Research Article

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Investigating traffic characteristics for merging sections in Iraq

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Abstract: Recurring congestion on highways is the primary cause of traffic congestion in the urban traffic system while jams on merging sections are the worst section along the expressway. Due to the presence of heavy congestion in the site of University of Technology, this study aims to discover the traffic characteristics of this site to determine the appropriate solutions. Therefore, this study selects a merging section on Mohammed Al-Qassim expressway to investigate some characteristics of such a section in Iraq. Field data have been collected from this site for 4 h. The data were collected from video cameras installed along the expressway in Baghdad city which is called Mohammed Al-Qassim Expressway. These data present flow of upstream and ramp. The Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks (AIMSUN) program was also adopted to investigate other characteristics which are difficult to get such as speed and occupancy for the current case. The results showed that the simulated and real data significantly corresponded. In this study, the AIMSUN program received recognition by utilizing Geoffrey E. Havers a method for comparing two sets of traffic volumes that are used in traffic engineering, traffic forecasting, and traffic modeling as it was discovered to be comparable to reality, and the road management was then enhanced by the addition of ramp metering and cycle (green) time control.

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1 Introduction

Recurrent traffic jams on highways are caused by specific infrastructure elements, such as on-ramps, lane drops, and sharp curves, but they do not always occur under the same traffic conditions or with the same traffic flow or density [1]. Therefore, merging sections are from the most congested sections within expressways. One of the significant means to regulate traffic in merging sections is the ramp metering (RM). RM is the most direct and efficient approach to freeway traffic flow management [2]. It aims at improving freeway traffic conditions by appropriately regulating the on-ramp inflows to the freeway mainstream [3]. The main defects of RM are three. First, RM is ineffective at maintaining the main line flow at or below its capacity. Second, RM cannot manage the flow on the main line, only from on-ramps. Third, because there is a limited amount of on-ramp storage space, controlling the inflow of cars from on-ramps may induce the creation of vehicle lineups at on-ramps [4]. Increased traffic congestion may also affect traffic safety, and traffic delays result in huge social costs. The RM technique is not utilized in Iraq yet. This study used the simulation for utilizing the RM in Iraq Baghdad city. The main contribution of this study is utilized by using the Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks (AIMSUN) software for Iraq RM simulation issue. The research aims to improve the capacity of merging sections on the expressway in Baghdad city using field data and AIMSUN model.

2 Characteristics of merging sections

The lower-level merging controller often has two separate responsibilities: first, establishing the right distance; and second, managing the speeds of the collaborating cars to ensure a quick and secure merger [5]. The "optimal" velocity profile is defined in the sense of minimizing acceleration deviations. An upper-level controller is utilized to allocate the gaps to the merging cars so that traffic can proceed at mainline speed [6]. The suggested control technique tries to match on-ramp merging vehicles to precisely constructed (or altered) gaps in the mainstream. When the arrival rate of the mainline flow is larger than a certain number, the cars from the ramp strongly [2] influence the pass of mainline vehicles, and the merging ratio varies as ramp vehicles increase. Additionally, it explains how the length of the merging section and the likelihood of lane changes affect the merging ratio of on-ramp bottlenecks, and some relevant intelligent control solutions are suggested in real-world traffic applications [2]. Numerous studies based on empirical data on expressways have been carried out to examine the traffic flow characteristics around merging zones in relation to on-ramp bottlenecks [2]. Most of the time, lane-changing behaviors have the biggest impact on traffic flow during an on-ramp congestion. Vehicles on the mainline may slow down and cause traffic congestion as a result of aggressive lane-changing behaviors. Each driver has his or her own [7] attribution; therefore, the drivers may be loosely divided as aggressive, neutral, and conservative drivers according to their driving habits.

1) The aggressive driver drives more aggressively than the neutral driver does, which demonstrates that the aggressive driver accelerates and speeds up more quickly than the neutral driver does.
2) The conservative driver exhibits more cautious driving than the neutral driver, as seen by the fact that the conservative driver accelerates and speeds less slowly.

Because of their intricate mechanisms, significant traffic jams have drawn a lot of attention in recent years. In order to describe it, several [8] traffic flow models have been developed. The cycle should be selected to make sure that gap G and the discharge of on-ramp cars are coordinated. Vehicles merging at on-ramps is one of the primary causes of traffic congestion on roads, and the green length the number of on-ramp vehicles for every traffic light cycle should be proportionate to the gap size [9]. To improve safety and reduce congestion issues, automated processes for cooperative vehicle merging are being developed [6]. One of the primary causes of traffic flow issues on highways, such as speed breakdown, traffic flow oscillations, and congestion, is the merging of the outgoing flow with the incoming flow at on-ramps [10,11]. The creation of integrating aid systems is the subject of an ever-increasing amount of effort [6]. Although the coordination of both on-ramp and mainstream traffic is necessary for the most efficient merging, the decisions in the first case are made in a traffic management center, whereas in the second case, the decisions are made on each individual vehicle and may be transmitted to the affected vehicles [12].

3 Asservissement Linéaire d'Entrée Autoroutière (ALINEA) method

Several RM algorithms have been developed over a period of more than 30 years to enhance freeway performance. Numerous of these algorithms have been implemented across the globe, and field evaluations have demonstrated their value in enhancing traffic conditions on motorways and ramps [13]. ALINEA was discovered to be the local RM strategy that was used the most. The algorithm is straightforward, and compared to other tactics, it is simpler to implement. Additionally, it guarantees the specified performance objectives as long as the on-ramp has enough storage [13].

