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# Utilizing TFLOW Fuzzy Logic for Advanced Modeling and Analysis of Urban Traffic Networks: A Case Study from Baghdad

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**ABSTRACT**

This study investigates the accuracy and reliability of traffic flow estimation results estimated using TransCAD software and compares them with observed traffic flow data, applying the TFF function and technique using PTV Visum software. The aim of this study is to evaluate the quality, utility, and validity of the TFF method to ensure the accuracy of estimated data and compare them with observed data so that decisions regarding transportation network infrastructure development are evidence-based. The TFF approach was applied to simulate an urban road network, namely the Army Canal Road. The methodology involved collecting traffic flow data and other data such as road capacity, number of lanes, speeds, and other data. The estimated data were compared with observed data, which was collected from field surveys using smart surveillance cameras during the morning peak hour. The results showed a strong relationship between the estimated and observed traffic volumes, with a regression equation (y = 0.9978x - 8.5827) and a coefficient of determination (R2) equal to 0.9959. The R2 value indicates that the model calibration is excellent and the small deviation between the estimated and observed values confirms the suitability and effectiveness of the TFF approach in traffic flow modeling and thus can be adopted in the field of transportation planning and future projects and support the decision-making process on road infrastructure development.

## 1. Introduction

Baghdad, the capital of Iraq, faces multiple challenges and problems due to several factors, including rapid and uncontrolled urban growth, in addition to many other factors [1]. Regarding road projects in Baghdad, the Polservice Company worked in 1973 to develop and implement an effective transportation plan. This plan was based on a set of road and street networks, in addition to an urban highway network. The study proposed a plan to serve the Rusafa side of the capital, Baghdad, by constructing a parallel urban road extending on both sides of the Army Canal. This canal was constructed in the early 1980s, in addition to constructing a similar road on the Karkh side of the capital. To facilitate vehicle movement and reduce travel time, the study also proposed the construction of a ring road for the capital, Baghdad [2]. The increasing ownership and use of cars and vehicles has led to many problems and obstacles in the traffic process [3]. In the twentieth century and during the late nineties, the rates of car ownership in Baghdad increased, which caused the deterioration of the traffic process. To overcome this problem, there was a need to implement a large-scale transportation planning for the city of Baghdad, as well as to conduct comprehensive studies and modern surveys that include accurate and reliable traffic statistics

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through which travel characteristics can be analyzed and known. During the period that included the late eighties of the twentieth century, there was a deterioration and failure to implement transportation planning methods according to the information provided by local agencies. In countries that are considered developing, including Iraq, failure to implement transportation planning methods leads to poor transportation policies and methods. Therefore, it is important to conduct studies and analyze current traffic characteristics in order to predict future traffic characteristics [4]. In a 2019 study by Al-Kawaz and Ismail, transportation demand was estimated from traffic count data using the results of the Transportation Demand Matrix and 1987 Baghdad data as a basis for forecasting travel and transportation demand, which was updated to include 2014 traffic count data. TransCAD software was used to estimate transportation demand. The study results provided information and guidance for making informed decisions and optimizing transportation-related revenues and resources [5]. In 2013, Almasri and Al-Jazzar presented a research paper demonstrating that estimating transportation demand and calculating traffic flow using TransCAD is an effective model that can be used to alleviate the burden and difficulties associated with traditional methods that require massive amounts of economic and social data [6]. A study conducted by Asmael and Wazer in 2022 demonstrated that conducting transportation analysis using TransCAD software enables the presentation of hypotheses and results that help decision makers make informed decisions regarding the implementation and evaluation of freight transport activities and their effectiveness [7]. Similarly, a study conducted by Qasim et al. in 2018 included an assessment and analysis of traffic flow patterns for a road network located in Dhi Qar city. TransCAD software was used in the network assessment and analysis process [8]. On the other hand, the fuzzy approach is a two-level algorithm based on fuzzy inference to accurately generate and estimate path choice ratios, using estimated and observed correlation flows [9]. In transportation planning, fuzzy logic has been used to arrive at solutions for flow control patterns. It has also been used to solve many O-D matrix estimation problems, where fuzzy logic is used and relied upon for multiple decision-making and when developing a mathematical model is difficult [10]. The TFlow Fuzzy algorithm has been widely used in recent years because it can be easily implemented using the PTVvisum software [11]. Several studies have been presented on O-D matrix estimation using fuzzy logic, including the study by Caggiani et al. (2013), in which fuzzy logic was applied as an algorithm and optimization method to solve several problems and limitations, including the absolute uncertainty in the data available for O-D matrix estimation. The study showed that the proposed method yields acceptable and good results [12]. The study presented by Sudakov in 2021 also aimed to find solutions to some problems involving finding the fuzzy (O-D) matrix. The proposed algorithm for estimating the fuzzy (O-D) matrix allows for the development and planning of transportation infrastructure by supporting the decision-making process for developing new air transport routes and determining the degree of confidence in decision-making [13].

