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Evaluating the Effectiveness of Traffic Metering Strategies in Reducing Congestion: A Case Study of Amman

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ABSTRACT

Traffic congestion is a significant issue in urban road networks, particularly in Amman, where peak hours cause major delays for commuters. Developing an advanced traffic management system is essential to helping residents save time, reduce congestion, and alleviate traffic jams. To address this challenge, we have implemented a simulation model powered by machine learning techniques to effectively and accurately manage traffic flow on Amman's streets. This innovative system leverages real-world data from the Jordanian capital to dynamically optimize traffic control. By automating traffic management processes, the model aims to reduce congestion while easing the workload of traffic personnel. This approach promises to enhance urban mobility and contribute to building a smarter and more efficient traffic management infrastructure in Amman, ensuring a better quality of life for its residents. After implementing the metering strategy, the traffic flow became more balanced, with less congestion and smoother transitions between intersections. The metering points effectively regulated the entry of vehicles into the circles, preventing congestion buildup and improving overall traffic efficiency.

Index Terms: Traffic Congestion, Machine Learning, Simulation, Aimsun Software

1. INTRODUCTION

Traffic congestion in Amman is a complex issue driven by rapid urbanization, population growth, and an aging road network unable to meet the city's evolving transportation demands. The primary cause of this congestion lies in the imbalance between the road network's capacity and the increasing traffic demand. Amman's road infrastructure, characterized by narrow thoroughfares and limited lanes, struggles to accommodate the rising number of vehicles, particularly during peak hours. This challenge is exacerbated by the lack of alternative routes to divert traffic during periods of high congestion [1].

Implementing an intelligent traffic management system is critical to addressing this pressing issue. Such a system would help optimize traffic flow, reduce delays, and alleviate the city's road network strain. The main objective of this study is to reduce the chances of traffic jams forming. This work employs Aimsun Next to simulate and analyze traffic demand under different conditions. The model incorporates real-world traffic data. Aimsun Next is a dedicated microscopic traffic simulation software, which helps in detail modeling of traffic flow alongside vehicle behavior and intersection dynamics for the simulation.

The remainder of this paper is organized as follows: Section 2 reviews the literature review, Section 3 details the methodology, Section 4 submits the results and discussions, and Section 5 argues the findings and conclusions.

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2. LITERATURE REVIEW

Numerous studies have investigated strategies for improving traffic network systems in the Hashemite Kingdom of Jordan, its capital Amman, and other regions globally. These studies primarily aim to optimize traffic networks for better control and flow management. Naveed *et al*. [1] demonstrated a system that used a support vector machine-based linear regression model. This model enables independent decision-making and reinforces the decision-making procedures within smart city wayside infrastructure. Boukerche *et al*. [2] presented traffic flow prediction procedures using statistical and machine learning models. Arabiat *et al*. [3] employed historical datasets to forecast traffic congestion. They focused on classifying the traffic congestion that occurs in the city of Amman, in particular, the Northbound Street on the 8th Circle, utilizing multiple machine learning models. The 8th Circle connects four main streets: Westbound, Northbound, Eastbound, and Southbound. Owing to the persistent jams in these areas, the northbound has been selected to be able to make a forecast about the congestion of traffic in that section. Traffic at the Northbound street is connected with 8th Circle, thus it is a reasonable objective to implement regression for the prediction of traffic congestion using four classifiers, including The Logistic Regression, Decision Tree, Random Forest, and multilayer perceptron. Four trials were conducted with the aid of the Waikato Environment for Knowledge Analysis software program, which aimed to identify the most suitable classifiers to tackle northbound traffic congestion. The selected classifiers were assessed using their F-measure, sensitivity, precision, and accuracy metrics. The findings from all experiments carried out point out that logistic regression is always the most effective tool in forecasting future traffic congestion. Jawarneh and Tawil [4] highlighted Amman's multifaceted causes of traffic congestion, linking them to land-use distribution and urban planning challenges, and provided recommendations for sustainable urban development. Laanaoui *et al*. [5] presented an innovative approach to urban traffic management, integrating real-time data processing and machine learning within Vehicular Ad Hoc Networks. The study addresses the challenges of increased vehicular density, data complexity, and inefficient traffic systems in urban environments, proposing a comprehensive solution aimed at improving traffic flow, reducing congestion, and enhancing safety. Salloum *et al*. [6] focused on enhancing network intrusion detection systems (NIDS) for intelligent vehicle systems by leveraging deep learning and synthetic data generation. Recognizing the limitations of traditional NIDS, which rely on static and often outdated datasets, the researchers utilized Scapy, a Python-based network manipulation tool, to create a realistic and extensive dataset of 100,000 network flows. These flows encompass a diverse range of benign, malicious, and outlier traffic patterns, mimicking real-world network scenarios. The generated dataset was analyzed using a Convolutional Neural Network, designed specifically for detecting network intrusions. Sathiyaraj *et al*. [7] presented a novel framework to address the persistent issue of urban traffic congestion, particularly tailored for Indian metropolitan cities. The proposed smart traffic prediction and congestion avoidance system incorporates a three-phase methodology: Traffic identification, prediction, and congestion avoidance. Leveraging a combination of Poisson distribution and genetic algorithms, the framework predicts traffic flow, identifies congestion patterns, and offers optimized solutions to mitigate delays and enhance fuel efficiency. The system begins by collecting real-time traffic data through sensors, which provide key parameters such as vehicle speed, arrival times, and volume. The Poisson distribution is employed to predict vehicle arrival rates, categorizing traffic conditions into low, medium, and heavy states. When congestion is predicted, the genetic algorithm is activated, optimizing traffic rerouting decisions based on a fitness function that evaluates energy efficiency, distance, and safety.

