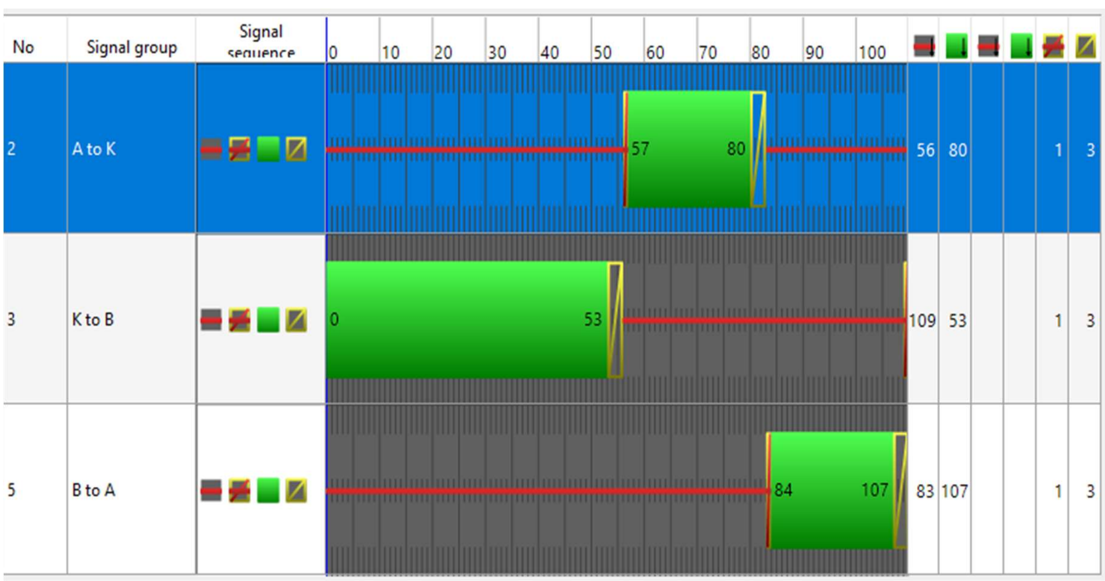

Figure 8: Manually Calculated Signal Program of the Malabe Intersection of the Pittugala – Malabe Corridor.

The simulation was again done using the optimized signal program and the manually calculated signal program of the Pittugala – Malabe corridor with priority rules. The simulation results are tabulated in Table 3.

Through the results of the simulation done using the optimized traffic signal controller timing, it was found that the total one-hour travel time within the road network was reduced by 14.75 %. The average vehicle delay and the average stop delay in the corridor decreased by 12.69 % and 8.56 %, respectively. The CO emission, NOx emission, and fuel consumption were reduced by 14.89 %.

The emissions percentages were calculated using Equation (1) below.

$$\mathrm{ER} = \frac{\mathrm{Emission}_{BO} - \mathrm{Emission}_{AO}}{\mathrm{Emission}_{BO}} \text{ x } 100\ \% \qquad (1)$$

where:

ER: Emission Reduction

BO: Before Optimization

AO: After Optimization

Table 3. Simulation Results were obtained Using the Optimized Signal Timing and Manual Signal Timing of the Pittugala – Malabe Corridor.

Parameters	Optimized Signal Timing	% Difference with Base Model	Manual Signal Timing	% Difference with Base Model
Total Average Travel Time	4620.68 sec/hour	14.75 %	4894.93 sec/hour	9.70 %
Average Vehicle Delay	58.19 seconds	12.69 %	50.89 seconds	23.65 %
Average Stop Delay	32.38 seconds	8.56 %	24.76 seconds	30.08 %
Total CO Emissions	18411.11 grams/hour	14.89 %	18578.58 grams/hour	14.11 %
Total NOx Emissions	3582.13 grams/hour	14.89 %	3614.72 grams/hour	14.11 %
Total Fuel Consumption	263.392 gallons/hour	14.89 %	265.79 gallons/hour	14.11 %

Through the results of the simulation done using the manually calculated traffic signal controller timing, it was found that the total one-hour travel time within the road network was reduced by 9.70 %. The average vehicle delay and the average stop delay in the corridor decreased by 23.65 % and 30.08 %, respectively. The CO emission, NOx emission, and fuel consumption were reduced by 14.11 %.

