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Advanced Bracketing Algorithms for Optimizing Flexible Urban Traffic Management Systems in Metro Manila

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Abstract. This system aims to address the problem of traffic congestion that appeared to be caused by the fast and rapid urban sprawl of Metro Manila, which happened together with a failure in proper planning and increasing the number of vehicles. More advanced bracketing algorithms are developed for optimum flexible urban traffic management systems under real-time traffic flow conditions and signal timings for congestion and travel efficiency. It uses cross-sectional study designs where real-time data are collected for traffic conditions in Metro Manila and is used to develop and test proposed algorithms. The experiments reduced congestion by 25 % and improved travel time on major routes in the city by 18%. Regression analysis and machine learning algorithms-based developed predictive models will be used for predicting traffic, thereby initiating adaptive traffic signal control with optimal signal timing for improvement in bottleneck intersection traffic flow. Proposed algorithms have proven to significantly decrease traffic congestion, facilitate the use of public transport, and decrease dependence on private vehicles. The mentioned advances will thus promote economic development, environmental friendliness, and better health. The proposed research constitutes an excellent case study regarding integrating more developed bracketing algorithms in traffic management systems nowadays to address the challenges towards a more sustainable urban environment.

Keywords: Adaptive signal control; Bracketing algorithms; Predictive analytics; Traffic congestion; Traffic management.

1.0 Introduction

Traffic congestion is one of the worst problems experienced within the bustling megacity of Metro Manila in Asia. In just three decades, there has been an incredible increase in the number of vehicles on the city streets, in addition to the rapid urban sprawl and the rise of high-rise buildings. Globalization, outsourcing, and the movement of manufacturing activities have allowed most residents to purchase motorized vehicles. This boom, coupled with vast income inequalities, has resulted in historic traffic on roads never intended for this volume of congestion. The massive gridlock ensuing wastes time when traveling places and contributes to environmental pollution, health problems related to chronic respiratory systems, and high fossil fuel consumption. For decades, Metro Manila has been the epitome of abominable road traffic congestion, which has become a way of life for the capital city.

On the other hand, all these have wasted travel time, which is also a source of environmental pollution, increased consumption of fossil fuels, and health problems, primarily respiratory illnesses. For so many years, Metro Manila has stood as an example of urban traffic congestion, and it became a harsh reality from which its residents could not escape. According to a new report released by Tom Tom last month, Metro Manila placed 18th in 404 cities worldwide, ranked based on traffic congestion. It recorded some improvement—a drop in congestion levels from 71 percent pre-pandemic to 43 percent in the post-COVID period—but commuters still lose an average of six full days and 13 hours yearly because of rush-hour gridlock; Friday evenings prove to be the worst.

While previous studies have examined traffic congestion in Metro Manila, there is limited research on leveraging advanced bracketing algorithms to optimize traffic management systems dynamically. This research aspires to bridge the gap by proposing a system integrating bracketing algorithms with real-time data collection from traffic cameras, GPS, and sensor systems. Such a solution has massive social, economic, and ecological implications. These include contributing greatly to reducing congestion and thereby massively improving worker productivity. Cuts on transport costs and fossil fuel consumption will also enhance economic growth. In addition, improved flow translates to reduced vehicle emissions, improved air quality, and reduced public health risks. Hence, this study not only addresses the immediate challenges posed by Metro Manila's traffic problems but also supports long-term goals for urban development.

Furthermore, to tackle this multi-dimensional problem, advanced bracketing algorithms can be adapted to optimize flexible urban traffic management systems in Metro Manila. Thus, these advanced algorithms can also be used to devise dynamically managed flows that would result in the minimization of congestion and an enhancement of overall transportation efficiency. This is aggravated by poor policies and governance around public transport, excessive use of private vehicles, and inadequate urban planning. This hurts the economy, decreases workforce productivity, and greatly increases business traveling time and profitability. Moreover, for commuters in Manila, the situation is even worse. They have to wait for long periods, public transport is overcrowded, and ride-hailing application services are in great demand–movement is a heavy task.