## 2. Study Area

Baghdad Governorate is considered the center and capital of the State of Iraq, and is located within the geographical coordinates of (44.361488) longitude, and (33.312805) latitude. The area of the capital, Baghdad, is (700) square kilometers, while its average height above sea level is (39) meters. The Tigris River passes through the city of Baghdad, dividing it into two parts: Karkh and Rusafa [14]. Baghdad is one of the most prominent and historically important cities in the Middle East. Like many other Middle Eastern cities, Baghdad has a rich cultural heritage and holds a prominent place in the region's history, the old urban centers within the city underwent two significant morphological transformations. This transformation occurred in two phases: the first involved the implementation of organic urban planning, and the second involved subsequent urban planning. The first phase was characterized by multiple features, including cul-de-sacs, street networks, winding roads, low-rise buildings, residential areas, and densely populated areas. In the twentieth century, the Iraqi state and its urban policy adopted multiple approaches to contemporary planning. These approaches aimed to introduce several elements, including significant zoning laws and urban grid street planning, progress in improving transportation infrastructure, and policies that included urban land use development [15]. Figure [1] shows the location of Iraq and its capital, Baghdad, in relation to the Middle East region, in addition to the urban center of the capital, Baghdad [16].

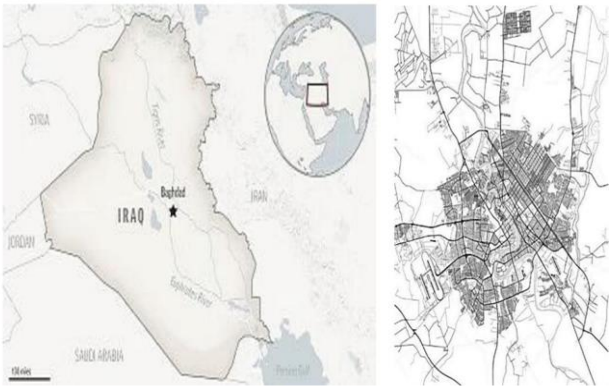



**Figure 1.** The location of Iraq and its capital, Baghdad, in relation to the countries of the Middle East [16].

The types of road networks within the city of Baghdad are classified according to functional and engineering criteria, and depend on the role of each road in regulating traffic within the city.

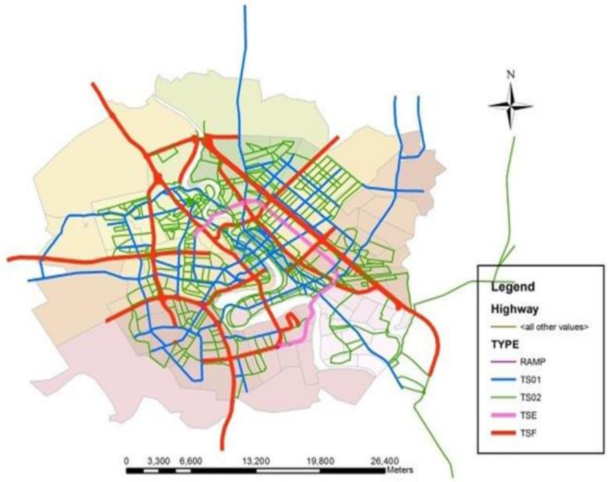



**Figure 2.** Road network and its distribution within Baghdad [5].

The study area included the urban road network within Baghdad, and this road is the Army Canal Road, which is one of the most important roads within the city, as it the southeast lies the 22-kilometer Army Canal Road, connecting Baghdad's most prominent areas: Rusafa, Ghadir, Shaab, Sadr City, and New Baghdad. This road is a vital artery that requires multiple rehabilitation and maintenance projects to ensure the continuity and efficiency of its services. This road is a vital road that requires the implementation of many rehabilitation projects and the most important methods of transportation planning and infrastructure improvement. Figure [3] shows the study area, which is the Army Canal Road, as it contains ten intersections (locations). Important data was collected within these locations, including the volume of vehicle flow during the morning peak hour.