The methodology proposed through the research (signal timing optimization through VISSIM) was compared to the manual signal timing calculation. The comparison showed that the difference in CO, NOx, and fuel consumption between the optimized signal timing and manual signal timing was 0.901 %. The difference in total travel time, average delay, and stopped delay between the optimized signal timing and manual signal timing was 5.6 %, 12.55 %, and 23.53 %, respectively. Through the overall comparison, it was found that the signal timing optimization provides much more improved results compared to the manual signal timing calculations. Therefore, signal timing optimization through VISSIM is a good alternative to optimize traffic signal timings.

5. Conclusion and Recommendations

In this study, a methodology was proposed for optimizing traffic signal controllers to reduce CO, NOx, and fuel emissions for congested traffic corridors. The study optimized the traffic signal controller timings on the Pittugala-Malabe corridor using the built-in optimization tools of VISSIM. The optimized cycle timing of 110 seconds was found to reduce emissions and fuel consumption by 14.89% while also reducing travel time and vehicle delays. It was found that the traffic signal optimization tools available in VISSIM are more efficient and less time-consuming than traditional optimization methods such as genetic algorithms. The optimized signal timings through VISSIM showed superior results to manually calculated timings. It was found that signal timing optimization through VISSIM is an effective alternative for optimizing traffic signal timings manually or through traditional optimization methods. And it was also found that using the proposed methodology, the optimized traffic signal timings could be identified in just a few hours.

In the next part of the study, it is planned to model corridors with various combinations of three-legged and four-legged, signalized and unsignalized intersections. It includes multiple signalized intersections (i.e., only three-legged signalized, only four-legged signalized, or both three-legged and four-legged signalized). It is recommended to use the built-in VISSIM traffic signal controller optimization as it is timesaving compared to optimizations done through different programs (i.e., GA, manual signal timing optimization, etc.) or different models (i.e., Webster model, etc.) based on personal experience. And also, the other microsimulation software does not consist of signal optimization tools and must be done manually or using another software or a model, which takes additional time. The same methodology is recommended to be used for the signalized four-legged intersections. The optimization results are more accurate and reliable as the optimizations are done within the VISSIM microsimulation software itself.

Acknowledgments

The authors wish to thank the VISSIM Company for providing the Thesis version of the software for this research. This research was supported by the Accelerating Higher Education Expansion and Development (AHEAD) Operation of the Ministry of Higher Education, Sri Lanka, funded by the World Bank.

Competing Interest Statement

The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data and Materials Accessibility

No additional data or materials were utilized for the research described in the article.

References

[1] S. M. Kiran, A. Verma, "Review of Studies on Mixed Traffic Flow: Perspective of Developing Economies", *Transportaion in Developing Economies*, vol. 2, No. 5, pp. 1-16, 2016.

[2] P. Hidas, "A functional evaluation of the AIMSUN, PARAMICS, and VISSIM microsimulation models", *Road and Transport Research*. Vol. 14, no. 4, pp. 45-59, 2005.

[3] S. Harvey, "Introduction to VISSIM - ppt video online download," 2016. [Online]. Available: https://slideplayer.com/slide/4453193/. [Accessed 3 1 2022].

[4] The Washington State Department of Transportation (WSDOT), "Signal timing review & optimization," [Online]. Available: https://tsmowa.org/category/intelligent-transportation-systems/signal-timing-review-optimization. [Accessed 21 6 2022].

[5] Knoema, "Sri Lanka - CO2 emissions from transport," 2021. [Online]. Available: https://knoema.com/atlas/Sri-Lanka/topics/Transportation/CO_2-Emissions-from-transport/CO_2-emissions-from-transport [Accessed 23 3 2023].

[6] T. ElAzzony, H. Talaat and A. Mosa, "Microsimulation approach to evaluate the use of Restricted Lefts/Through U-turns at major intersections — A Case Study of Cairo-Egypt urban corridor," *13th International IEEE Conference on Intelligent Transportation Systems*, Funchal, Portugal, 2010, pp. 1324-1329.

[7] S. Labib, H. Mohiuddin, I. Hasib, S. Sabuj, S. Hira, "Integrating Data Mining and Microsimulation Modelling to Reduce Traffic Congestion: A Case Study of Signalized Intersections in Dhaka, Bangladesh," *Urban Science*, vol. 3, no. 2, pp. 1-23, 2019.