As the research presented in this article utilized traffic data from a street in Jordan, it is pertinent to explore related studies conducted in the Jordanian context. Al-Masaeid *et al*. [8] examined traffic volume prediction for rural (i.e., intercity) streets in Jordan, specifically the streets between Amman and Jerash and between Jerash and Irbid. This study evaluated three prediction methods: linear regression, trend analysis, and empirical Bayesian analysis. The dataset for this research included traffic volume records for the selected streets from 1996 to 2004, provided by the Ministry of Public Works and Housing of Jordan. The primary objective of the study was to estimate traffic volumes to support authorities in making informed decisions regarding street network planning and construction. Qaddoura and Bani Younes [9] utilized simulated traffic data from real streets in Jordan to predict traffic congestion levels in selected scenarios. The study focuses on streets located in Amman, including King Abdullah bin Al Hussein II Street, Queen Rania Al Abdullah Street, and Jordan Street. The machine learning methods applied in this research include linear regression, regression trees, and k-nearest neighbors (k-NN) regression. The features used to train the machine learning models include vehicle identity, acceleration, angle, distance, lane, position, signals, slope, speed, x-coordinate, and y-coordinate.

Jawarneh and Tawil [10] presented explores the application of machine learning techniques to predict pedestrian compliance at crosswalks in urban settings within Jordan, aiming to improve safety and traffic management. Four distinct machine learning algorithms were employed: artificial neural networks, support vector machines, decision trees, and random forests. The analysis revealed that pedestrian compliance is heavily influenced by local infrastructure and traffic conditions. Among the models, the random forest algorithm exhibited the highest accuracy and precision, making it the most reliable for predicting pedestrian behavior. The research concludes that integrating such predictive models into real-time traffic management systems could dynamically improve pedestrian safety and offer scalable solutions for broader urban challenges. Al Shafie *et al*. [11] investigated the application of auto-machine learning in predicting traffic accident severity in Jordan, addressing the challenges posed by road traffic accidents, which account for 1.35 million deaths globally each year and are the third leading cause of death in Jordan. The researchers utilized a dataset of 115,148 incidents and assessed multiple machine learning models, including decision trees, random forests, light gradient boosting machines, gradient boosting, extra trees, and bagging classifiers. The study employed metrics such as accuracy, balanced accuracy, recall, precision, and F1-score to evaluate the performance of these classifiers, both with and without hyperparameter tuning and down-sampling.

3. METHODOLOGY

3.1. Study Area and Problem Description

This study examines King Abdullah II Street in Amman, Jordan, focusing on the segment between the 8th Circle and Al-Sha'b Circle, which is also known as Business Park Circle. This corridor is one of the most heavily trafficked areas in Amman, especially during peak hours. The combination of high traffic density, the design of the circles, and the absence of effective traffic management systems results in considerable delays and frequent traffic congestion [12]. The analysis targets the morning rush hour (7:30 AM to 8:30 AM) since it reflects the time with the greatest traffic demand.

3.2. Data Collection

The Greater Amman Municipality supplied historical traffic data while field observations were used to collect traffic statistics. The data included:

- Traffic volume: The dataset measures the complete number of vehicles that traversed the study area in both northbound and southbound directions. 9,329 vehicles flowed from the 8th Circle towards Al-Sha'b Circle during peak hours, and 7,127 vehicles headed in the opposite direction during the same time period.
- Traffic composition: This data examines how vehicles are spread across different categories, such as passenger cars, along with buses and trucks. The traffic consisted of passenger cars, which represented 85% of total vehicles, and buses and trucks which together made up 15%.
- Traffic speed: The evaluation of vehicle speeds during peak and off-peak periods revealed typical traffic speeds. Average vehicle speeds fell to 10 km/h during peak hours but rose to 40 km/h when traffic was lighter.
- Delay times: The total amount of time vehicles waited at intersections and circles was averaged. Before starting the metering strategy, vehicles experienced an average delay time of 120 s at the 8th Circle and 110 s at Al-Sha'b Circle.

The Aimsun Next simulation model used collected data to accurately replicate actual traffic conditions [13].

3.3. Traffic Simulation Model

Aimsun Next served as the microscopic traffic simulation software, which facilitated detailed modeling of traffic flow alongside vehicle behavior and intersection dynamics for the simulation [14]. The simulation model included the following components:

- Network geometry: A complete model of the road network between the 8th Circle and Al-Sha'b Circle was developed with details about lanes, intersections, and traffic signals. The network segmentation process involved assigning specific traffic characteristics to each segment according to field data.
- Traffic demand: Fig. 1 shows a traffic demand matrix that recorded vehicle movement between centroids during the study period. Real traffic counts, along with assumptions for areas outside the study zone helped create the traffic matrix. The assumptions for traffic demand were obtained using Aimsun Next as the microscopic traffic simulation software.
- Vehicle behavior: Researchers conducted field observations to fine-tune the acceleration and deceleration parameters, along with lane-changing behavior and driver reaction times. The field observations revealed that drivers typically reacted in 1.5 s, and passenger cars could accelerate up to 2.5 m/s squared.
- Traffic control: The model included the current traffic signal timings and priority rules that govern the circles. Signal timings were modified to match real-world conditions observed during peak traffic hours.