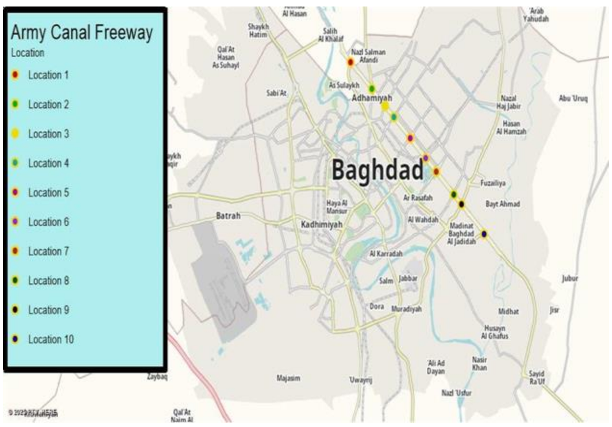



**Figure 3.** The search area is located within the city limits of Baghdad.

## 3. Methodology

The methodology involves collecting observed traffic flow data from the sites and using TransCAD version 4.5 to extract estimated traffic flow data. PTV Visum 2023 is then used, enabling the application of the TFF technique, an optimization method that enhances model effectiveness and measures the inaccuracy and uncertainty between the observed data and the data estimated using TransCAD. Figure [4] Shows the steps followed within the methodology.

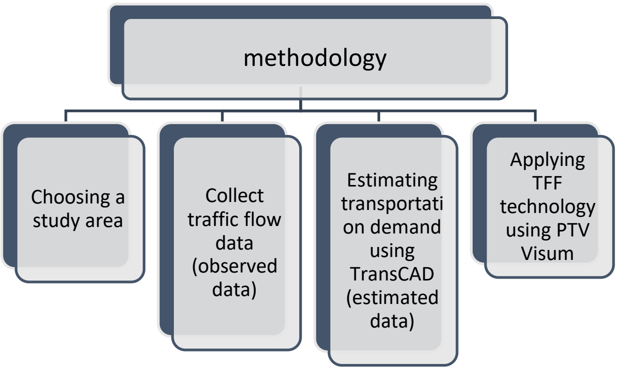



**Figure 4.** Research methodology.

Traffic volume data (observed data) were collected at ten locations along the Army Canal Road, along with data on the geometric design characteristics of these locations, including speed, capacity, and number of lanes. Combining this data with the observed traffic data is critical for analyzing and estimating demand using TransCAD. Figure [5] shows the locations and routes for which data were collected.


**Figure 5.** Selected sites for data collection within the study area.

*3.1 Transportation Demand Analysis and Estimation Using TransCAD.*

TransCAD is a software that can be used to model travel demand using geographic information systems. TransCAD also includes the four traditional stages used in urban transportation modeling and planning [17]. A study area network and data table (Dataview table) were created, containing the most important aggregated data needed to complete the transportation demand analysis and estimation process. One of the assignment methods provided by TransCAD, the "all-or-none" method, was then used. It's worth noting that demand estimation within the program relies on selecting the shortest route within the transportation network, as the program considers travel time as a cost factor. Travel time is calculated in TransCAD using a formula that involves dividing the route length by its speed.

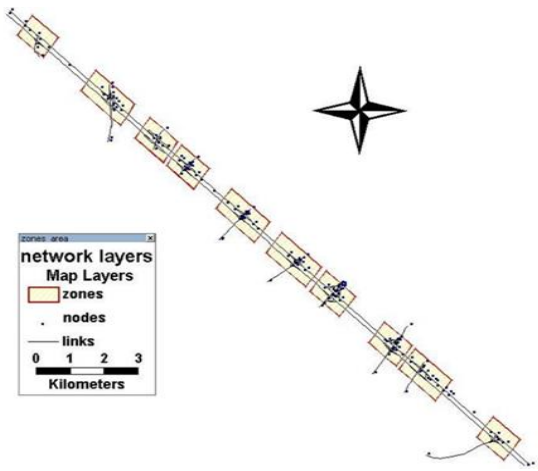



**Figure 6.** Study area network in Trans CAD.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | – | 29.50 | 141.74 | 55.50 | 63.19 | 82.58 | 36.89 | 21.99 | 34.86 | 629.36 | 1095.60 |
| 2 | 29.50 | – | 1183.29 | 78.45 | 83.31 | 109.78 | 38.97 | 21.65 | 35.78 | 26.23 | 1606.95 |
| 3 | 141.74 | 1.00 | – | 11.79 | 32.06 | 61.95 | 24.80 | 15.02 | 27.45 | 405.06 | 720.88 |
| 4 | 55.50 | 78.45 | 11.79 | – | 98.22 | 161.38 | 30.77 | 16.00 | 30.83 | 22.12 | 505.06 |
| 5 | 63.19 | 83.31 | 32.06 | 98.22 | – | 274.01 | 22.24 | 11.91 | 26.58 | 19.33 | 630.85 |
| 6 | 82.58 | 109.78 | 61.95 | 161.38 | 274.01 | – | 8.38 | 6.52 | 19.13 | 15.07 | 738.78 |
| 7 | 36.89 | 38.97 | 24.80 | 30.77 | 22.24 | 8.38 | – | 5.13 | 31.68 | 19.94 | 218.79 |
| 8 | 21.99 | 21.65 | 15.02 | 16.00 | 11.91 | 6.52 | 5.13 | – | 1.00 | 68.51 | 167.73 |
| 9 | 34.86 | 35.78 | 27.45 | 30.83 | 26.58 | 19.13 | 31.68 | 1438.98 | – | 321.91 | 1967.20 |
| 10 | 629.36 | 26.23 | 405.06 | 22.12 | 19.33 | 15.07 | 19.94 | 68.51 | 321.91 | – | 1527.52 |
| Sum | 1095.60 | 424.66 | 1903.17 | 505.06 | 630.85 | 738.78 | 218.80 | 1605.71 | 529.22 | 1527.52 | 9179.36 |

