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Traffic Simulation of Urban Street to Estimate Capacity

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ABSTRACT

This research aimed to develop a simulation traffic model for an urban street with heterogeneous traffic capable of analyzing different types of vehicles of static and dynamic characteristics based on trajectory analysis that demonstrated psychophysical driver behavior. The base developed model for urban traffic was performed based on the collected field data for the major urban street in Baghdad city. The parameter; CC1 minimum headway (represented the speed-dependent of the safety distance from stop line that the driver desired) justified in the range from (2.86sec) to (2.17 sec) indicated a good match to reflect the actual traffic behavior for urban traffic streets. A good indication of the convergence between simulated and field data of maximum error of 8% and below 10% for traffic flow rate and that provided a successfully simulated model by VISSIM for urban traffic behavior. The traffic speed decreased slowly, but still, variation in a large range from (30 km/hr to 55 km/hr) until a flow rate of 1000 vehicles/hr was reached, then the traffic speed decreased sharply. The dispersion between data points was caused by driver behavior and the special characteristics of the urban street. This dispersion of data points reduced and became less significant when it reached the capacity of the road. The obtained capacity value for divided urban traffic streets was (1610 vehicles/hr) with an optimum traffic density of 64 vehicles/km. Traffic simulation utilizing VISSIM parameters had been developed successfully since the simulation could estimate the field capacity with an acceptable range of error of 7.5 % (less than 10%).

Keywords: Traffic simulation, Capacity estimation, VISSIM, Urban Street.

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محاكاة المرور لشوارع حضرية لتقدير السعة

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قسم الطرق والنقل

الخلاصة

يهدف هذا البحث الى تطوير نموذج محاكاة حركة المرور في الشوارع الحضرية وله القابلية على تحليل أنواع مختلفة من المركبات ذات الخصائص الثابتة والديناميكية بناءا على مسار المركبات وخصائص تصرف السائق. تم تطوير موديل أساس للمرور اعتمادا على البيانات الحقلية للطرق الحضرية الرئيسية في مدينة بغداد. معامل التقادم الزمني الادنى (والذي يعتمد على السرعة ومسافة الأمان من خط الوقوف والتي يرغب بها السائق) تراوح بين 2.17-2.86ثانية اعطت نتائج جيدة لعكس واقع حال سير المرور في الطرق الحضرية وهذا أعطى مؤشر جيد لتقارب نتائج موديل المحاكاة والبيانات الحقلية وبنسبة خطأ لاتتجاوز 10% للحجم المروري مما يبين نجاح موديل المحاكاة باستخدام برنامج VISSIM لحركة المرور في الطرق الحضرية. السرعة المرورية نقصت تدريجيا لكن بقى التباين كبير يتراوح مابين 30 -55 كم/ساعة عند الوصول الى تدفق مروري 1000 مركبة /ساعة ثم يبدأ التباين في البيانات للسرع والاحجام المرورية نتيجة سلوك السائق بالنقصان ويصبح غير ملحوظ عند وصول السعة الاستيعابية للطريق. قيمة السعة الاستيعابية المستحصلة للشارع الحضري 1610 مركبة/ساعة وكثافة مرورية حرجة 64 مركبة/كم. المحاكاة المرورية باستخدام برنامج VISSIM تم تمثيلها بنجاح وامكانية حسابه للسعة الاستيعابية الحقلية مع نسبة خطأ مقبول لايتجاوز 7.5% وهو اقل من الحد الأعلى 10%.

الكلمات الرئيسية: محاكاة المرور , تقدير السعة, برنامج VISSIM, شوارع حضرية.

1. INTRODUCTION

Reducing congestion and increasing highway capacity is considered one of the biggest challenges of traffic engineers for better traffic operation, improving fuel efficiency, and reducing greenhouse gas emissions. The adverse effect of traffic jams on economic cost and environmental impact in large metropolitans such Baghdad city; accordingly the capacity of urban street and freeways is a major factor that should consider for transportation systems infrastructure improvements. Ratrout and **(Rahman, 2009)** illustrated the differences between used macroscopic and microscopic software used for traffic simulation models. They revealed that CORSIM, AIMSUM, and VISSIM were suitable for simulated congested urban streets and freeways and had the potential to apply intelligent transportation systems (ITS) **(Ratrout and Rahman, 2009**). The calibration of parameters in the simulation model had been concerned recently to identify the critical parameters to be calibrated, and sensitivity analysis was performed to minimize the number of parameters that significantly affected on simulation model **(Siddharth, and Ramadurai, 2013), (Mathew and Radhakrishnan, 2020). (Menneni et al., 2008)** demonstrated the calibration procedure of default parameters implemented in simulation VISSIM model used optimizing algorithm techniques to develop a new methodology for estimating capacity from flow-density-speed relationships based on field data collection **(Menneni and Vortisch, 2008)**. **(Joseph and Nagakumar, 2014)** explored different parameters such as level of service, volume/capacity ratio, and capacity. The obtained results for the level of service were found to be F during the survey period and 17 min **(Joseph and Nagakumar. 2014)**. **(Gajjar and Mohandas, 2016)** estimated the existing critical capacity of urban streets in Mumbai, and the obtained results demonstrated the incapability to sustain excessive traffic volume. **(Chang and Kim, 2000)** used the quantitative methods to define capacity by estimating the distribution of headway and volume from the obtained field traffic flow data. They concluded to take 95% cumulative distributions of observed traffic flow and eliminate 5% of long headways. **(Pratik and Khode, 2016)** found the capacity of urban roads by using the Greenshield model and compared the results with the microscopic simulation model. **(Gajjar and Mohandas, 2016)** analyzed the existing critical potential capacity of major roads in Mumbai, and the obtained results for volume per lane were beyond the capacity and notwithstanding excessive volume. **(Al-Ghamdi A.S, 1999)** and **(Al-Ghamdi A.S, 2001)** studied the distribution of time headway, which follows Gamma distribution, which is considered as a direct empirical method for capacity estimation. The Erlang headway time distribution was found to fit the field observed data at high traffic flow.