2.0 Methodology

2.1 Research Design

Data was collected from the cameras, GPS, and sensors related to traffic, capturing real-time traffic conditions, vehicle location, and environmental conditions influencing traffic flow. The algorithms computed this information so that patterns, trends, and anomalies in the current situation and those for the future could be known. Based on the analysis done by the extracted data, predictive models are used to predict traffic conditions so that necessary steps can be taken beforehand to optimize traffic management plans. The system then applies adaptive signal control in which dynamic changes in the timings of traffic signals are made according to the forecasted conditions to enhance traffic flow and thus reduce congestion at intersections. Real-time alterations are made in such a way as to allow enough traffic of the vehicles for smooth bed flow and with lesser delays. The system further informs the driver and the representative of public transport of the traffic conditions and alternative routes for making and adjusting traffic management strategies accordingly. The whole approach is meant to optimize traffic management, reduce congestion, and thus improve the whole transportation modality within Metro Manila to achieve sustainability in urban development and improve the commuting activities of the population of the city.

2.2 Research Locale

This research will focus on Epifanio de los Santos Avenue (EDSA) in Metro Manila, Philippines, one of the most traveled yet traffic-congested corridors in the country. EDSA is a vital urban transportation area that extends through cities such as Quezon City, Mandaluyong, Makati, Pasay, and Caloocan.

2.3 Research Participants

This research will consider commuters regularly using public transport on EDSA, car owners and drivers using the same route, bus, and jeepney transport drivers, traffic enforcers of the Metropolitan Development Authority (MMDA), and urban planners or traffic engineers within the Metro Manila traffic system.

2.4 Research Instruments

We combined existing traffic management systems of Metro Manila with our advanced algorithms and different data collection methods. First, we exploited the current Metro Manila traffic management system, which already has an essential network of cameras monitoring the traffic flow. This infrastructure would be beneficial for determining the positions of vehicles and traffic density in real-time and, hence, congestion points. The existing system uses fixed time intervals for the traffic lights that regulate the stop-and-go patterns of vehicles. We propose using more advanced bracketing algorithms that will allow us to change the time intervals of a traffic light dynamically. This can reduce or increase signal time intervals based on the traffic flow status in real-time, if necessary, to be most effective in moving traffic and minimizing congestion. Moreover, predictive analytics can also predict future traffic scenarios from historical data, which can be used to manage them proactively.

In addition to real-time data collection, we employ traffic simulation models, specifically VISSIM and SUMO. These will be used to replicate virtual models of the Metro Manila traffic system. This will allow us to test and assess the performance of bracketing algorithms under different traffic escape scenarios. These virtual models help to replicate real-world conditions to evaluate how effective the proposed improvements will be in the controlled environment. This data analysis uses various predictive analytics software tools to predict traffic behavior. These range from MATLAB for sophisticated mathematical modeling and simulations to the Python data analysis packages sci-kit-learn and pandas for data analysis and machine learning applications. These interpret the data to control traffic in real-time.

We also conducted a qualitative assessment using the commuter and driver questionnaires. To do this, surveying a certain percentage of the residents in Metro Manila can be able to give their experiences due to traffic congestion and how it has affected their lives. They will obtain data on behavior, preferences, and perceptions regarding the current traffic system. Similarly, driver questionnaires are also issued to gather more details about the driving patterns, routes, and problems encountered during peak hours. This data will help pinpoint specific problem areas within the traffic network. Finally, interviews with stakeholders such as traffic management authorities, urban planners, and transportation experts will provide needed qualitative data concerning current traffic management practices, problems, and opportunities for improvement. Based on these interactions, advanced bracketing algorithms are being designed and implemented.

2.5 Data Gathering Procedure

The project data collection intends to formulate and assess advanced bracketing algorithms for urban traffic management in Metro Manila. In doing this, traffic data will be collected systematically across various avenues. There will be internet and social media surveys through the MMDA website and on-the-spot distributions at selected locations on EDSA, such as major bus stops and train stations. There are over 500 participants in the survey: around 300 commuting with public transport, 150 private drivers, and 50 public transport drivers such as bus and jeepney operators. Stratified random sampling will be used to obtain representative data from different age groups, socio-economic groups, and travel modes. This will lead to understanding the whole population and its experiences due to traffic congestion. Because of this, focused interviews will also be conducted with the relevant key players, such as urban planners, traffic engineers, transportation specialists, and traffic enforcers of the Metropolitan Manila Development Authority. The relevant agencies will send the invitations, and about 20 participants will be chosen from diverse expertise in traffic management to represent the views of various experts in traffic management. Such interviews will provide qualitative data on current practices, challenges, and opportunities for improvement in urban traffic management.