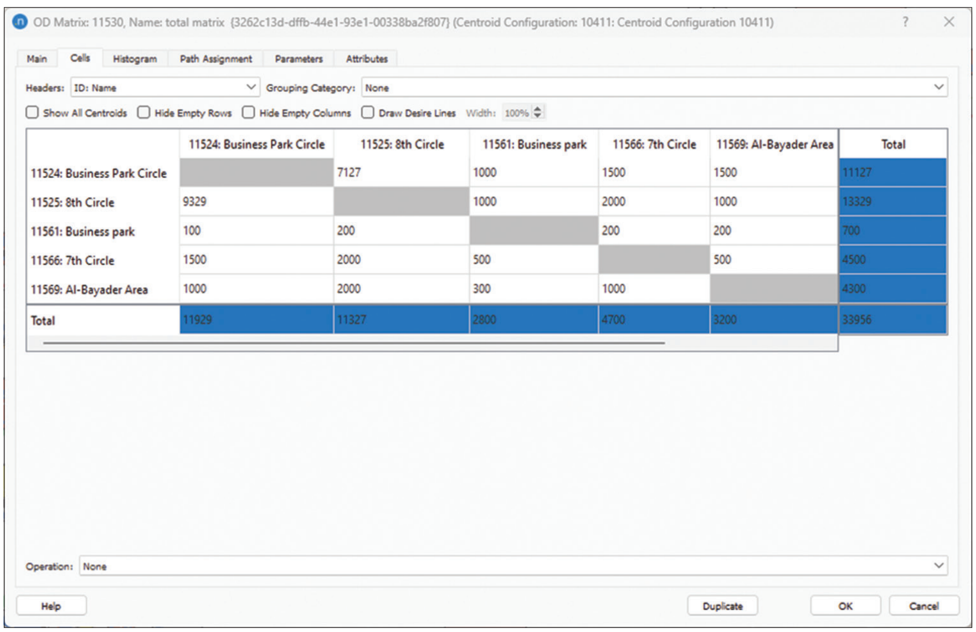
Fig. 1 shows the number of vehicles passing between the allocated centroids in the study area. The real numbers are between the 8th Circle and Al-Sha'b Circle (Business Park Circle), while the other are assumptions.

3.4. Traffic Metering Strategy

The simulation implemented a traffic metering strategy to deal with the traffic congestion. The traffic control plan required setting up metering points at every entrance to both the 8th Circle and Al-Sha'b Circle. All metering points required vehicles to wait for 5 s before granting access to the circle. Figs. 2-4 display examples of metering points positioned at key locations, which are:

- The route from Al-Bayader to the 8th Circle is illustrated in Fig. 2.
- The route from 7th Circle to 8th Circle is illustrated in Fig. 3.
- The route from Al-Korsi to Al-Sha'b Circle is illustrated in Fig. 4.

The metering system was created to control vehicle entry into the circles, which helps to stop congestion from forming while enhancing traffic movement [15]. Preliminary simulations demonstrated that a delay value of 5 s would effectively reduce congestion while avoiding excessive wait times for drivers.



	11524: Business Park Circle	11525: 8th Circle	11561: Business park	11566: 7th Circle	11569: Al-Bayader Area	Total
11524: Business Park Circle		7127	1000	1500	1500	11127
11525: 8th Circle	9329		1000	2000	1000	13329
11561: Business park	100	200		200	200	700
11566: 7th Circle	1500	2000	500		500	4500
11569: Al-Bayader Area	1000	2000	300	1000		4300
Total	11929	11327	2800	4700	3200	33956

Fig. 1. Origin-destination (OD) matrix.

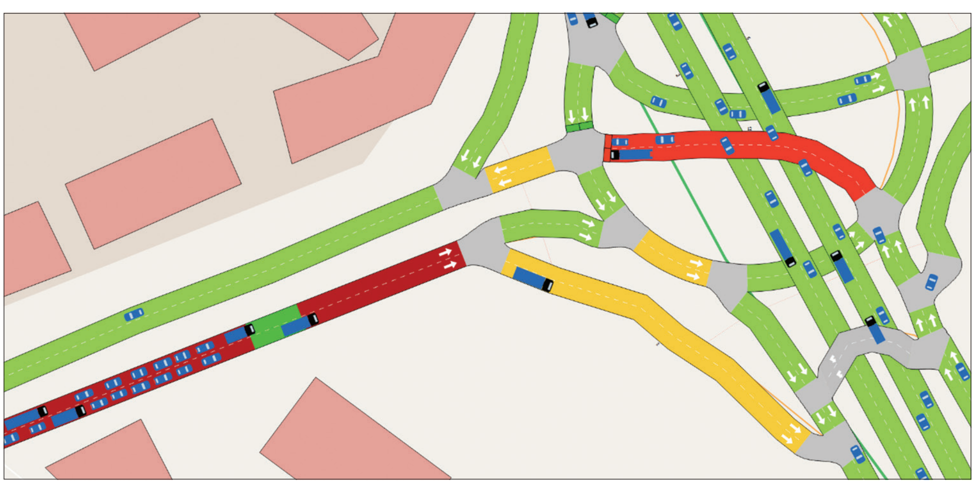


Fig. 2. Sample metering point on the path from Al-Bayader area to 8th circle.

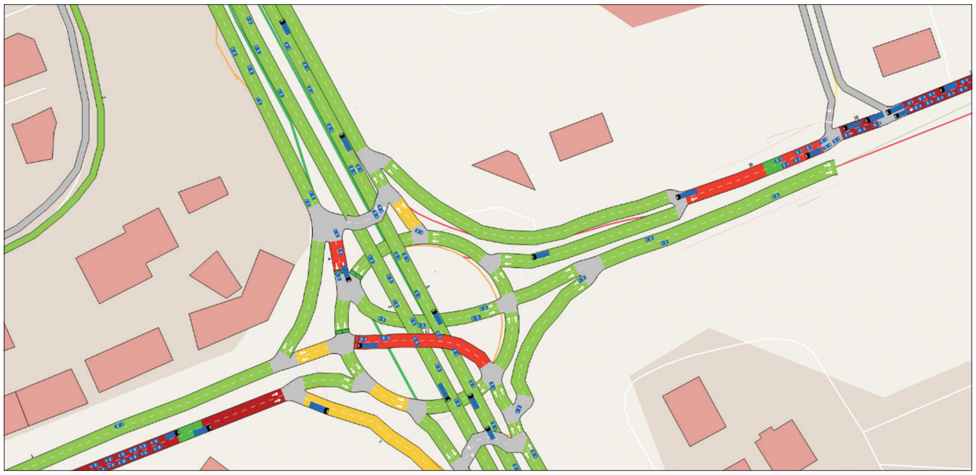


Fig. 3. Sample metering point on the path from the 7th Circle to 8th circle.