2. Case Study

2.1 Site selection

Palestine urban street is considered one of the major urban streets in Baghdad city, which passed through different areas of mixed land uses and produced a higher number of daily trips on their corridor, links, and intersections **(Alkaissi, 2017)**. **Fig.1** presented the location of the case study with a coordinated map **(Alkaissi, et al., 2020)**. Palestine urban street consists of a six-lane divided highway along its corridor from Mustansiriyah University to the Al-Nakhala intersection. The selected segment for the study was most loaded and congested during the recurrent peak hour period, leading to oversaturated conditions where the demand exceeds the capacity.

2.2 Field data collection

The field data of this research that had been used for developed simulation model and calibration were based on data collected for the study area from **(Alkaissi, 2018)**, **(Alkaissi, 2018)** and **(Alkaissi, and Hussain, 2020)**. Field data included the following:

- Traffic volume at a different location in different directions (north and south directions) **(Alkaissi, 2018)**.
- Time headway at different periods by recording the time elapsed between the passing of the first vehicle and following vehicle and determining the time difference over the test point of each lane **(Alkaissi, 2018)**.
- Speed variations along the corridor using global positioning system GPS were used for speed distribution and reduced speed area **(Alkaissi, and Hussain, 2020)**.

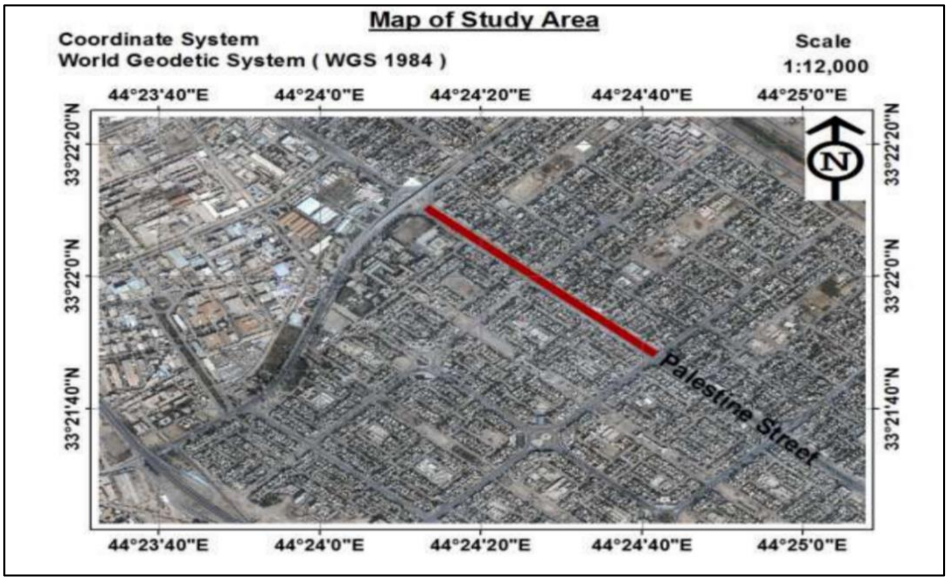


Figure 1. Location of Study Site and Target Case Study of Palestine Urban Street. **(Alkaissi, et al., 2020)**.

2.2.1 Traffic flow rate data

The traffic survey of data collection aimed to capture data that accurately reflected the actual operation of traffic state in studied urban streets. Counting period of 15 min periods during the peak hours from 4:00 to 9:00 PM Monday 22/5/2017 and Tuesday 23/5/2017were selected to justify the rush hours of congestion as stated by previous research for the same study area **(Alkaissi, 2018)**. The traffic volume data passing the section of Palestine urban street in the north and south direction were depicted in **Fig. 2**. This data of traffic flow rate is crucial information for analyzing the traffic operation of the urban street to predict the sustained capacity during congestion periods and to fulfill the demand for simulation model developed by VISSIM.