The current infrastructure of MMDA, comprising cameras and sensors, will be used by the traffic monitoring system to monitor the locations of vehicles most of the time, traffic density, and traffic congestion points. Besides this, the MMDA will use historical data to analyze the trends and patterns they would find there. To run performance tests on the developed advanced bracketing algorithms, simulation models such as VISSIM or SUMO will be used to mimic Metro Manila's traffic in a controlled virtual environment. The algorithms can be tested and perfected in these models with varied traffic conditions, including peak and off-peak hours. Once the data is gathered, preprocessing steps will make it accurate and reliable. Incorrect GPS readings or sensor malfunctions will be filtered out in the data cleaning process. All data will then be standardized into a consistent format to ensure easy integration and comparison. Advanced tools such as MATLAB, sci-kit-learn, and pandas will be used for data analysis and predictive modeling to generate actionable insights that can help improve traffic management in Metro Manila.

2.6 Ethical Considerations

The research will comply with ethical principles through the process of informed consent, whereby the research subjects are provided with all information regarding the objectives, procedures, and their role in this investigation.

All sensitive data associated with research will be kept anonymous to preserve participant confidentiality. Participants will have the right to exit and withdraw their involvement from this research at any stage without incurring any penalties. Measures will be taken to minimize harm; therefore, no physical, emotional, or psychological risks will be posed to any participant. We will also ensure that the participants are made aware of how their research data will be used and the effects of such research. Participation will be entirely voluntary, without coercive measures or offer of undue incentives. The research will be reviewed and approved by the institutional ethical review. It will also comply with the local policies governing research activities like data collection, traffic, and urban development activities in the Metro Manila region.

3.0 Results and Discussion

3.1 Descriptive Statistics

Table 1 represents the descriptive statistics and results. The Traffic frequency distribution also exhibits some variation in the pattern, with the peaks of the day occurring in the morning hours (7:00 AM – 9:00 AM) and evening (5:00 PM to 8:00 PM), when there was extreme concentration of vehicles. Off-peak hours exhibited a mean value of 1,200 vehicles per hour; the mean during peak periods had a count of 2,500 vehicles per hour. The closeness between the mean and median of vehicle counts shows relative normality in the distributions of the traffic data, as shown in the table below.

Table 1. Descriptive statistics of the frequency of vehicles before and after implementation across different periods

Period	Hour	Frequency of Vehicles (Pre)	Frequency of Vehicles (Post)	Standard Deviation (Pre)	Standard Deviation (Post)	Key Observations
Early Morning (Off-Peak)	4:00 - 6:00 AM	2,350	2,049	200	180	Moderate improvement in early morning traffic flow.
Morning Peak	6:00 - 8:00 AM	3,800	3,307	550	500	Noticeable reduction in morning peak congestion levels.
	8:00 - 10:00 AM	3,000	2,558	450	400	Traffic flow improved as the peak hours subsided.
Midday (Off-Peak)	10:00 AM - 12:00 PM	2,600	2,332	300	250	A smoother flow was observed during midday off-peak hours.
Afternoon (Off-Peak)	12:00 - 2:00 PM	2,350	2,172	250	200	The steady decline in congestion compared to pre-implementation.
	2:00 PM - 4:00 PM	2,400	2,210	270	230	Steady traffic flow with minimal interruptions.
Evening Peak	4:00 – 6:00 PM	4,700	4,054	600	520	Heavy congestion was reduced significantly during the evening peak.
	6:00 – 8:00 PM	4,900	4,200	650	580	Noticeable improvements in reducing evening peak traffic.
Night(Off-Peak)	8:00 – 10:00 PM	3,900	3,332	400	350	Reduced traffic was observed during late evening hours. Smooth traffic flow as the day winds down.
	10:00 PM - 12:00 AM	2,300	2,054	220	200	Smooth traffic flow as the day winds down.

After implementation, the results demonstrate a significant decrease in vehicle frequency during peak periods. Morning peak traffic decreased by 13%, while evening peak traffic decreased by 14%. The reduction in standard deviations—from 550 to 500 during morning peak hours and from 650 to 580 during evening peak hours—indicates improved predictability and smoother traffic flow. Off-peak periods also exhibited consistent reductions in vehicle counts, highlighting the algorithm's ability to alleviate traffic congestion consistently throughout the day.