It is possible to use the well-known feedback RM algorithm ALINEA for local RM [8] or as a crucial part of a coordinated RM system. The ramp flow merging region, which may be only a few hundred meters downstream of the metered on-ramp nose, is where ALINEA obtains its real-time occupancy readings. RM is a significant method of regulating motorway traffic in several situations [14–17]. Over the past three decades, several field applications have shown the value of RM. ALINEA is a well-liked and effective local RM technique that was created using feedback control theory [18]. ALINEA has been effectively used on hundreds of motorway sites throughout the world since its design concept was created in the late 1980s [15]. It is capable of being coupled with coordinated RM schemes despite its local operating nature [19].

According to the [14] principle, ALINEA must receive occupancy readings from the RM area in order to achieve its goal of maximizing highway throughput. Due to a non-negligible time delay between the RM operation and its influence on traffic flow dynamics at the bottleneck site, there is cause for worry in the design of RM controllers. In response to the issue [18], provided extensive theoretical analyses that showed occupancy measurements in this situation have to be taken at the bottleneck [14]. In order to avoid congestion and capacity loss at the bottleneck, the feedback RM controller ALINEA seeks to maintain [20] the bottleneck flow around the bottleneck capacity.

Due to the same observed occupancy across lanes, ALINEA is provided with the density of the times [21] of greatest flow. However, especially with the higher speed restrictions, the pace is higher in the median lane. This suggests that the median lane's maximum flow is much higher than the central and shoulder lanes' maximum flows [21]. Low-speed zones widen the gap between the relative speeds of the lanes, which widens the lane Vehicles on the mainline are changing lanes abruptly [2] because of this. It could be difficult to define the criterion for lane switching at on-ramp bottlenecks by only taking the distance into account. Before changing lanes, drivers will take into account the entire scenario, including the space and speed. A vehicle wanting to change lanes can require a significant separation if the target lane's speed is very high. In contrast, a vehicle may change lanes while confronting a relatively tiny gap when traffic is moving slowly in the target lane.

4 AIMSUN model

A micro-simulation model called AIMSUN was created in Spain, and it has 3D animation capabilities in addition to features not found in corridor traffic simulation or Sim Traffic. Because AIMSUN enables dynamic trip assignment and the simulation of ITS system effects, it was chosen for assessment [22]. Since AIMSUN is the only package that has been tested to satisfy these requirements, it may be desirable to limit its use to situations that call for its full capabilities [22]. The United States is now using AIMSUN, a well-liked microsimulation program that was previously more widely utilized in Europe. Additionally, it provides the ability to dynamically assign traffic. The purpose of using Aimsun or Aimsun Online is to offer remedies for immediate and medium-term planning and operational issues for which the dynamic and disaggregate [23].

It gives an explanation of the AIMSUN model and its possible uses. Also, it gives a thorough explanation of AIMSUN's dynamic assignment capabilities. The mainline corridor, on-off ramps, and arterial highways in San Diego are all covered by the comprehensive and extensive AIMSUN network. A new implementation of Heuristic Ramp-Metering Coordination algorithm was created from algorithms, whereas ALINEA algorithm is already part of AIMSUN's basic distribution [24].

5 Methodology

One of the significant steps of this research is the use of real highway data in Iraq Al-Technology merging section and using the AIMSUN as a simulation model. This simulation model will be verified, calibrated, and validated using two sets of field data. Then, this simulated model will be used to test different scenarios.

The AIMSUN model was used to analyze the real data, and the same design was made for the merging section, and after doing calibration and validation for the real data using graphical and statistical test Geoffrey E. Havers (GEH), it was proven that the program represents reality. Flow improvement, occupancy reduction, and speed increase were made by adding the metering to the on-ramp.

5.1 Description of the site

The site that is under consideration in this study is the University of Technology site. This site is the third location out of sixth sites of entrance to the Mohammed Al-Qassim Expressway as indicated in Figure 1.

This site consists of a slip road which is the start of the ramp that has a length of (174.59 m), a width of (9 m), an area of (1356.44 m^2), and an acceleration lane that has a length of (85.75 m), and an area of (368.45 m^2). The vehicles flow in acceleration lane increase speed to enter the freeway merge section. Figure 1 indicates this site and its characteristics. Figure 2 shows the site of University Technology from video. The ramp way consists of two lanes while the freeway consists of three lanes. The study is solving congestion issue in the ramp way. Therefore, the applied methodology is employed for solving this problem.

5.2 Data collection

Data have been extracted from a camera-type NVR (network video record) recording for a time duration from 7:00–11:00 AM on Saturday October 15, 2022. However, this camera is able to record traffic data at the site for 24 h. These 4 h are the peak hours; therefore, it is sufficient for studying the problem of congestion on this site. Manual data inspection was conducted from video recording, and special software was utilized to extract the relevant data. The software can provide several characteristics for vehicles such as vehicle flow, vehicle count number, vehicle pass time, and classification of vehicles (car, truck, and pedestrians). Figure 3 illustrates the flow of freeway and on-ramp. This flow shows the fluctuations around the peak hour. Table 1 shows the 5 min traffic volume data extracted for the site.

Figure 1: University of Technology merging section in Baghdad.

Figure 2: The merging section at the site of the University of Technology.