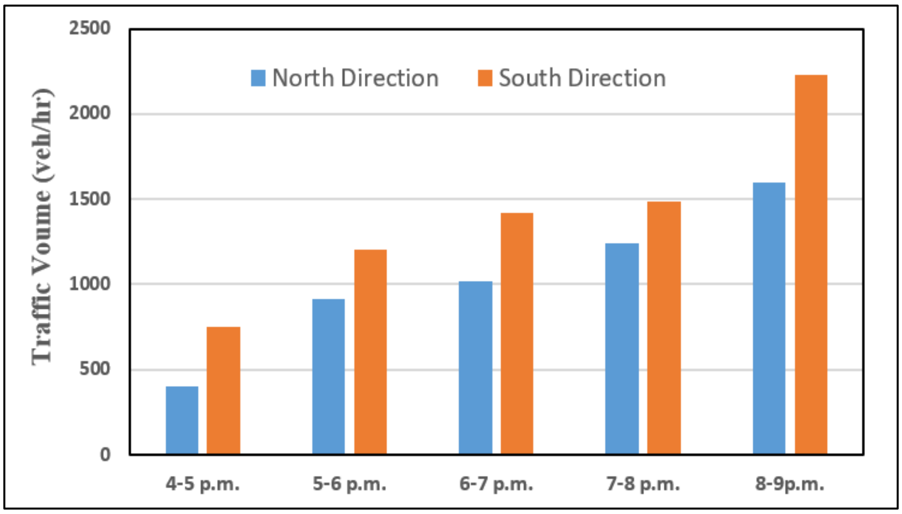
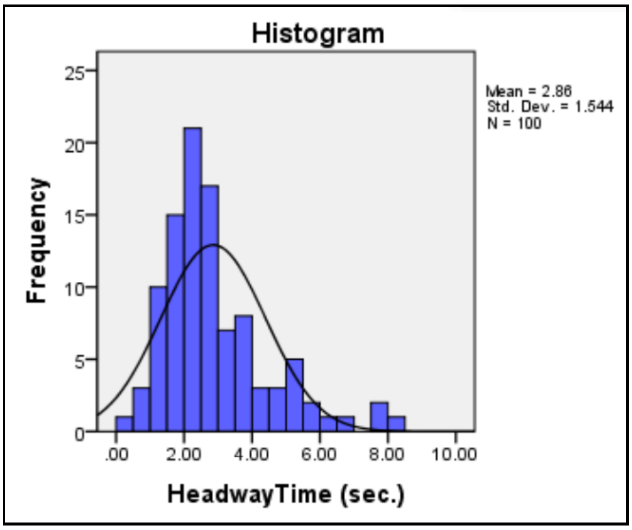


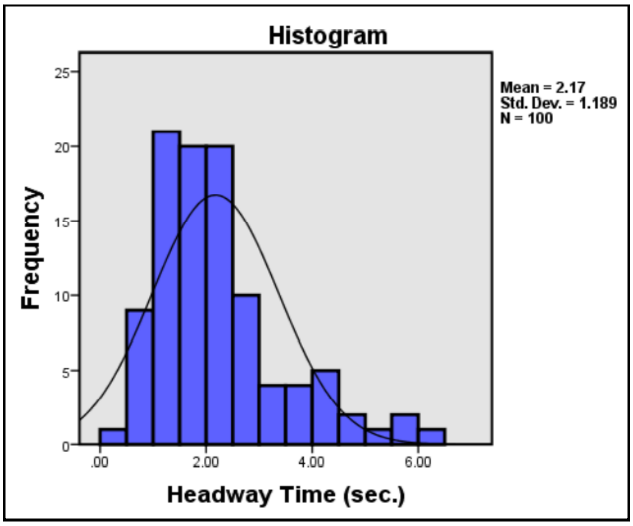
Figure 2. Hourly Traffic Volume Variations **(Alkaissi, 2018)**.

2.2.2 Headway time distribution

The collected data is for urban Palestine street from Al-Mawal intersection to Bab Al-Moathum intersection at two different periods 6:00- 6:30 PM with flow rate 1042 vph and 6:30-7:00 PM with flow rate 1308 vph by **(Alkaissi, 2018).** The selected link was chosen in this research to compromise the effect of commercial and residential regions on vehicle arrival and headway time distribution that adopted in the traffic simulation model by VISSIM through the calibration process as explained in the next paragraphs. The frequency distributions of time headway with the normal curve are estimated using SPSS (SPSS ver.21 statistical software) as presented in **Fig. 3**.



a) Time Period 6:00-6:30 PM at 1042 vph flow.



b) Time Period 6:30-7:00 PM at 1308 vph flow rate.

Figure 3. Time Headway Distribution for Selected Urban Street **(Alkaissi, 2018)**.