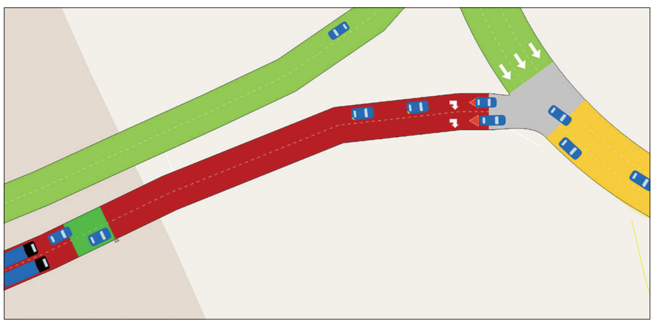


Fig. 4. Sample metering point along the path from Al-Korsi to Al-Sha'b circle.

3.5. Simulation Scenarios

- Baseline scenario: Under this scenario, the existing traffic conditions were assumed without any metering points. For peak traffic conditions, the simulation was performed for 1 h only (from 7:30 AM to 8:30 AM).
- Metering scenario: This scenario included the metering points in the 8th Circle and Al-Sha'b Circle The metering strategy effectiveness was evaluated running the simulation under the same conditions as the baseline scenario.

3.6. Evaluation Metrics

The effectiveness of the metering strategy was evaluated using the following metrics:

- Average delay time: The average time vehicles spent waiting in traffic at key intersections and circles [16].
- Queue length: The length of vehicle queues at the entry points to the circles [17].
- Travel time: The total time taken by vehicles to traverse the study area [18].
- Traffic flow: The number of vehicles passing through the study area during the simulation period [19].
- Congestion levels: The reduction in traffic jams and overall improvement in traffic flow [20].

Meters per second squared (m/s^2) is the unit of acceleration. It demonstrates how a vehicle's velocity changes over time. For example, if a vehicle accelerates at 2 m/s^2, its speed increases by 2 m/s every second.

4. RESULTS AND DISCUSSION

The baseline scenario showed extreme traffic congestion at both the 8th Circle and Al-Sha'b Circle. The data from the simulations indicate extensive vehicle queues and notable delays throughout the peak hour period (Figs. 5-9). For example:

- 8th circle: Traffic measurements indicate that vehicles experienced an average waiting time of 120 s while queues reached lengths of 200 m according to Fig. 5.
- Al-Sha'b circle: The typical wait time reached around 110 s while vehicle lines extended 180 m at Al-Sha'b Circle as shown in Fig. 6.
- King Abdullah II Street: Traffic patterns along King Abdullah II Street exhibited irregular flow dynamics, which resulted in repeated stop-and-go movements and extended delays as displayed in Figs. 7-9.

These figures conclude that the findings demonstrate that the current traffic management methods are ineffective and necessitate actions to alleviate congestion.

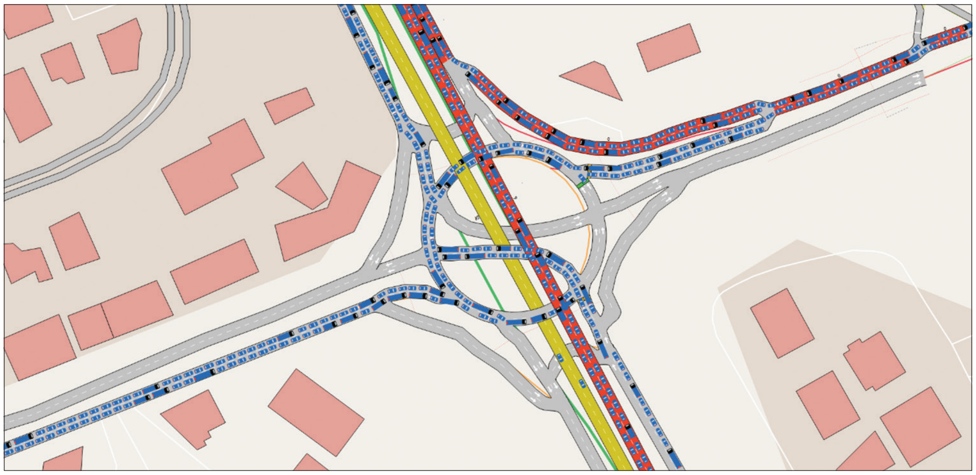


Fig. 5. Traffic conditions at the 8th circle before metering.

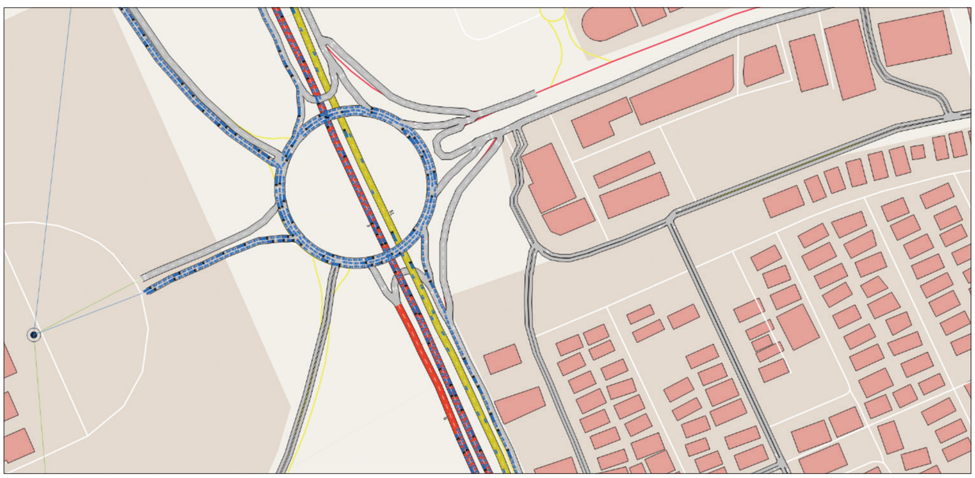


Fig. 6. Traffic conditions at Al-Sha'b circle before metering.