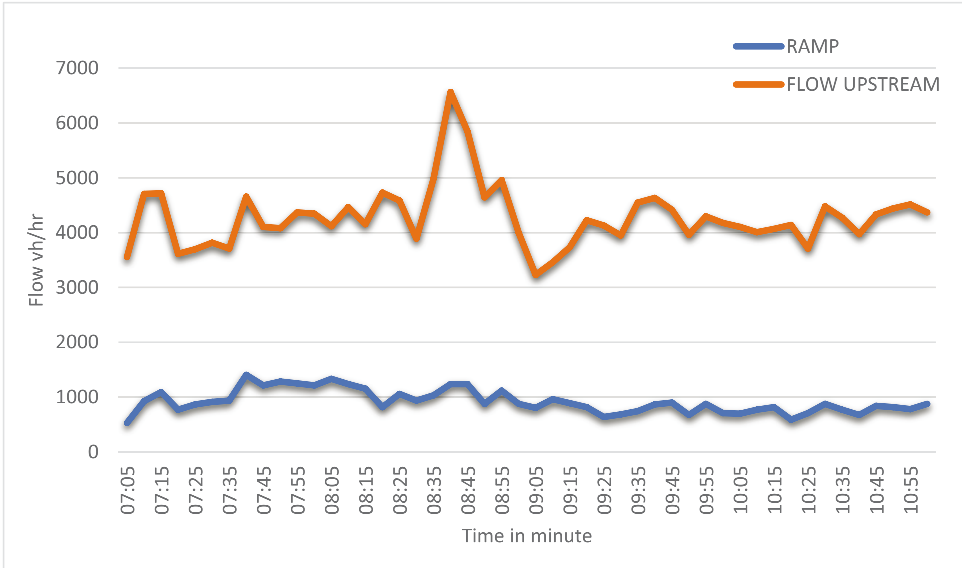

Figure 3: Data for flow highway with flow of ramp.

5.3 GEH test

To compare two sets of traffic volumes, the GEH Statistic is a formula used in traffic engineering, traffic forecasting, and traffic modeling. GEH, a transport planner in London, England, in the 1970s, is credited with creating the GEH formula [25]. The GEH Statistics are computed using the simulation and real-time volumes captured [26]

$$\text{GEH} = \sqrt{\frac{2(m-c)^2}{m+c}}, \tag{1}$$

where m is the output traffic volume from the simulation model (vph), and c is the input traffic volume (vph).

Applying this formula, if the GEH ≤ 5, the simulation is fit for representing reality.

Table 1: Data collected

Time	Flow upstream	Ramp
7:00–7:05	3,024	528
7:05–7:10	3,780	924
7:10–7:15	3,624	1,092
7:15–7:20	2,844	768
7:20–7:25	2,832	864
7:25–7:30	2,904	912
7:30–7:35	2,772	936
7:35–7:40	3,252	1,404
7:40–7:45	2,892	1,212
7:45–7:50	2,796	1,284
7:50–7:55	3,120	1,248
7:55–8:00	3,132	1,212

5.4 Calibration process

The significant stage of testing the accuracy of the simulation model is to calibrate this tool with the field data. This set of data consists of 4 h starting at 7:00 AM and ending at 11:00 AM as indicated in Figure 4. As mentioned before, AIMSUN has been used as a simulation tool to mimic reality. Then, the GEH test has been used for testing the level of accuracy of simulated data. If the value of GEH is less than or equal to 5, the simulated data could be accepted to represent the real case.

Furthermore, the graphical representation between the simulated and actual data, the GEH = 0.01. This value was obtained after the change in the behavior factors of the driver, where it became 50 for the cooperative and 50 for the aggressive as indicated in Figure 4 which represents another type of testing the accuracy of simulated results. Figure 4 shows an acceptable behavior to mimic reality. Furthermore, there is a significant consistency between simulated and field data for each 5 min as indicated in Figure 4.

5.5 Validation process

Another set of field data has been used to testify to the accuracy of the simulated results. Accordingly, the results show a significant consistency with the field data from 11:00 AM and ending at 1:00 PM as shown in Figure 5.

Figure 4 indicates how the simulated data is close to the real data. Furthermore, the statistical test (GEH) has

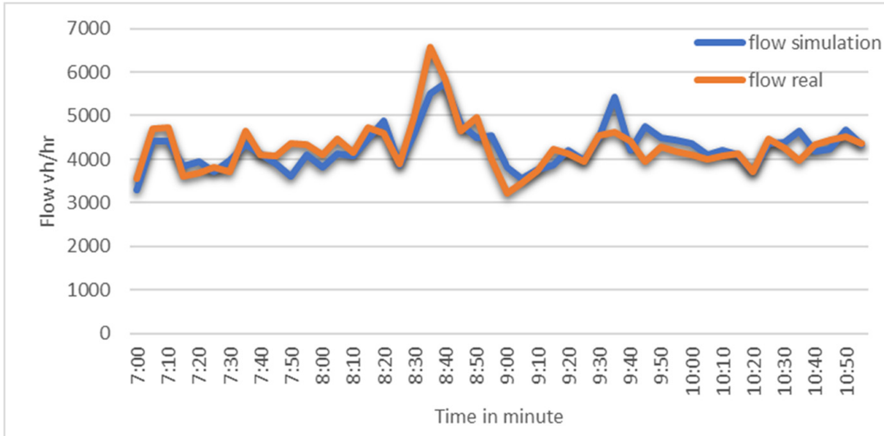

Figure 4: Flow simulation with real flow.

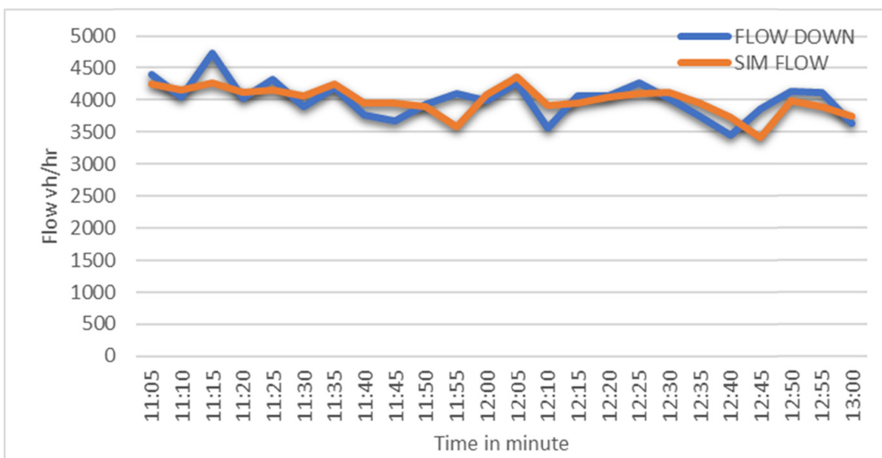

Figure 5: Simulated flow with real data.

been also used with a value of 0.2 which indicates a high consistency between simulated and actual data. Table 2 indicates value of data and value of GEH test.