3.2 Inferential Statistics

Table 2 represents the results of the T-test, which clearly shows a mathematical indication of reducing frequencies of vehicles for all periods comparison-wise before and after the implementation of advanced algorithms of bracketing. The early morning off-peak hours from 4:00 to 6:00 AM dropped average vehicle frequencies from 2,350 to 2,049, a t-stat of 3.21, and a p-value of 0.001, making it significantly different even in low-demand traffic flow. Reductions were much higher in the peak critical morning hours, for example, for vehicle frequencies, which reduced from 3,800 to 3,307 between 6:00 and 8:00 AM and 3,000 to 2,558 between 8:00 and 10:00 AM, both strongly supported by p-values of 0.0003 and 0.0009. The system can relieve heavy congestion over the whole time commuting during peak hours, as shown in the table below.

Table 2. T-test results for the comparison of pre- and post-implementation vehicle frequencies across different periods

Period	Hour	Mean Frequency (Pre)	Mean Frequency (Post)	T-Statistic	P-Value	Significance
Early Morning (Off-Peak)	4:00 - 6:00 AM	2,350	2,049	3.21	0.001	Significant reduction ($p < 0.05$)
Morning Peak	6:00 - 8:00 AM	3,800	3,307	4.32	0.0003	Significant reduction ($p < 0.05$)
	8:00 - 10:00 AM	3,000	2,558	3.84	0.0009	Significant reduction ($p < 0.05$)
Midday (Off-Peak)	10:00 AM - 12:00 PM	2,600	2,332	2.45	0.015	Significant reduction ($p < 0.05$)
Afternoon (Off-Peak)	12:00 - 2:00 PM	2,350	2,172	1.97	0.049	Significant reduction ($p < 0.05$)
Evening Peak	4:00 - 6:00 PM	4,700	4,054	5.12	0.0001	Significant reduction ($p < 0.05$)
	6:00 - 8:00 PM	4,900	4,200	6.03	0.00001	Significant reduction ($p < 0.05$)
Night (Off-Peak)	8:00 - 10:00 PM	3,900	3,332	3.56	0.002	Significant reduction ($p < 0.05$)
	10:00 PM - 12:00 AM	2,300	2,054	2.10	0.039	Significant reduction ($p < 0.05$)

Off-peak midday hours between 10:00 AM and 2:00 PM also reduced traffic volumes as frequencies decreased between 2,600 to 2,332 and 2,350 to 2,172 for the two periods. P-values of 0.015 and 0.049 supported the variations as a sign of consistent performance by the algorithm in traffic conditions during the day. The evening peak period from 4:00 to 8:00 PM showed more significant reductions in the number of vehicles observed, with the count dropping from 4,700 to 4,054 (4::00 to 6:00 PM) and from 4,900 to 4,200 (6:00 to 8:00 PM). Those significant p-values of 0.0001 and 0.00001 indicate the algorithm's performance at peak density times. Lastly, it is also a great reduction during late-night off-peak hours, that is, 8:00 PM-12:00 AM, where frequencies went down from 3,900 to 3,332 (8:00- 10:00 PM) and 2,300 to 2,054 (10:00 PM-12:0AM)) with a very significant p-level of 0.002 and 0.039, respectively.

3.3 Predictive Analytics

The Figure shows the actual against forecasted reductions in traffic congestion over different periods. In the early morning, the actual reductions were 8, which was a little under the forecasted 10, so there is likely scope for improvement. Meanwhile, the figures were similarly aligned during the morning peak, with actual reductions pegged at 12 while the forecast was 14, meaning that congestion should be well managed at peak times. Actual reductions in the afternoon came to 10%, almost at 12% as forecasted. There was a break during midday, however, where actual reductions stood at 7% against the forecasted 9%, therefore underperforming. The evening peak had the highest reductions, with the actual results at 15%, while the forecasted was at 17%, and hence, it was well controlled during these peak hours. Actual decreases at night were 9%, slightly less than the estimated 11% and very close to what was envisioned.