**Figure 7.** Estimating transportation demand within the (origin-destination) matrix.

*3.2.Drawing and analyzing the transportation network of the study area*

Visum can be defined as a software package used for transportation modeling. This package combines public transport (Put) and private transport (Prt), as well as software containing a wide range of methodologies. Visum is produced and developed by PTV, headquartered in Germany [18]. In the field of transportation planning, PTV Visum offers a four-stage modeling process, which is used in many studies [19]. PTV Visum is one of the world's leading programs for modeling and planning transportation systems. Used and adopted by more than 1,000 organizations and institutions, it provides modeling for various transportation networks and features the ability to analyze the most important external influences on traffic and transportation, including noise levels and air pollution [20]. Urban planning is closely linked to traffic. Before a transportation and traffic route can be created, the road must be planned. Even after the road is planned, it is essential to ensure its sustainability for years to come. Therefore, the PTV Visum Program includes three main and important components: first, the demand model, second, the network model, and third, the travel impact model [21]. The study area network was created within the scope of the PTV Visum program as shown in Figure [8].

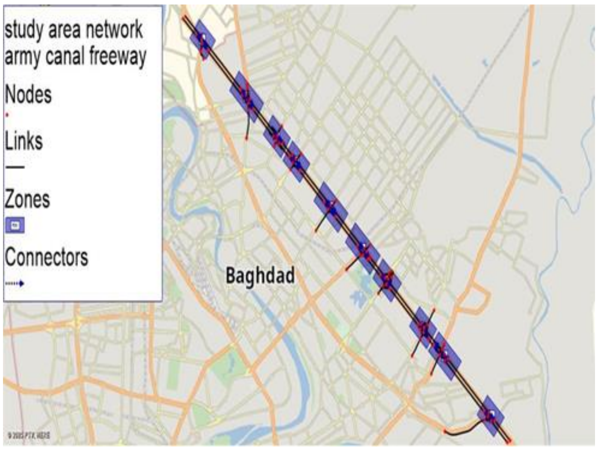
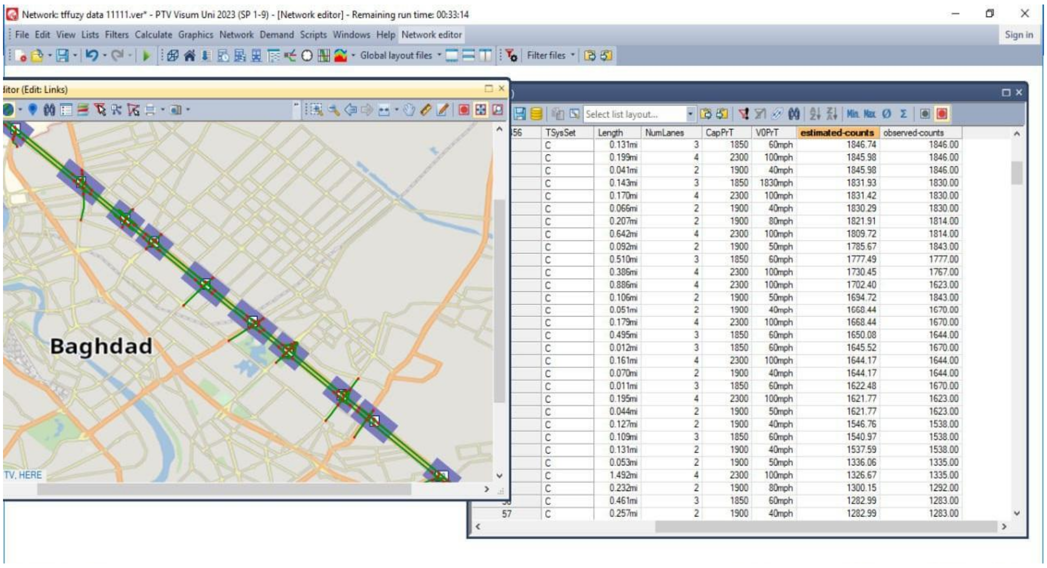