6 The application of AIMSUN

Having conducted the calibration and validation processes, the simulation model (AIMSUN) can represent reality to some extent. Several scenarios have been applied to find some parameters such as speed and occupancy in addition to applying the RM management to find out the significant effect of RM on the performance of merging sections.

Table 2: The value of GEH test

The tested data	GEH
Data from 7 am–11 am	0.01
Data from 11 am–1 pm	0.2

6.1 Flow–occupancy relationship

The flow–occupancy relationship is significant for determining the congestion issue. A bottleneck case leads to lower capacity. The merging area bottleneck also appears downstream due to the existence of bottlenecks, for example, upgrade, curvature, lane drop, or a tunnel, or an uncontrolled downstream in the on-ramp. In these cases, the measured occupancy that feeds the feedback RM controller should be collected at the downstream bottleneck location [27]. By ALINEA algorithm, the mainstream occupancy (mainstream traffic density) is measured and the error between the measured occupancy and the critical occupancy (density) value is used to update the RM signal [25].

The critical value of occupancy ranges from 17 to 25% [28]. Figure 5 indicates the occupancy of Lane 1. The maximum value is 19% which is the highest among other lanes as indicated in Figure 6(a)–(c). This could be attributed to the fact that the high interaction of merging sections happens in Lane 1.

Figure 6(c) indicates that the third lane has less occupancy than other lanes (Lanes 1 and 2). This could be attributed to less attraction in the third lane with high speed.

6.2 Speed–flow relationship

The obtained results from the simulated model show good behavior for the speed–flow relationship as indicated in Figure 7. The speed values in Lane 1 range from 65 to 85, because Lane 1 is affected by the merging area. Whereas Lanes 2 and 3 have higher speeds than Lane 1 because as mentioned before these lanes are away from the interactions between vehicles in the merging section.

7 RM management

RM is installed to regulate the speed at which vehicles enter mainline traffic. This prevents the critical volume of a freeway from building up in order to manage demand. In addition, it breaks up platoons of vehicles entering the freeway upstream of the signal to lessen weaving at merge points. RM is expected to reduce or even eliminate queues, enhance air quality, safety, and traffic flow, shorten overall travel times, boost performance metrics, and regulate demand in order to create a reliable highway system [29].

RM is a type of access control for highways that uses traffic signals at on-ramps to control the flow of vehicles and maintain the capacity of the highway. According to their effective scope, RM algorithms can be divided into two groups: local control and coordinated control. The on-ramp and nearby motorway mainline traffic conditions are used by the local control algorithm to establish the metering rate. On the other hand, coordinated RM techniques control individual ramp signals for the best network performance based on measurements from the entire motorway network [30].

RM is the most effective technology now available for reducing motorway congestion, and field implementation

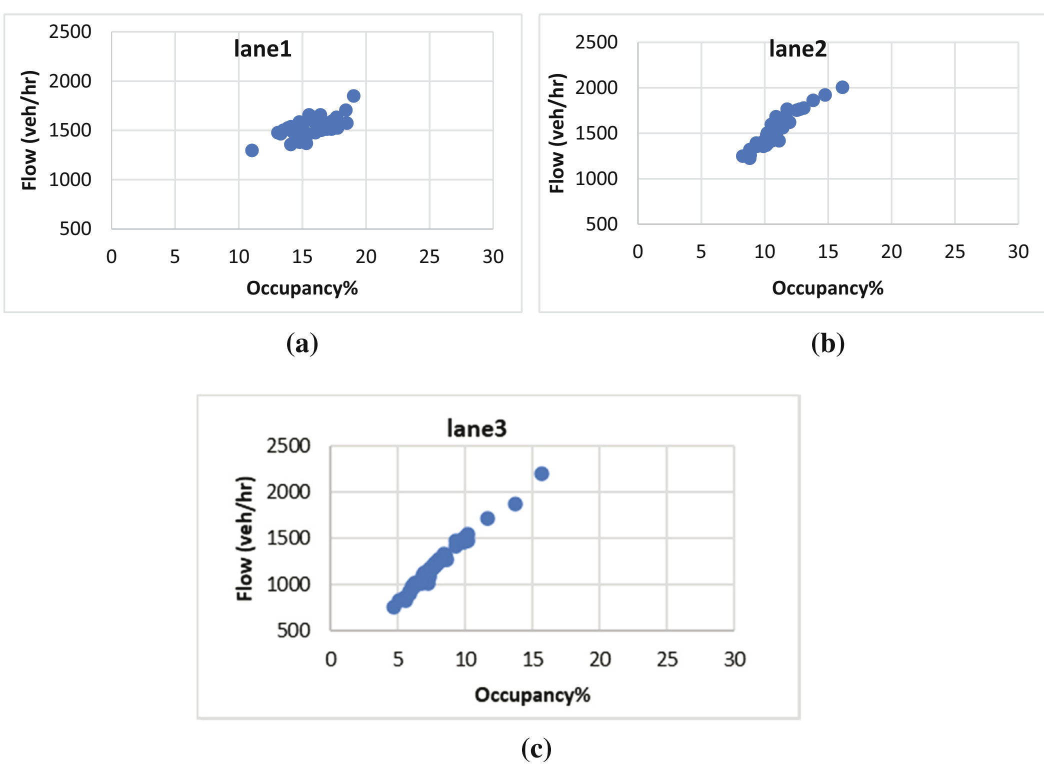

Figure 6: Flow–occupancy for Lanes 1 (a), 2 (b), and 3 (c).