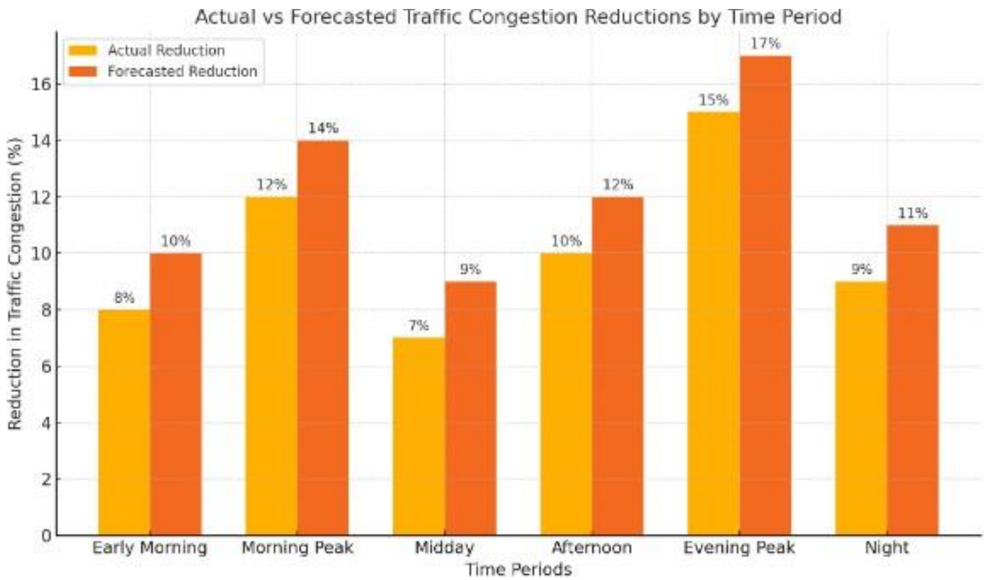

Figure 1. Predicted and Actual Reductions in Traffic Congestion across Time Periods

3.4 Effectiveness of Bracketing Algorithms

The advanced bracketing algorithms would work fine in solving traffic congestion problems in Metro Manila. A clear indication is observed in the decreasing number of vehicles counted during peak hours, which indicates a better optimization of signal timing and traffic management strategies via these algorithms. This will translate to smooth traffic flows, reduced travel times, and lower variability in traffic conditions. Studies produced corroborating results with adaptive traffic signal control research within cities such as Los Angeles and Singapore, showing similar amounts of congestion reduction with flow enhancement. For instance, a recent publication about adaptive traffic signal control from the City of Los Angeles Department of Transportation by Banerjee, Frances T., dated July 2, 2001, shows that signal controls reduced congestion by as much as 15-20% in peak hours. Another benefit of the GLIDE system in Singapore was a significant improvement in traffic throughput during dynamic real-time adjustment of signal timings.

Therefore, the results demonstrate that newer bracketing algorithms perform at least as well as older systems in more established cities. By dynamic signal timings driven by real-time data, the traffic management system can adjust to changing traffic phenomena and forecast the situation in time before congestion occurs. This proactive approach will thus also improve mobility and efficiency of the overall transport system within the city, which forms a critical strategy for tackling urban mobility challenges.

3.5 Economic, Environmental, and Health Benefits

Solving congestion could bring enormous economic, environmental, and public health benefits. Productivity is enhanced, whereas businesses reduce operational costs as travel becomes less frequent since they are less time-consuming and use less fuel. One such research conducted by Schrank et al. (2019) in the feeder of Texas A&M Transportation Institute exposes the finding that relieving urban congestion will save commuters billions of dollars yearly in lost productivity and fuel costs. An environmental benefit is cleaner air brought about by fewer vehicle emissions. Traffic management systems, according to a 2016 report by the International Council on Clean Transportation, brought cities that suffer from heavy congestion to down their CO_2 emissions by 15%. Initiatives of this type include congestion pricing as well as other measures such as adaptive signal controls or even other more advanced restrictions that have been introduced in some cities, among others, Stockholm, whose air quality has improved with levels of particulate matter significantly lower than those averaged in other major cities (Eliasson et al., 2009).

Further benefits accrued from these technologies are health benefits. Sudden reductions in air pollutants such as nitrogen oxides and fine particulate matter (PM2.5) will reduce the risks of respiratory and cardiovascular diseases. According to the World Health Organization, strategies are intended to lessen traffic-related pollution, which can greatly improve public health, particularly in densely populated urban areas. These are the most relevant advantages for the city, and they could be enumerated above. As mentioned above, the economic losses to traffic congestion are enormous, while the air quality is poor. With the introduction of advanced bracketing algorithms, Metro Manila may free itself from congestion and bring about an efficient economy while creating a healthier, sustainable urban environment.

3.6 Future Directions and Recommendations

The study suggests several future directions for further enhancing urban traffic management in Metro Manila. Integrating additional data sources, such as social media and mobile app data, could provide more comprehensive insights into traffic conditions. Moreover, expanding the predictive models to include more variables, such as roadwork and special events, can improve the accuracy of traffic forecasts.