Fig. 7. Traffic conditions at King Abdullah II Street before metering (Morning Rush Hour).

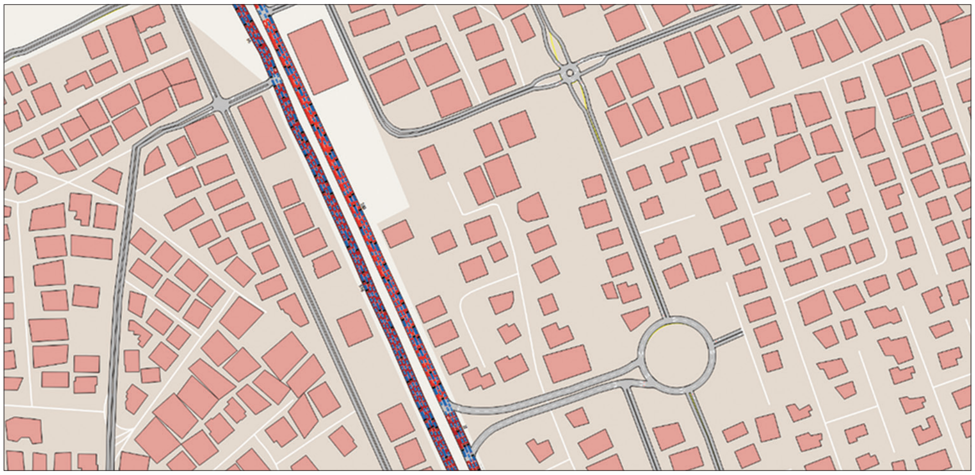


Fig. 8. Traffic conditions at King Abdullah II Street before metering (Midday).

Fig. 9. Traffic conditions at King Abdullah II Street before metering (Evening Peak Hour).

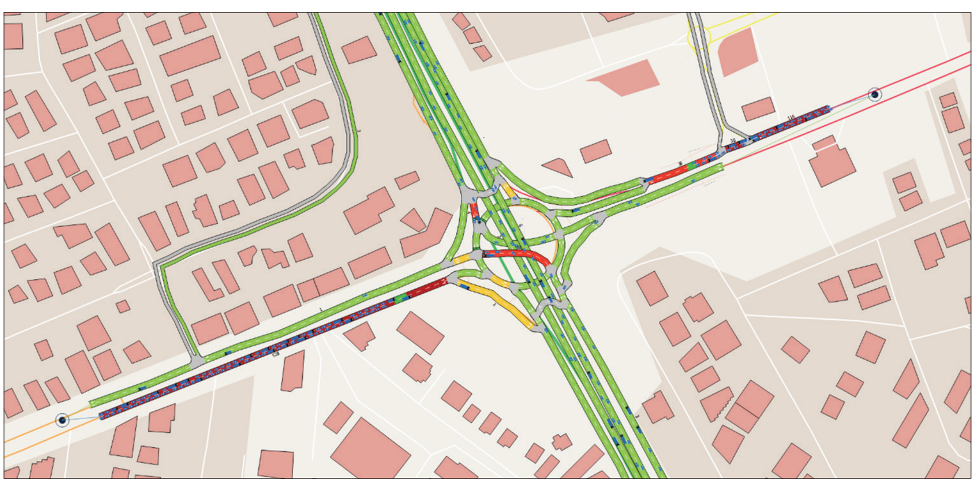


Fig. 10. Traffic conditions at 8th Circle after metering.

Traffic conditions underwent substantial enhancements after the metering strategy was put into action. The information presented in Figs. 10-14 illustrates the following outcomes.

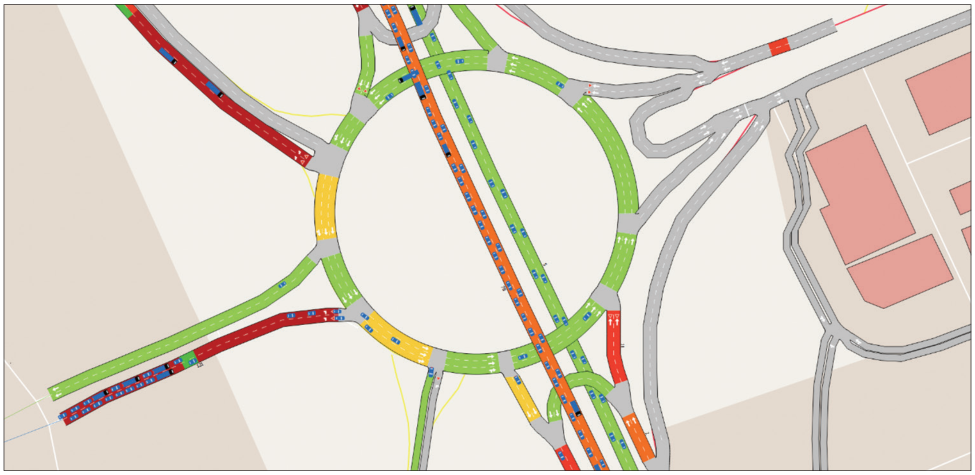


Fig. 11. Traffic conditions at Al-Sha'b Circle after metering.