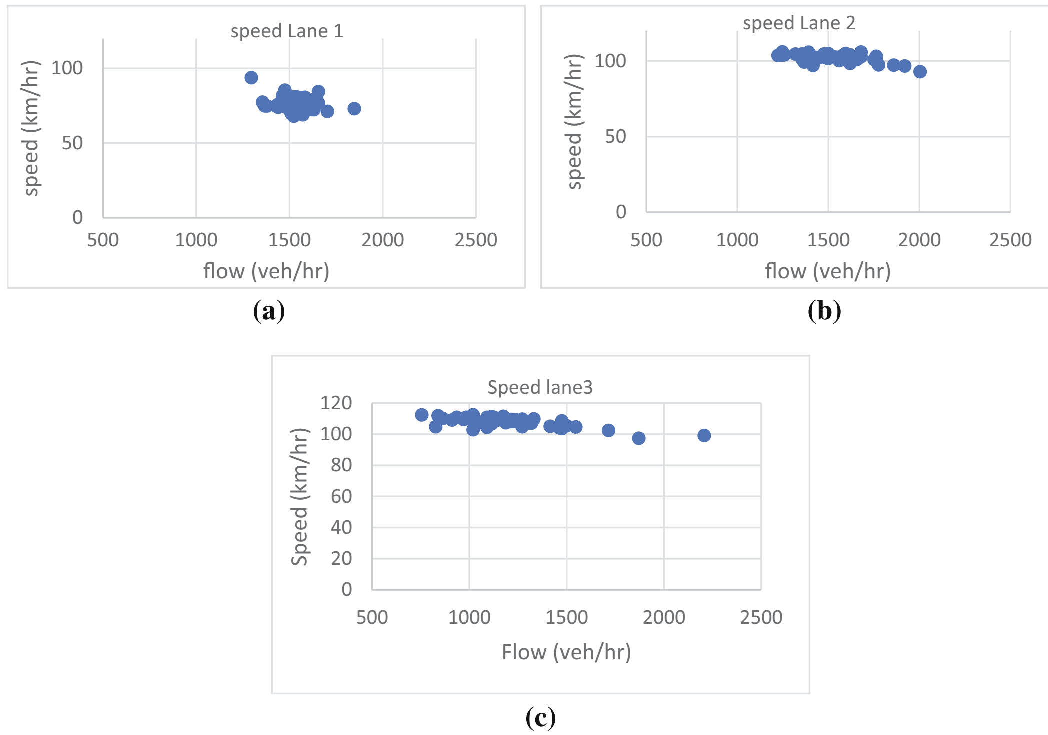

Figure 7: Speed–flow relationships for Lanes 1 (a), 2 (b), and 3 (c).

results have already demonstrated how effective it is (Kotsialos et al. [15]). RM regulates traffic entering the highway using a traffic signal at an on-ramp. Without RM, heavy ramp flows merging into the mainline of the highway raise the possibility of flow breakdown and drastically lower capacity. Therefore, RM tends to give mainline traffic more priority. The fundamental idea of RM is to temporarily hold ramp traffic to keep total demand at the merging section around capacity for managing congestion. Ramp traffic, however, may also benefit because their chances of using the highway are eventually decreased by the mainline's congestion [30].

Ramp meter systems are controlled by control algorithms that use input characteristics linked to traffic, including crash and accident data, vehicle speed, journey periods, and traffic flow density, to mention a few. RM has several advantages, including an overall increase in mobility, dependability, efficiency, and safety; lowering congestion (i.e., raising traffic speed and volume); and decreasing demand [31].

Controlling and managing of RM strategy is an effective approach for solving problems of traffic freeway [32]. The local algorithm of ALINEA performs a control for traffic signals that are close to RM for computing the metering rate [32]. This algorithm costs less and is convenient for RM congestion decreasing and safety improvements [33–35]. The stated algorithm has shown improvements for all parameters of microsimulation that utilize local RM in Istanbul freeway D-100 [33]. Application of RM in California planning, design, and operation has proven results in safety and benefits. The traffic management of RM is an effective manner for keeping operating the freeway system near capacity [34]. Adaptation and prediction of traffic parameters are calculated by the RM method [35]. In metering rate calculation, the traffic parameters (flow, speed, and occupancy) are used to avoid freeway breakdown and onramp queues [35]. The total time spent in freeway network is reduced by using RM [36]. Also, entrance on-ramp flowrate control of the freeway network is achieved using RM [37]. Another step has been taken in this study using the RM in the simulation model (AIMSUN). The calibrated and validated AIMSUN model has been used to apply this management. Then, the RM was controlled by changing the course of time with the platoon storage lane. Several iterations have been applied to get the higher speed with minimum occupancy. The best results have been obtained with the green time of 40 s with 10 vehicles as storage or 10 platoons a collection of moving vehicles that are either voluntarily or involuntarily traveling in a group due to signal control, geometry, or other circumstances [38]. It was noted that the change takes place on the first lane, due to its impact on the