2.2.3 Vehicle speed data and profile

The vehicle speed data were estimated along Palestine urban street (from Al-Mawal to Maysaloon Square) based on the data from GPS obtained during 60 test runs in the south and north directions at peak hours (12:00 - 3:00 PM) on a Monday and Tuesday in May 2019. **Fig. 4 and Fig. 5** show the speed profile along the Palestine arterial street in both directions. The maximum speed was about 60 km/hr, which represents the posted speed limit for Palestine Street. The speed distribution was adopted in the calibration process of VISSIM simulation model.

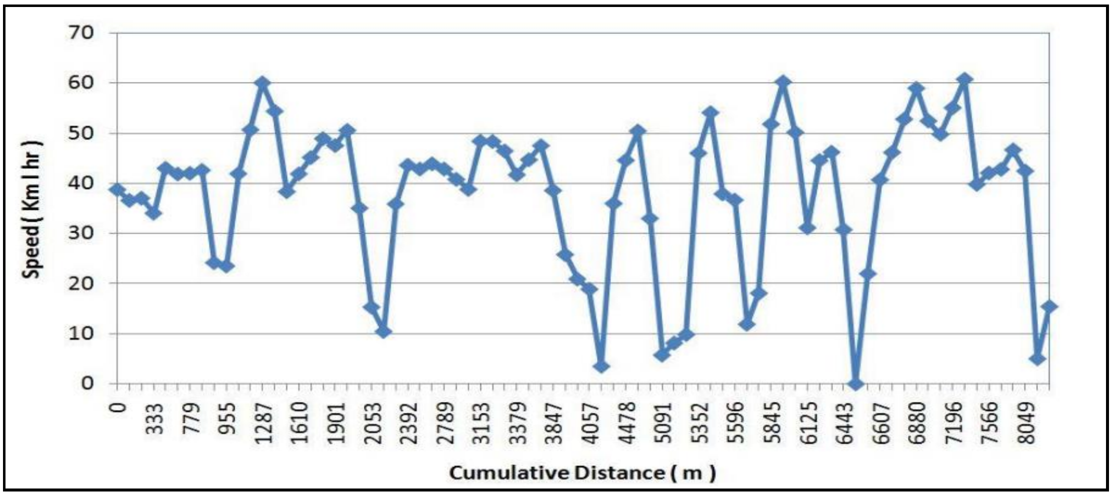


Figure 4. Speed Profile along Palestine Arterial Street (South Direction), **(Alkaissi, and Hussain, 2020)**.

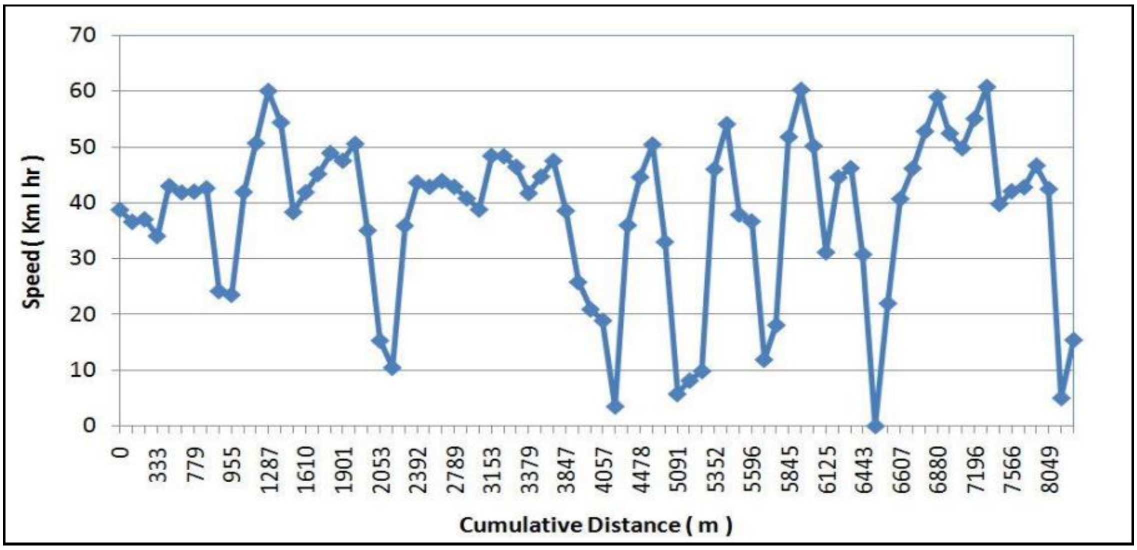


Figure 5. Speed Profile along Palestine Arterial Street (North Direction), **(Alkaissi, and Hussain, 2020)**.

3. TRAFFIC SIMULATION

This research aimed to develop a simulation traffic model for the urban street with heterogeneous traffic capable of analyzing different types of vehicles of static and dynamic characteristics based on trajectory analysis that demonstrated psychophysical driver behavior. VISSIM version (9) (which was developed in Germany based on Widemann of car-following behavior) had been utilized in this work to develop a microsimulation model of urban traffic. The methodology of this research for microsimulation analysis is arranged in the following three phases; model development, model calibration, and validation; results and presentation.