**Figure 8.** Study area network in PTVVisum.

PTV Visum provides a method known as Tflow Fuzzy, which uses statistics from traffic flow data. This method is used when the collected data is uncertain; in other words, it increases the reliability of the collected data when estimating transportation demand. The TFF method addresses the issue of uncertainty and ambiguity in traffic flow data. TFF can also be considered an optimization technique, as it can reduce the difference between the collected (observed) traffic flow data and the estimated traffic flow data by adopting data analysis using linear algebra between the observed and estimated data. The TFF method in PTV Visum requires entering some data, including the observed and estimated traffic flow data, into the software while drawing the network of the study area. After a series of steps, the results of the TFF method are exported as an Excel sheet file




| TSysSet | Length | NumLanes | CapPrT | V0PrT | estimated-counts | observed-counts |
|---|---|---|---|---|---|---|
| C | 0.131mi | 3 | 1850 | 60mph | 1846.74 | 1846.00 |
| C | 0.199mi | 4 | 2300 | 100mph | 1845.98 | 1846.00 |
| C | 0.041mi | 2 | 1900 | 40mph | 1845.98 | 1846.00 |
| C | 0.143mi | 3 | 1850 | 1830mph | 1831.93 | 1830.00 |
| C | 0.170mi | 4 | 2300 | 100mph | 1831.42 | 1830.00 |
| C | 0.066mi | 2 | 1900 | 40mph | 1830.29 | 1830.00 |
| C | 0.207mi | 2 | 1900 | 80mph | 1821.91 | 1814.00 |
| C | 0.642mi | 4 | 2300 | 100mph | 1809.72 | 1814.00 |
| C | 0.092mi | 2 | 1900 | 50mph | 1785.67 | 1843.00 |
| C | 0.510mi | 3 | 1850 | 60mph | 1777.49 | 1777.00 |
| C | 0.386mi | 4 | 2300 | 100mph | 1730.45 | 1767.00 |
| C | 0.886mi | 4 | 2300 | 100mph | 1702.40 | 1623.00 |
| C | 0.106mi | 2 | 1900 | 50mph | 1694.72 | 1843.00 |
| C | 0.051mi | 2 | 1900 | 40mph | 1668.44 | 1670.00 |
| C | 0.179mi | 4 | 2300 | 100mph | 1668.44 | 1670.00 |
| C | 0.495mi | 3 | 1850 | 60mph | 1650.08 | 1644.00 |
| C | 0.012mi | 3 | 1850 | 60mph | 1645.52 | 1670.00 |
| C | 0.161mi | 4 | 2300 | 100mph | 1644.17 | 1644.00 |
| C | 0.070mi | 2 | 1900 | 40mph | 1644.17 | 1644.00 |
| C | 0.011mi | 3 | 1850 | 60mph | 1622.48 | 1670.00 |
| C | 0.195mi | 4 | 2300 | 100mph | 1621.77 | 1623.00 |
| C | 0.044mi | 2 | 1900 | 50mph | 1621.77 | 1623.00 |
| C | 0.127mi | 2 | 1900 | 40mph | 1546.76 | 1538.00 |
| C | 0.109mi | 3 | 1850 | 60mph | 1540.97 | 1538.00 |
| C | 0.131mi | 2 | 1900 | 40mph | 1537.59 | 1538.00 |
| C | 0.053mi | 2 | 1900 | 50mph | 1336.06 | 1335.00 |
| C | 1.492mi | 4 | 2300 | 100mph | 1326.67 | 1335.00 |
| C | 0.232mi | 2 | 1900 | 80mph | 1300.15 | 1292.00 |
| C | 0.461mi | 3 | 1850 | 60mph | 1282.99 | 1283.00 |
| C | 0.257mi | 2 | 1900 | 40mph | 1282.99 | 1283.00 |