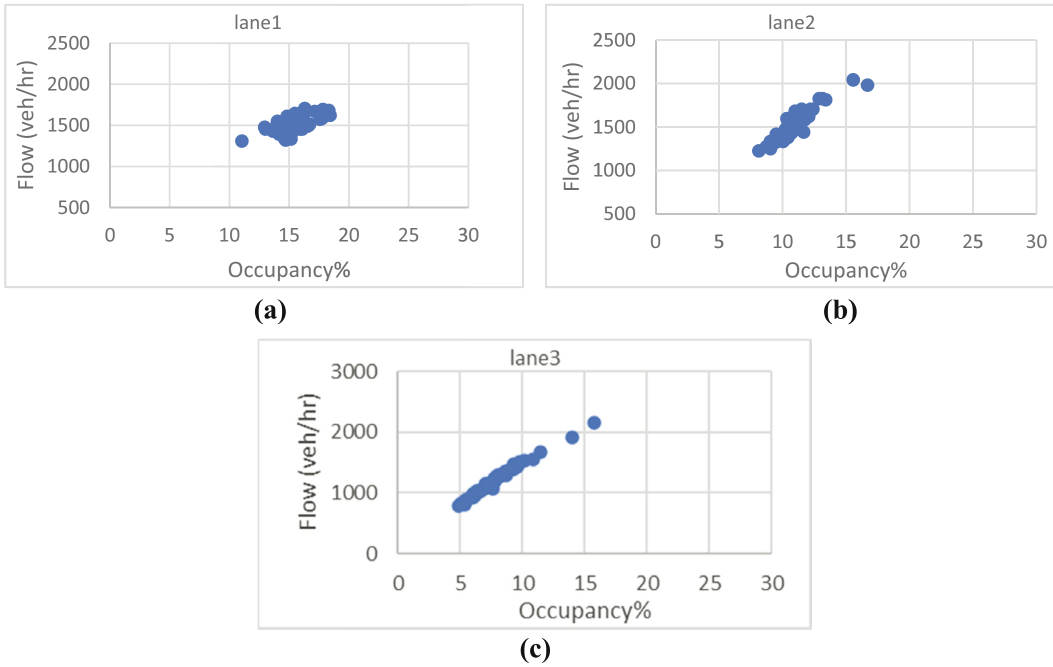

Figure 8: Flow–occupancy relationships for Lanes 1 (a), 2 (b), and 3 (c) with RM.

merging area, as well as the effect of RM. Figure 7 indicates that the occupancy of Lane 1 is less than the corresponding value for the same conditions as indicated in Figure 6. Figure 8(a)–(c) shows the results after applying RM. This figure shows the improvements of the metering method for solving congestion issues in the site of study, where, in lane 1, the occupancy has been decreased from 19 to 18%.

Figure 8(c) indicates that Lane 3 has the minimum value of the occupancy among other lanes which is consistent with the actual behavior due to the high speed of the third lane as mentioned before.

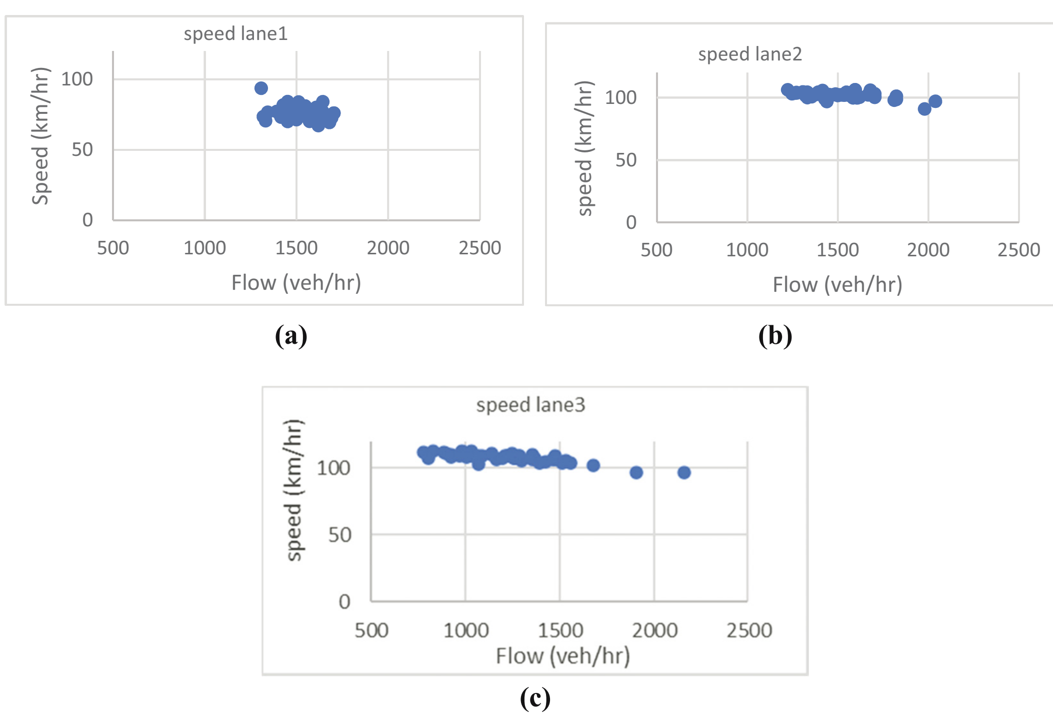

Figure 9: Speed–flow relationships for Lanes 1 (a), 2 (b), and 3 (c) with RM.