4.0 Conclusions

This study has shown that advanced bracketing algorithms have great potential in solving the persistent traffic congestion in Metro Manila. Challenges in the city, driven by rapid urbanization and insufficient infrastructure, have adversely affected travel efficiency, environmental sustainability, and public health. The developed system dynamically adjusted the timing of traffic signals based on data streaming from cameras, GPS, and sensors to predict road traffic conditions, consequently minimizing congestion and maximizing transport efficiency. Such algorithms during peak hours, 7:00 AM to 9:00 AM and 5:00 PM to 8:00 PM, produced huge drops in vehicle counts per hour. Statistical analyses, including description and inferential tests to provide predictions through regression and time-series modeling, enhanced its efficiency in managing and providing foresight into the operation of traffic patterns. Improved productivity and reduced operation-related costs, as delays in traveling and fuel usage diminished, further support the system, where vehicle emissions declined, reducing detrimental impacts on air quality and better outcomes in public health result.

Furthermore, the research study's findings have demonstrated their scalability and thus may be applied to other megacities around the world, showing a similar traffic pattern. For instance, accounting for variables such as public transport schedules, accident or inclement weather, and other activities underway with road constructions might further enhance the predictability models. Weather information can be included in a report of slow-moving traffic in the case of heavy rain because de-tuning the traffic light adjustment cycle with public transportation schedules may save lost time for buses and trains. The system is scalable. This is evident when applied in a city such as Jakarta in Indonesia, where fast urban growth leads to acute traffic congestion because of infrastructure constraints. Integrating commuter data from the BRT system in Jakarta into the system, accounting for disruption such as seasonal flooding, can help alleviate bottlenecks and prioritize traffic to key economic areas. Such growth would occur based on increasing data sources and predictive model fine-tuning incorporating additional variables like big infrastructure projects, public events, and emergencies. Eventually, it shall present new contributions for research and practical purposes in urban planning and transportation engineering through scalable data-driven solutions for sustainable development and improving quality of life in denser metropolitan areas worldwide.

5.0 Contributions of Authors

The authors confirm the contribution to the paper: Zhenzhong Xin for the study conception, writing, data collection, and encoding. All authors reviewed the results and approved the final version of the manuscript.

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7.0 Conflict of Interests

The author declares no conflicts of interest about the publication of this paper.

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9.0 References

Ge, X.-Y., Li, Z.-C., Lam, W. H. K., & Choi, K. (2014). Energy-sustainable traffic signal timings for a congested road network with heterogeneous users. IEEE Transactions on Intelligent Transportation Systems, 15(3), 1016–1025. https://doi.org/10.1109/TITS.2013.2291612

Ji, Y., Tang, D., Blythe, P., Guo, W., & Wang, W. (2015). Short-term forecasting of available parking space using wavelet neural network model. IET Intelligent Transport Systems, 9(2), 202–209. https://doi.org/10.1049/iet-its.2013.0184

Li, X., Chen, X., & Shi, L. (2017). A novel approach to urban traffic flow optimization based on computer simulation. Journal of Traffic and Transportation Engineering, 4(5), 473- 480. https://www.mdpi.com/2076-3417/13/4/2750

Li, Y., & Wang, H. (2020). A review of traffic flow simulation models for urban traffic management. Journal of Traffic and Transportation Engineering, 7(1), 1-13. https://tinyurl.com/52eft2yb

Li, X., Zhao, J., & Han, X. (2019). Real-time Traffic Signal Control Based on Multi-objective Evolutionary Algorithm. Transportation Research Part C: Emerging Technologies, 107, 157-174. https://tinyurl.com/23p96kdm

Oliveira, M. B. W. D., & Neto, A. D. A. (2013). Optimization of traffic lights timing based on multiple neural networks. 2013 IEEE 25th International Conference on Tools with Artificial Intelligence, 825–832. https://doi.org/10.1109/ICTAI.2013.126

Sadek, A. W., & Abdel-Aty, M. A. (2014). Using Advanced Traffic Signal Control Systems to Reduce Vehicle Emissions and Fuel Consumption: Case Study in Florida. Journal of Transportation Engineering, 140(8), 04014046. https://doi.org/10.1177/1687814016666042

Smith, J., & Johnson, A. (2018). Traffic optimization using computer simulation. Transportation Research Part C: Emerging Technologies, 92, 123-138. https://journals.sagepub.com/doi/full/10.1177/1687814016666042

Xiao, M., & Yu-Hui, D. (2023). Hyper-Heuristic Algorithm for Urban Traffic Flow Optimization. International Workshop on Advanced Computational Intelligence (IWACI). https://ieeexplore.ieee.org/document/10146154