**Figure 9.** The transport network and the table containing the data within the PTV Visum software.

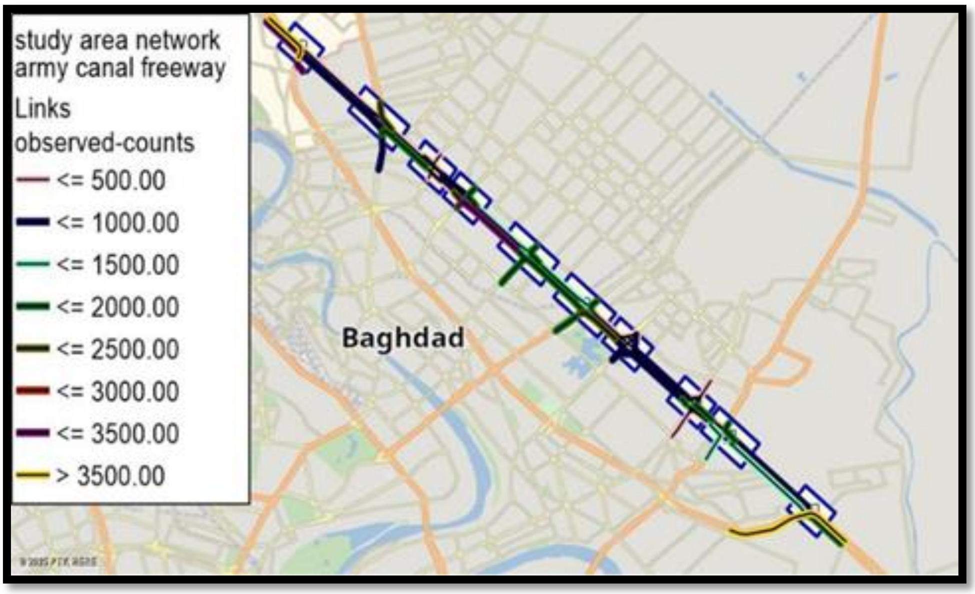



**Figure 10.** Observed traffic flow data within the study area network.

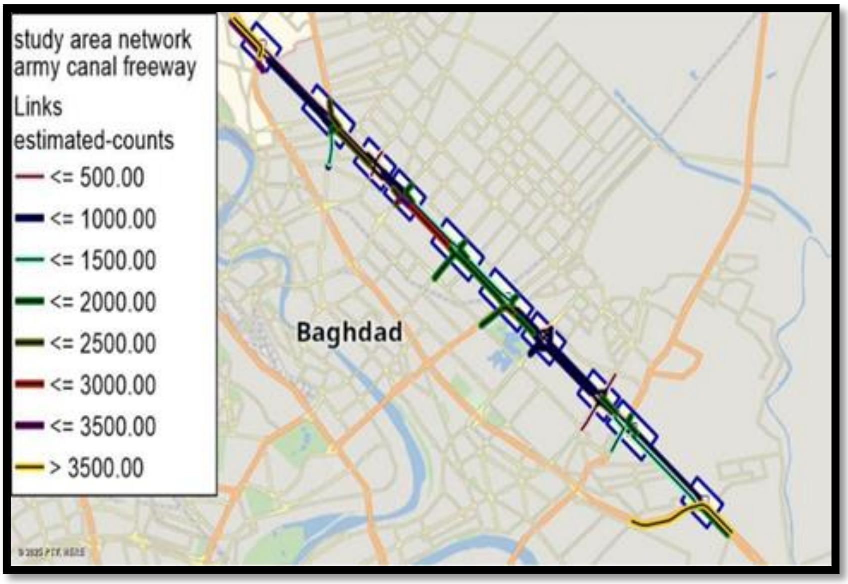



**Figure 11.** Estimated traffic flow data within the study area network.

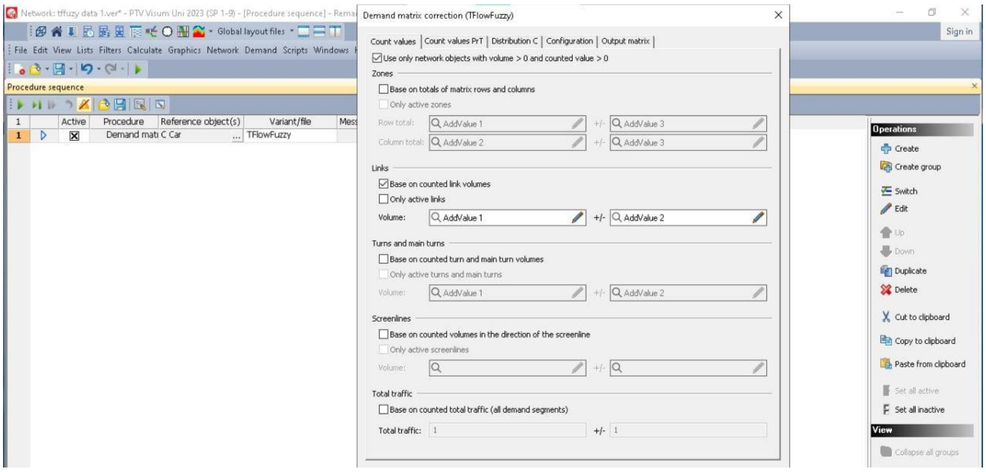



**Figure 12.** Select TFF method in PTV Visum.

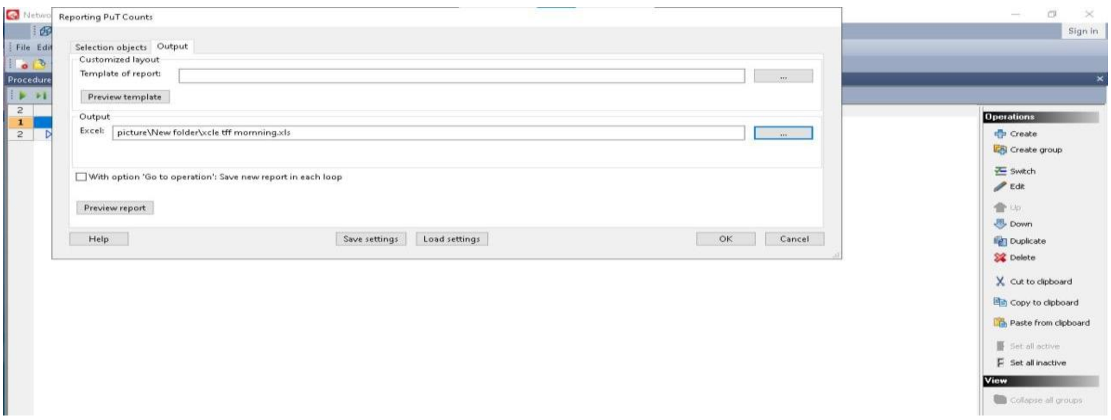
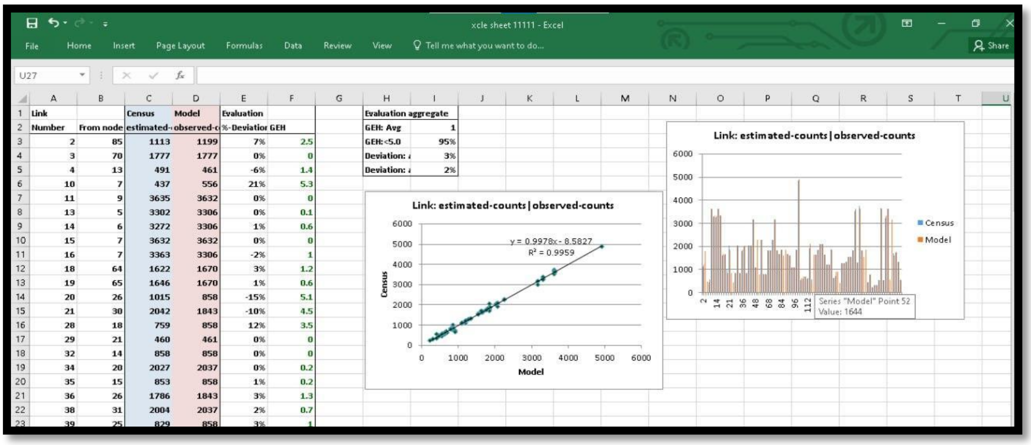



**Figure 13.** Export TFF method results from PTV Visum as an Excel spreadsheet file.



| Link Number | From node | Census estimated- | Model observed-c | Evaluation %-Deviation | GEH |
|---|---|---|---|---|---|
| 2 | 85 | 1113 | 1199 | 7% | 2.5 |
| 3 | 70 | 1777 | 1777 | 0% | 0 |