3.1 Development model

Field data collected on Palestine urban street for different directions; north and south directions as explained previously, were used for building, calibration of the base model, and validation. The base developed model for urban traffic was performed based on the collected field data for major urban streets in Baghdad city as described previously in the paragraph of the case study. A 1.03 km length of Palestine Street corridor from Mustansiriyah University to Al-Nakhala intersection passed through different land uses of residential, educational, and commercial land uses. A 3 –lane divided highway of 3.6 m width and average median width of 3.5m had been simulated using Links Behavior/ Links Display type as shown in **Fig. 6**. The linking behavior and attributes were created using the urban link behavior type based on Widemann 99 car-following behavior. The input traffic data of the simulation model for volume and speed distribution were implemented with a simulation period of (3600 sec) to simulate the real world of traffic operation.

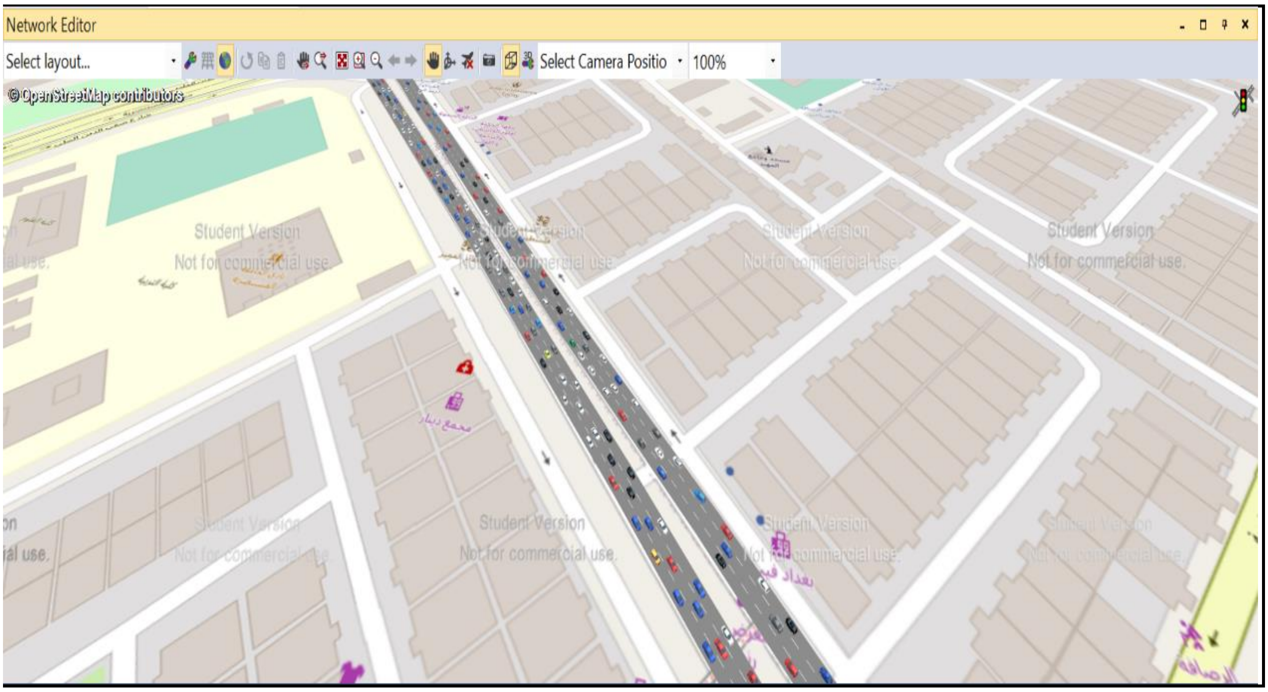


Figure 6. VISSIM Model of Urban Traffic Street.

3.2 Model validation and calibration

A comparison of simulated output data for traffic flow rate and field data for the north direction segment of Palestine urban street is presented in **Fig. 7**. The field data of traffic flow rate was obtained for 15 minutes period intervals and compared with simulated results at the same periods. The comparison indicated a significant difference between field and simulated data for the traffic flow rate of a large percent of error (54%) at 60 min period due to the default value parameters were not able to reflect the field data. So there was an urgent need for the simulated model to set the calibration process to reduce the percentage error and difference between simulated and field data and enhance the developed model to reflect the field traffic behavior of urban streets.