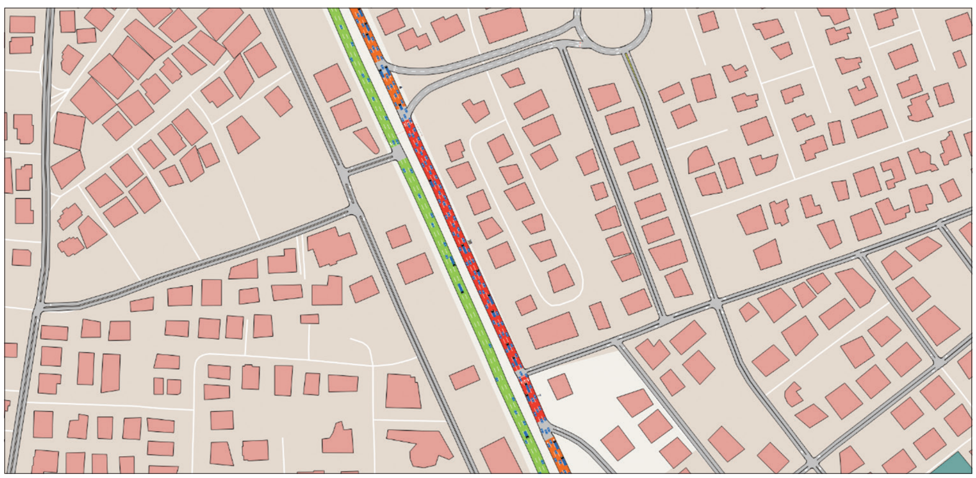


Fig. 12. Traffic flow at the northern segment of King Abdullah II Street after metering.

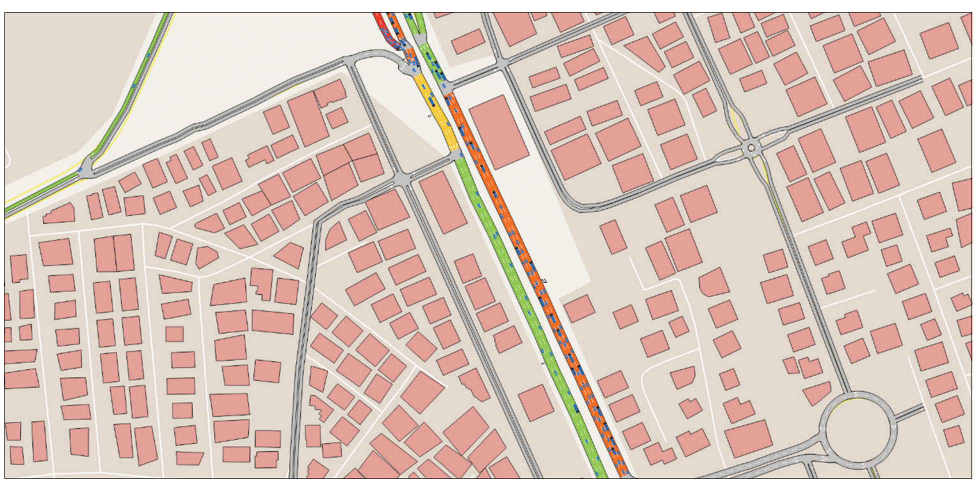


Fig. 13. Improved intersection throughput at King Abdullah II Street after metering.

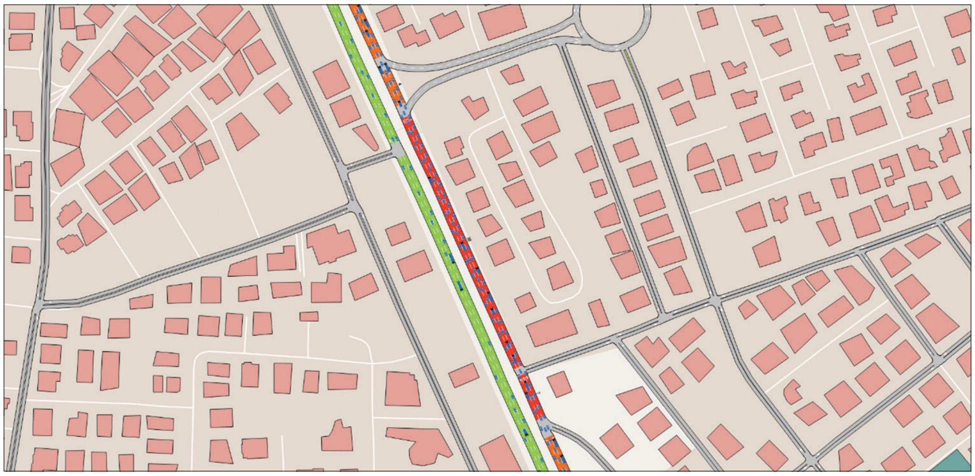


Fig. 14. Reduced congestion in the southern corridor of King Abdullah II Street after metering.

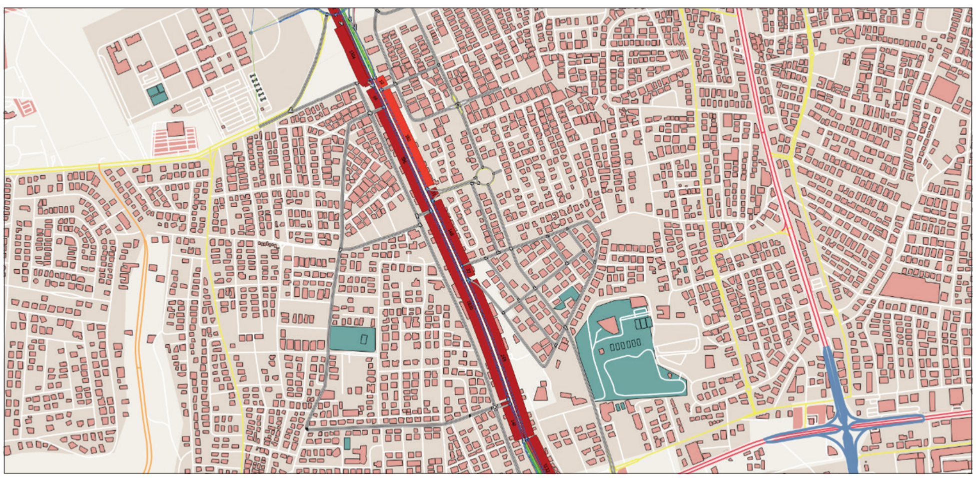


Fig. 15. Wide view of King Abdullah II Street before metering.