| 4 | 13 | 491 | 461 | -6% | 1.4 |
| 10 | 7 | 437 | 556 | 21% | 5.3 |
| 11 | 9 | 3635 | 3632 | 0% | 0 |
| 13 | 5 | 3302 | 3306 | 0% | 0.1 |
| 14 | 6 | 3272 | 3306 | 1% | 0.6 |
| 15 | 7 | 3632 | 3632 | 0% | 0 |
| 16 | 7 | 3363 | 3306 | -2% | 1 |
| 18 | 64 | 1622 | 1670 | 3% | 1.2 |
| 19 | 65 | 1646 | 1670 | 1% | 0.6 |
| 20 | 26 | 1015 | 858 | -15% | 5.1 |
| 21 | 30 | 2042 | 1843 | -10% | 4.5 |
| 28 | 18 | 759 | 858 | 12% | 3.5 |
| 29 | 21 | 460 | 461 | 0% | 0 |
| 32 | 14 | 858 | 858 | 0% | 0 |
| 34 | 20 | 2027 | 2037 | 0% | 0.2 |
| 35 | 15 | 853 | 858 | 1% | 0.2 |
| 36 | 26 | 1786 | 1843 | 3% | 1.3 |
| 38 | 31 | 2004 | 2037 | 2% | 0.7 |
| 39 | 25 | 829 | 858 | 3% | 1 |

| Evaluation aggregate | |
|---|---|
| GEH: Avg | 1 |
| GEH:<5.0 | 95% |
| Deviation: | 3% |
| Deviation: | 2% |