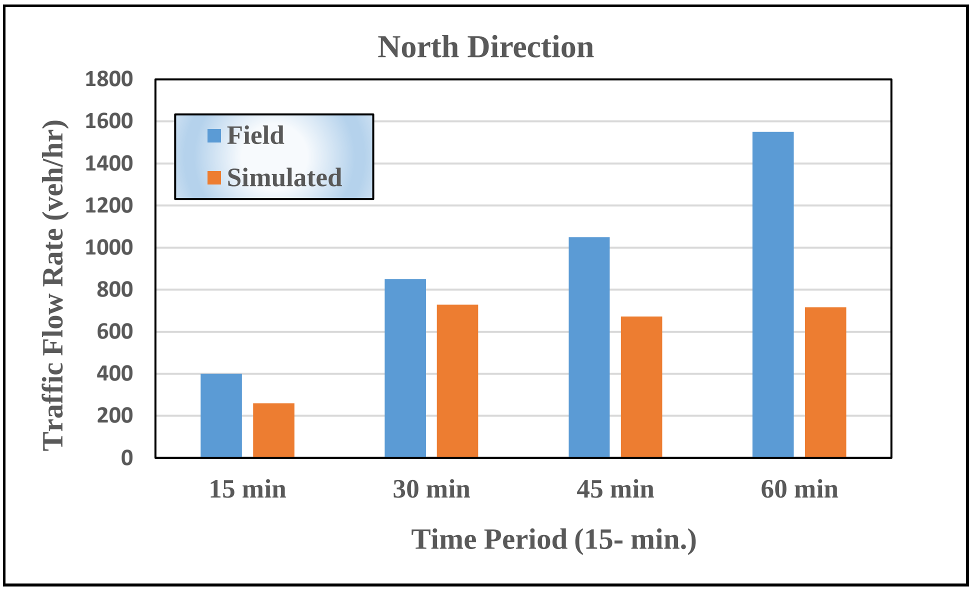


Figure 7. Comparison of Simulated and Field Data for Traffic Flow Rate.

The adopted desired speed distribution was based on the surveyed field data using the global positioning system GPS. Accordingly, the default speed distribution was justified by choosing the rectangular distributions from (12 km/hr) to (38 km/hr). Also, the headway distribution was based essentially on the desired speed reduction, which was justified by the reduced speed area and the car following car model (Wiedemann 99) parameters. The parameter; CC1 minimum headway (represented the speed-dependent of the safety distance from stop line that the driver desired) justified in the range from (2.17sec.) to (2.86 sec.) respectively as presented in **Fig. 3**. The post calibration of simulated data was compared with field data of south direction, as shown in **Fig. 8**. A good indication of the convergence between simulated and field data of maximum error of 8% and below 10% for traffic flow rate provided a successfully simulated model by VISSIM for urban traffic behavior.

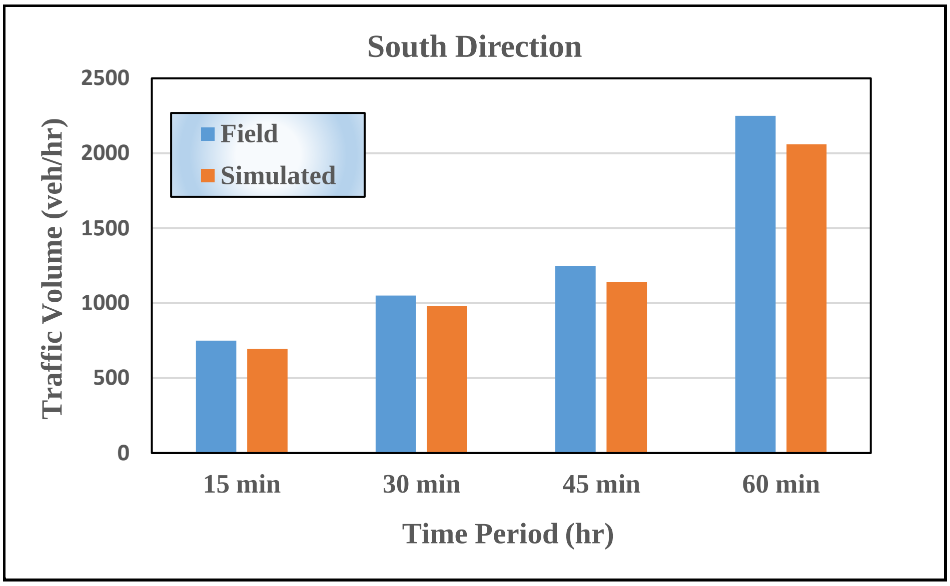


Figure 8. Post Calibration Comparison of Simulated and Field Data for Traffic Flow Rate.

4. RESULTS AND DISCUSSIONS

4.1 Analysis of speed -flow-density relationships

Based on simulated data for Palestine arterial street model using VISSIM, the speed flow curve was established and depicted in **Fig. 9**. The flow rate and traffic speed were simulated based on 5 min period. With the increase of traffic volume, the traffic speed decreased slowly but still variation in a large range from (30 km/hr to 55 km/hr) until a flow rate of 1000 vehicles/hr was reached, then the traffic speed decreased sharply.