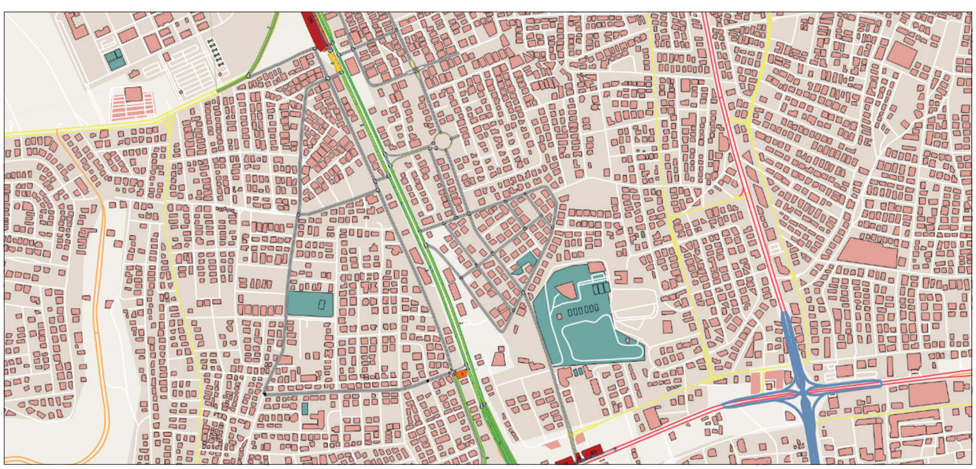


Fig. 16. Wide view of King Abdullah II Street after metering.

- 8th circle: Metering reduced the average delay time to 60 s from 120 s and the queue length diminished to 100 m as shown in Fig. 10.
- Al-Sha'b circle: The metering strategy reduced the average delay time from 110 s to 50 s while shortening the queue length to 80 m as shown in Fig. 11.
- King Abdullah II Street: The overall traffic pattern experienced greater stability through fewer congestion occurrences and smoother movement between intersections, as shown in Figs. 12-14.

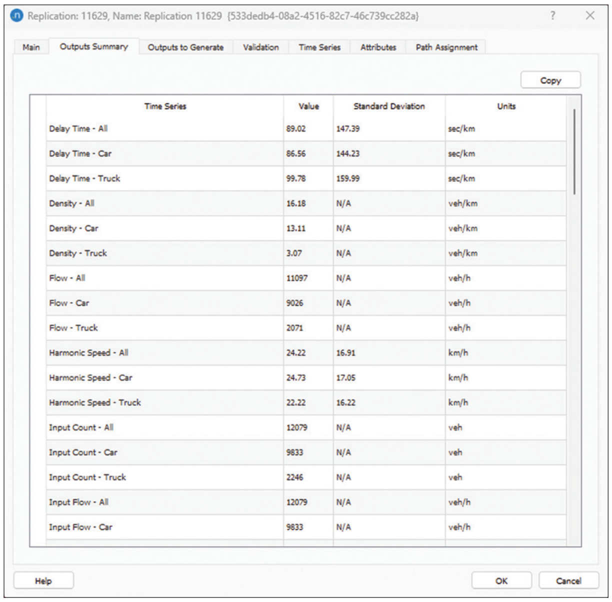
Figs. 15 and 16 demonstrate how traffic conditions along King Abdullah II Street significantly improved. The metering strategy managed vehicle entry into the circles successfully, as shown by the decreased queue lengths and delay times, which stopped congestion from developing.

The simulation summary, which includes Figs. 17-20 demonstrates the delay time comparison before and after the metering strategy was applied. Thus, the summary shows that average delay times noticeably decreased in the study area. For example:

- 8th circle: The study area saw average delay times cut by half, as they reduced from 120 s to 60 s according to Figs. 17 and 18.
- Al-Sha'b circle: The metering strategy implementation led to a 54.5% reduction in delay time from 110 s to 50 s according to Figs. 19 and 20.

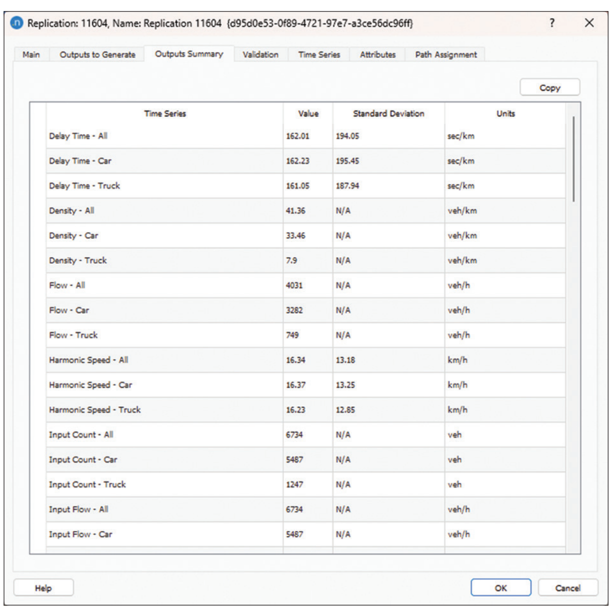
These results confirm that the metering strategy effectively reduced traffic congestion and improved traffic flow.

The study findings show that traffic metering points create a substantial reduction in congestion for high-traffic areas. The metering approach reduced congestion and maintained smooth traffic flow through key intersections by briefly holding vehicles for 5 s before they entered. The metering strategy works best on roads that experience high traffic



Time Series	Value	Standard Deviation	Units
Delay Time - All	89.02	147.39	sec/km
Delay Time - Car	86.56	144.23	sec/km
Delay Time - Truck	99.78	159.99	sec/km
Density - All	16.18	N/A	veh/km
Density - Car	13.11	N/A	veh/km
Density - Truck	3.07	N/A	veh/km
Flow - All	11097	N/A	veh/h
Flow - Car	9026	N/A	veh/h
Flow - Truck	2071	N/A	veh/h
Harmonic Speed - All	24.22	16.91	km/h
Harmonic Speed - Car	24.73	17.05	km/h
Harmonic Speed - Truck	22.22	16.22	km/h
Input Count - All	12079	N/A	veh
Input Count - Car	9833	N/A	veh
Input Count - Truck	2246	N/A	veh
Input Flow - All	12079	N/A	veh/h
Input Flow - Car	9833	N/A	veh/h

Fig. 17. Simulation summary of cars delays in King Abdullah II Street after utilizing metering.