**Figure 14.** Excel sheet file imported from PTV Visum.

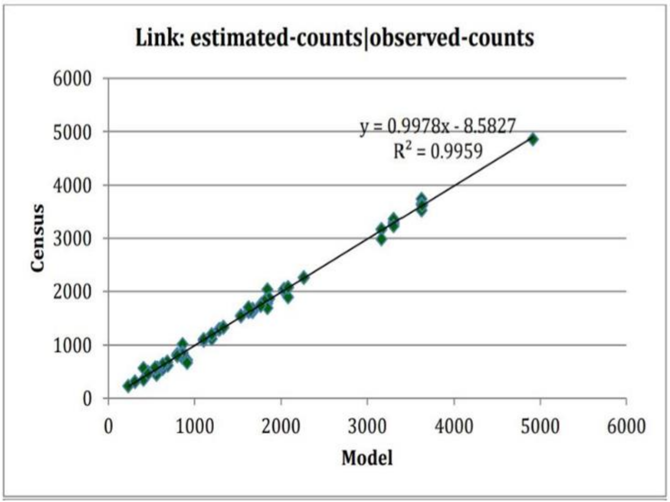



**Figure 15.** Linear relationship between observed and estimated data using the TFF method.

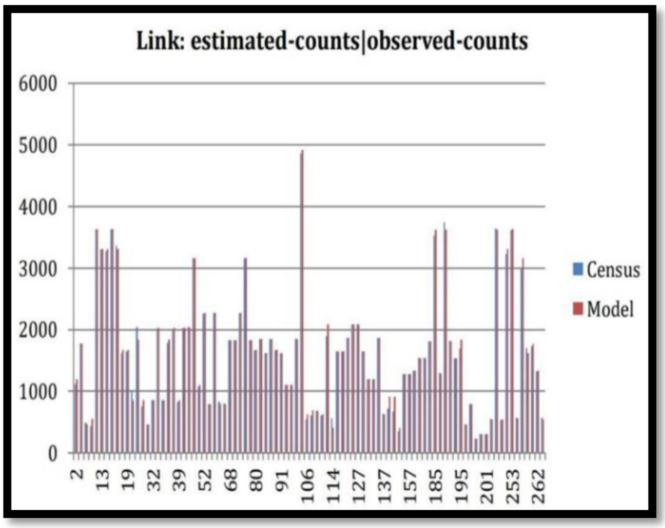



**Figure 16.** Traffic flow volume between observed (model) and estimated (count) data.

## 4. Results and discussion

Accurate estimation of the origin-destination matrix (O-D matrix) is essential for urban transportation planning and traffic network performance optimization. The application of time-dependent flow filtering (TFF) is crucial in this context, as it improves the accuracy of O-D matrix estimation. This contributes to a better representation of actual traffic behavior in the O-D matrix, reducing estimation bias and thus improving the reliability of results. The use of accurate TFF-based O-D matrices also improves the performance of traffic simulation models, allowing for more accurate scenario assessment and better infrastructure planning. The TFF method function was applied within the scope of the PTV Visum program to simulate the Army Canal road network in Baghdad. One of the most important results of the TFF method is the existence of a linear relationship between the observed and estimated data, where the horizontal axis (model) represents the observed traffic flow data, and the vertical axis (Census) represents the estimated traffic flow data. The comparison results showed a high degree of agreement between the observed and estimated values, with the regression equation equal to ($y=0.9978x-8.5827$), and the coefficient of determination ($R^2$) equal to 0.9959. This means that the model is able to explain 99.59% of the variances in the observed data, reflecting the effectiveness of the adopted model. The most important results can be summarized as follows:

1. The closeness between the observed and estimated values indicates excellent calibration of the model using the TFF function, demonstrating the efficiency and success of the model.
2. The small deviation of the constant part within the regression line equation (-8.5827) indicates a small difference in the estimates but has little effect on the accuracy of the model.
3. Its slope value close to one (0.9978) reflects a strong response of the model and confirms that the estimated values follow the pattern of observed values exactly.
4. The results demonstrated the efficiency of the TFF technique and also indicated the feasibility of adopting this method in evaluating future traffic scenarios.

## 5. Conclusion

The results of this research demonstrated the effectiveness and accuracy of using the Traffic Flow Function (TFF) in PTV Visum to simulate traffic conditions within the studied network. Comparison of model-estimated traffic values with field-observed data showed a high agreement, with a coefficient of determination of $R^2 = 0.9959$, indicating a high level of calibration and model reliability. The small deviation between the estimated and observed values reflects the TFF model's ability to accurately represent actual traffic behavior, enhancing the model's validity for use in analyzing future scenarios and supporting planning decisions related to transportation infrastructure. Based on these results, it can be confirmed that the application of the TFF method in Visum is an effective tool in traffic planning and management, especially in environments that require accurate modeling to assess the potential impacts of changes in demand or network characteristics.

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