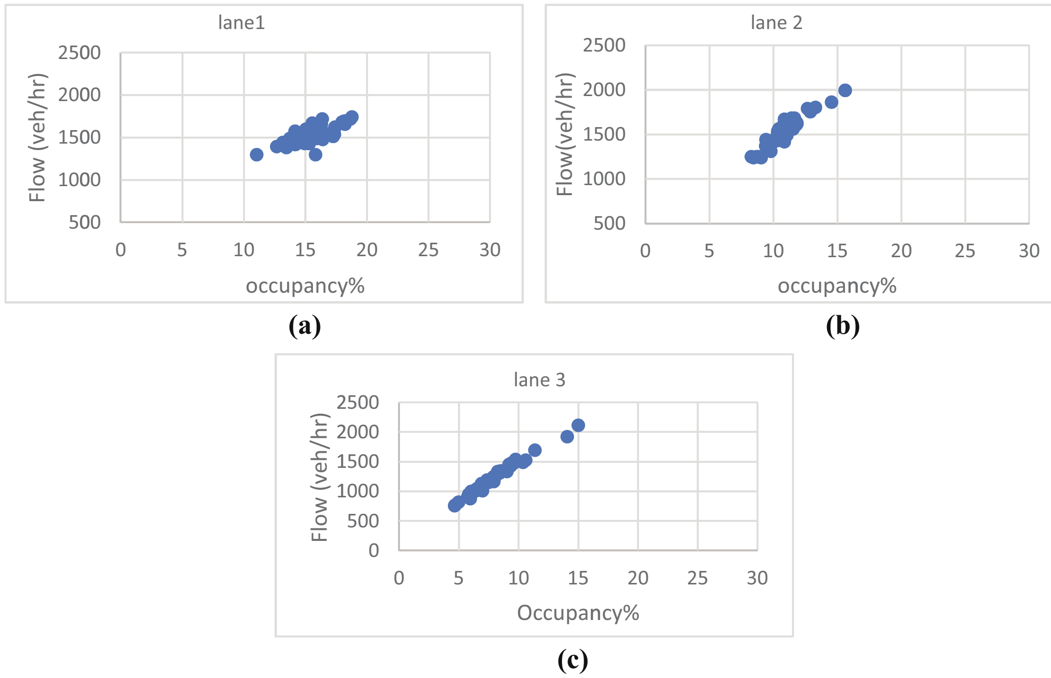

Figure 10: Flow–occupancy relationship for Lanes 1 (a), 2 (b), and 3(c) with RM.

For the same green time and platoon characteristics, the obtained speed–flow relationships also indicate a normal behavior as indicated in Figure 9.

The simulated results from AIMSUN model as shown in Figure 9(c) display that the third lane is the highest as in the previous example. This also shows the normal behavior of traffic flow. Another scenario is using the green time of 30 s with storage of 30 vehicles. The results of simulated data show that the occupancy is about 18% for Lane 1 as indicated in Figure 10, whereas for Lane 2 the occupancy is 15%. Figure 10(c) illustrates that the value of Lane 3 is about 15%. This is an improvement in applying the RM method for solving congestion issues for the site under consideration.

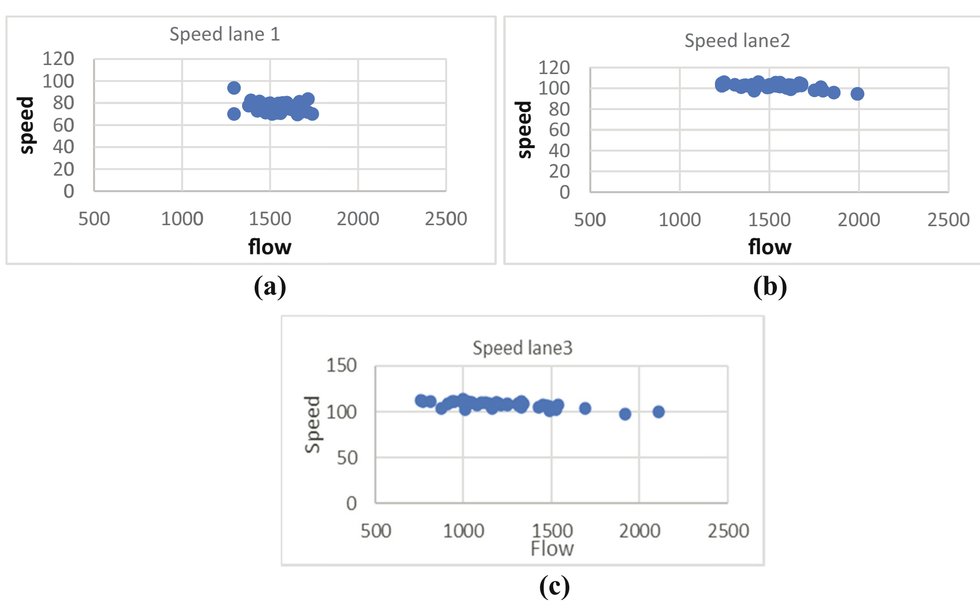

Figure 11: Speed flow for Lane 1 (a), 2 (b), and 3 (c) with RM.