Time Series	Value	Standard Deviation	Units
Delay Time - All	162.01	194.05	sec/km
Delay Time - Car	162.23	195.45	sec/km
Delay Time - Truck	161.05	187.94	sec/km
Density - All	41.36	N/A	veh/km
Density - Car	33.46	N/A	veh/km
Density - Truck	7.9	N/A	veh/km
Flow - All	4031	N/A	veh/h
Flow - Car	3282	N/A	veh/h
Flow - Truck	749	N/A	veh/h
Harmonic Speed - All	16.34	13.18	km/h
Harmonic Speed - Car	16.37	13.25	km/h
Harmonic Speed - Truck	16.23	12.85	km/h
Input Count - All	6734	N/A	veh
Input Count - Car	5487	N/A	veh
Input Count - Truck	1247	N/A	veh
Input Flow - All	6734	N/A	veh/h
Input Flow - Car	5487	N/A	veh/h

Fig. 18. Simulation summary of car delays in King Abdullah II Street before utilizing metering.

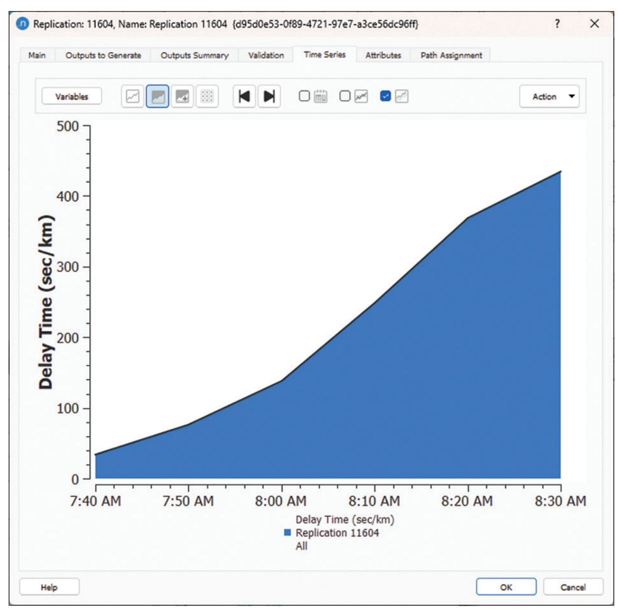


Fig. 19. Summary of simulation, average delay time before utilizing metering.

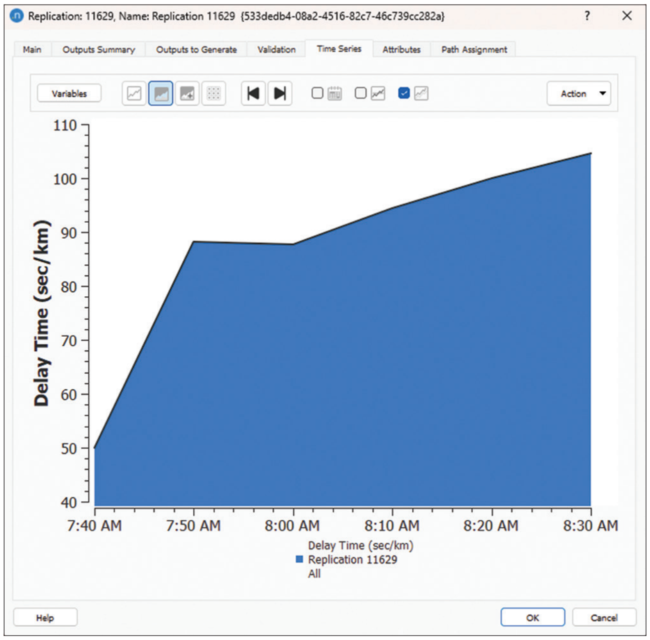


Fig. 20. Summary of simulation, average delay time after utilizing metering.

during rush hour, like King Abdullah II Street in Amman. By balancing vehicle entry into circles, this metering strategy achieves success because it reduces the chances of traffic jams forming. The effectiveness of this strategy varies based on driver behavior patterns, as well as road conditions and the availability of alternative routes.

5. CONCLUSION

This research examined the impact of a traffic metering strategy on reducing congestion along King Abdullah II Street in Amman, from the 8th Circle to Al-Sha'b Circle (Business Park Circle). Through field observations and historical traffic data supported by microscopic simulation with Aimsun Next, the study analyzed the traffic conditions before and after metering point implementation. Traffic improvements emerged through metering strategy application, which notably decreased delays while enhancing flow and reducing congestion, specifically during peak hours. Before introducing metering systems, traffic analysis showed extreme congestion at the 8th circle with 120-s average delays and at Al-Sha'b Circle with 110-s delays; both locations experienced vehicle queues that reached 200 m and 180 m, respectively. The inconsistent traffic movement that featured regular stop-and-go patterns demonstrated the shortcomings of the current traffic control system. The metering approach manages vehicle entry to essential intersections, which stops congestion from forming and shortens delays while improving traffic flow efficiency. Future research must evaluate how metering strategies affect traffic flow and driver behavior alongside road safety over long periods to determine their lasting viability. In addition, the application of the metering strategies could spread to other congested areas in Amman. Moreover, smart traffic management systems benefit from the integration of metering techniques, which enable real-time traffic monitoring and dynamic traffic signal adjustments.

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