Flow- density relationship of simulated data are presented in **Fig. 10** which expressed the traffic state conditions of a roadway segment. The data were basically estimated at midblock and aggregated for 5 min. to characterize the traffic flow behavior of urban street. Different factors such as heterogeneous vehicle, stochastic characteristics of traffic flow and driver behavior lead to larger scatter data point as shown in **Fig. 10**. The dispersion between data points is caused by driver behavior and the special characteristics of the urban street. This dispersion of data points is reduced and becomes less significant when reaching the road's capacity.

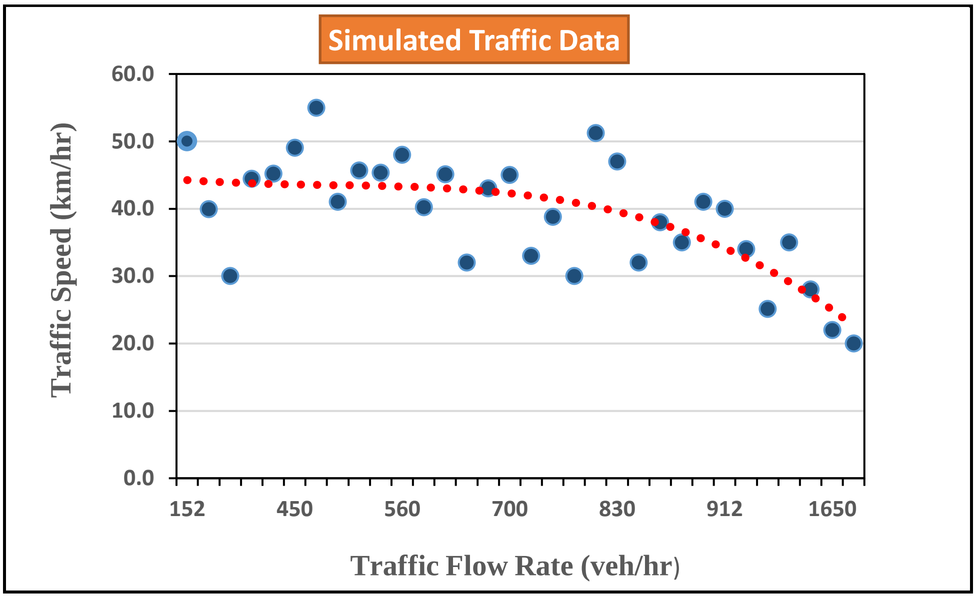


Figure 9. Speed - Flow Relationships for Heterogeneous Traffic Flow using VISSIM.

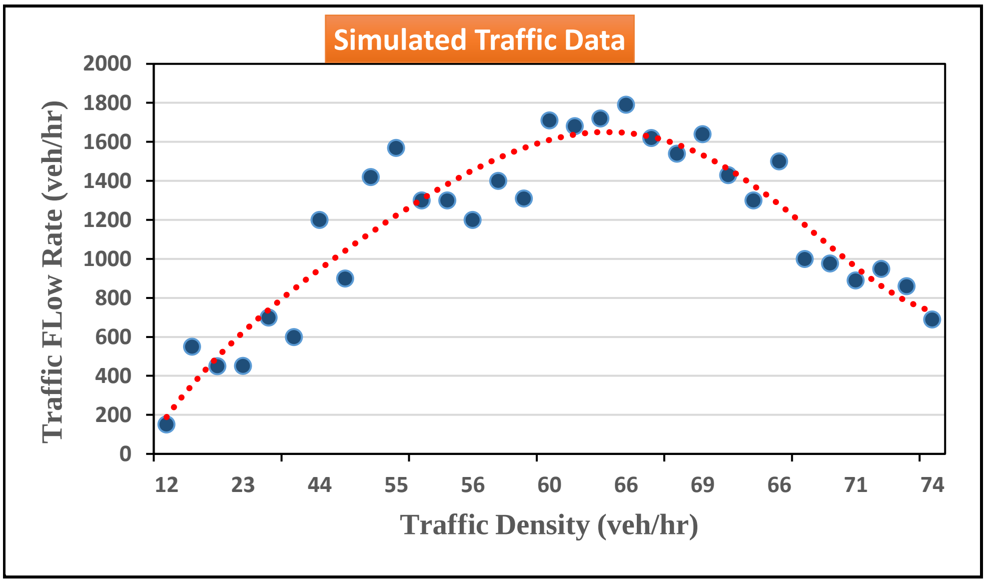


Figure 10. Flow - Density Relationships for Heterogeneous Traffic Flow using VISSIM.