[8] K. C. Roy, S. Barua, A. Das, "A Study on Feasible Traffic Operation Alternatives at Signalized Intersections in Dhaka City," *International Conference on Recent Innovation in Civil Engineering for Sustainable Development (IICSD-2015),* Department of Civil Engineering, Gazipur, Bangladesh, Paper ID: TE-004, 2015.

[9] D. Sariri, M. Hustim, M. Pasra, "Microsimulation of Traffic at the 3-Way Junction with PTV VISSIM Software," *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, 8(4S), pp.73-77, 2019.

[10] A. Valencia, C. Montt, A. M. Oddershede, L. E. Quezada, "A Micro Simulation Approach for a Sustainable Reduction Traffic Jam," *Title of host publicationIntelligent Methods in Computing, Communications and Control - Proceedings of the 8th International Conference on Computers Communications and Control ICCCC 2020*, 2021, pp. 206-219.

[11] M. Gökçe, E. Öner, G. Işık, "Traffic signal optimization with Particle Swarm Optimization for signalized roundabouts," *Simulation*, vol. 91, no. 5, pp.456-466, 2015.

[12] Y. Wu, J. Lu, H. Chen, H. Yang, "Development of an Optimization Traffic Signal Cycle Length Model for Signalized Intersections in China", *Mathematical Problems in Engineering*, pp. 1-9, 2015.

[13] G. Salvo, L. Sanfilippo, "Traffic-Light Cycle Coordinated by Microsimulation: A Solution to the Traffic Congestion in Palermo," *SIMUL 2014: The Sixth International Conference on Advances in System Simulation*, 2014, pp.7-13.

[14] P. Wang, Y. Qun, "Genetic Algorithms Based Traffic Signal Optimization at a Congested Intersection," *Applied*

Mechanics and Materials. Trans Tech Publications, Ltd., vol. 209-211, pp. 814-817, 2012.

[15] N. T. Imran, M. I. Nayyer, "Signal Coordination in Transportation Engineering by Using Microsimulation Tool," *Sustainable Civil Engineering Practices, Lecture Notes in Civil Engineering*, vol. 72, May 2020, pp. 11-121.

[16] L. Singh, S. Tripathi, H. Arora, "Time Optimization for Traffic Signal Control Using Genetic Algorithm," *International Journal of Recent Trends in Engineering*, vol. 2, no. 2, pp. 4-6, 2009.

[17] X. Zhang, X. Fan, S. Yu, A. Shan, S. Fan, Y. Xiao, F. Dang, "Intersection Signal Timing Optimization: A Multi-Objective Evolutionary Algorithm," *Sustainability*, vol. 14, no. 3, pp.1-16, 2022.

[18] C. C. Khang, N. X. Hui, A. Rahman, M. K. M. Ali, "Optimization of traffic signal plan for isolated intersection using genetic algorithm," *AIP Conference Proceedings*, vol. 2423, 2021.

[19] J. Lee, B. Abdulhai, A. Shalaby, E. Chung, "Real-Time Optimization for Adaptive Traffic Signal Control Using Genetic Algorithms," *Journal of Intelligent Transportation Systems*, vol. 9, no. 3, pp.111-122, 2005.

[20] D.U.A Edirisinghe, SLIDA, Sri Lanka Institute of Development Administration Colombo Sri Lanka, "MANAGING TRAFFIC CONGESTION IN COLOMBO AND ITS SUBURBS," 20 10 2014. [Online]. Available: http://www.slida.lk/slidatest/application_resources/images/mpm_reso/policypaper/pp5.pdf. [Accessed 23 3 2023].

[21] D. Gunarathne, N. Amarasingha, V. Wickramasighe, A. Kulathunga, "Experience in Calibrating the VISSIM Microscopic Simulation Model for a Signalized Intersection," *H.L.K. Perera (Ed.), Proceedings of the Transportation Research Forum 2020,* Department of Civil Engineering, University of Moratuwa, 2020.

[22] D. Gunarathne, N. Amarasingha, V. Wickramasinghe, " Effect of the Traffic Flow with Change in Time on Driver Behavior Parameter Values in Micro-Simulation," *The 14th International Conference of Eastern Asia Society for Transportation Studies (EASTS)*, Hiroshima, Japan, 2021. [Online]. Available: https://www.easts.info/on-line/proceedings/vol.13/pdf/PP2958_R1_F.pdf