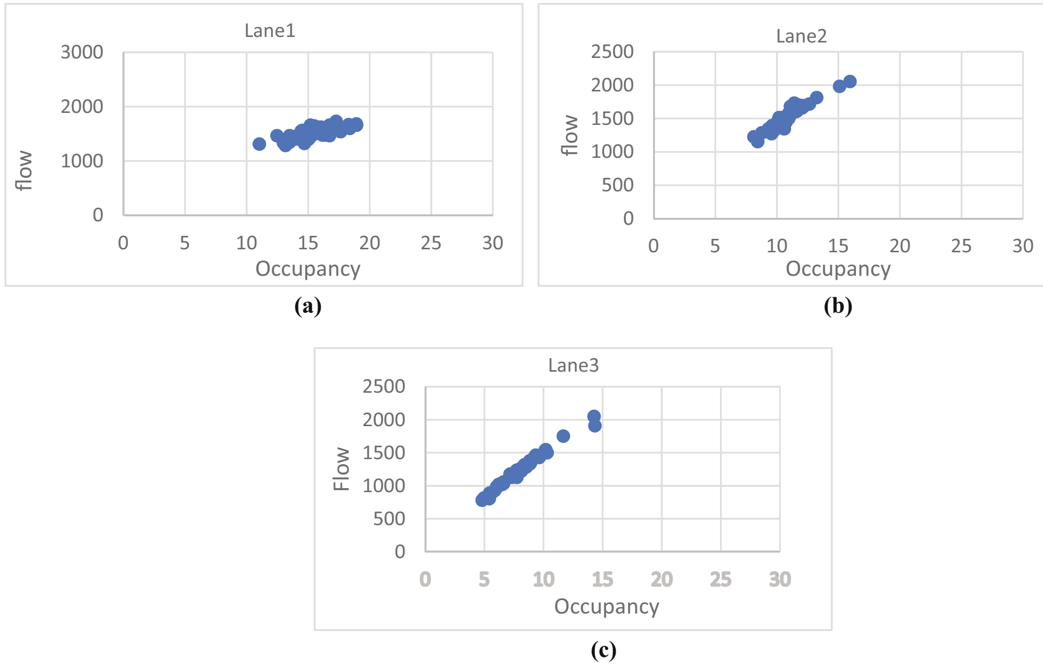

Figure 12: Flow–occupancy relationships for Lane 1 (a), 2 (b), and 3 (c) with RM.

For the same green time of 30 s and 30 platoon characteristics, the obtained speed–flow relations also indicate a normal behavior in Lane 1 because it is affected by the merging section. The speed is less valuable than in Lane 2 as indicated in Figure 11.

The results in Figure 10(c) indicate that Lane 3 has a high value due to attributes of the lanes away from the interactions between the vehicles in the merging section, whereas changing use of the green time is 30 s with 10 vehicles stored. The simulation results show that the

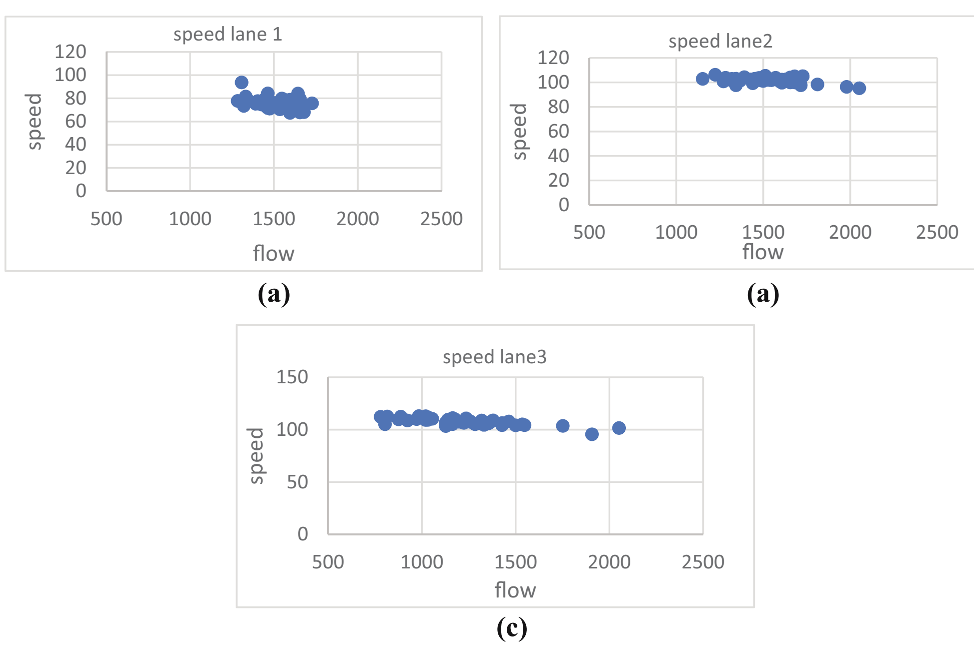

Figure 13: Speed flow for Lanes 1 (a), 2 (b), and 3 (c) with RM.

occupancy rate is less than 19% for Lane 1 as shown in Figure 12, while the occupancy rate for Lane 2 is 15%. Figure 12(c) shows that the lees value of Lane 3 is about 14%. For the same 30 s green time and 10 veh/lane platoon characteristics, the obtained speed flow relationships also indicate a slight increase in speed due to the normal behavior of Lane 1 as it was affected by the merging section. In the second lane, the speed increases from the previous results, as indicated in Figure 13. In Figure 13(c), the occupancy of the third lane is shown. This figure shows normal behavior.

8 Conclusion

Through the results obtained from GEH, it was found that the simulated model (AIMSUN) software is similar to reality and that the real flow coincides with the simulated flow through it, and by adding slope measurement, it seems to increase flow, reduce occupancy, and increase speed. This indicates when the course uses 30 s green time with the storage length on ramp 10 vehicles/lane where the ramp consists of two lanes, showing its effect on the first lane and the second of the expressway. However, the third lane of the expressway has a high speed according to the normal behavior of the traffic flow because it is far from the affected merging area. The result showed an improvement when applying ALINEA algorithm for this site. Therefore, this algorithm is significant for solving the problem of congestion on this site. As for occupancy, the percentage before using the measurement was 19%, while when measuring it decreased to 18% for the first path and the second path 15%, and the third showed that the occupancy was less than the previous results; it approximately valued 14%. Therefore, it is recommended to conduct further investigation to collect more data and to investigate more characteristics such as cooperative and lane utilization behaviors.

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