4.2 Capacity estimation

The capacity of a roadway segment is considered a critical parameter in modeling traffic flow in a roadway network. The main objective of this paper is to estimate capacity from a simulation model based on field observed data. The simulated traffic flow rate aggregated over 5 min periods and utilized to create the speed-flow- density curve presented in **Fig. 9** and **Fig.10**, respectively.
The peak of the curve in Figure 10, which represents the intersection point of free flow and congested vectors is considered the capacity value of simulated urban street. The obtained capacity value for divided urban traffic street is (1610 vehicles/hr) with an optimum traffic density of 64 vehicles/km. The displayed results are shown in **Fig. 11**. For validation of capacity valued estimated from the simulation model, a comparison with field data of capacity (1740 vehicles/hr) was made for the same case study of the North

direction. It can demonstrate that the calibration of traffic simulation utilizing VISSIM parameters had been developed successfully since the simulation could estimate the field capacity with an acceptable range of error of 7.5 % (less than 10%).

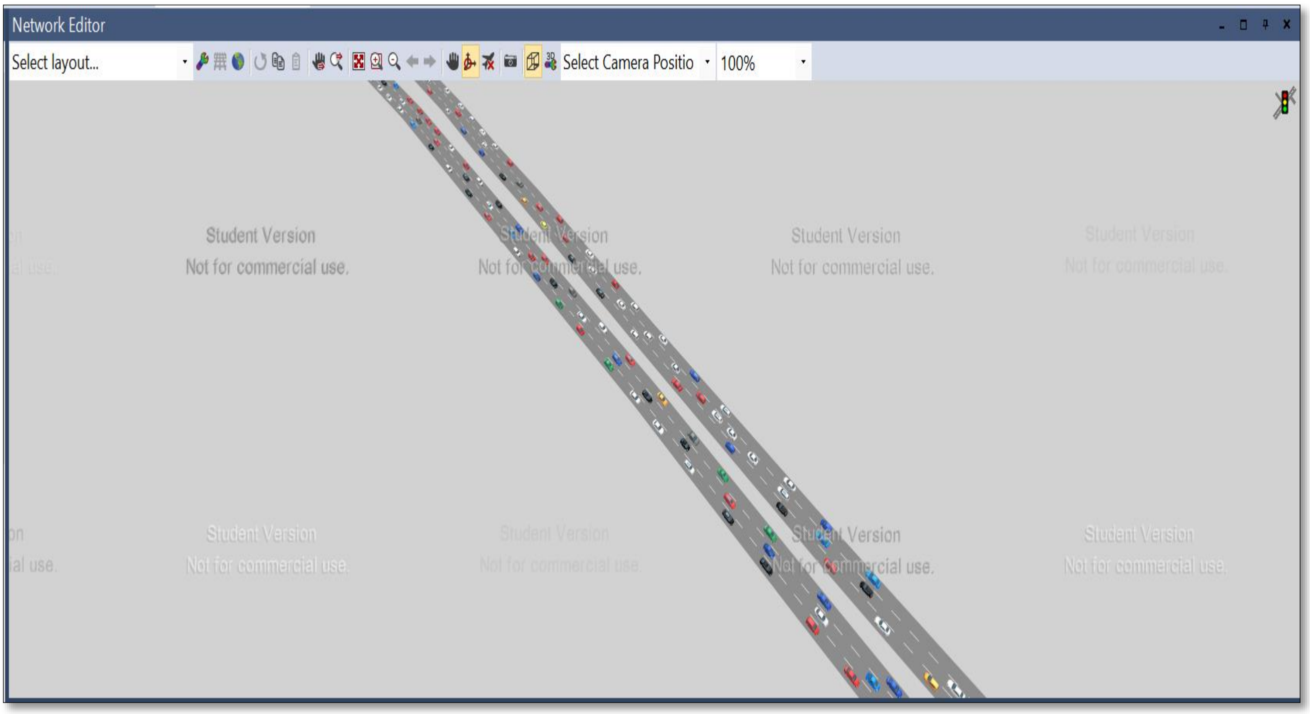


Figure 11. Simulation Model for Traffic Flow using VISSIM.

5. CONCLUSIONS

This research illustrated the ability of the traffic simulation model to estimate the capacity of urban streets using VISSIM simulation software. The following points were concluded:

1. The parameter; CC1 minimum headway (represented the speed-dependent of the safety distance from stop line that the driver desired) justified in the range from (2.5sec) to (1.53 sec) indicated a good match to reflect the actual traffic behavior for urban traffic streets. A good indication of the convergence between simulated and field data of maximum error of 8% and below 10% for traffic flow rate and that provided a successfully simulated model by VISSIM for urban traffic behavior.
2. The traffic speed decreased slowly, but still, variation in a large range from (30 km/hr to 55 km/hr) until a flow rate of 1000 vehicles/hr was reached, then the traffic speed decreased sharply. The dispersion between data points was caused by driver behavior, and the special characteristics of the urban street, and this dispersion of data point reduced and become less significant when reach the capacity of the road.
3. The obtained capacity value for divided urban traffic streets was (1610 vehicles/hr) with an optimum traffic density of 64 vehicles/km. Traffic simulation utilizing VISSIM parameters had been developed successfully since the simulation could estimate the field capacity with an acceptable range of error of 7.5 % (less than 10%).

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