The Egyptian International Journal of Engineering Sciences and Technology

https://eijest.journals.ekb.eg/

Vol. 41 (2023) 1–12

DOI: 10.21608/EIJEST.2022.130296.1150

ISSN:1687-1006

Traffic Assignment Model for Sustainable Transportation Planning of Cities-An Overview

Metwally Gouda[a], Mohamed Abdelghany [b], Mohamed Shalaby[c], Ahmed Osama[d*]

[a]*Professor of Highway and Airport Engineering, Faculty of Engineering, Zagazig University, Egypt*
[b]*Associate Professor of Highway and Airport Engineering, Faculty of Engineering, Zagazig University, Egypt*
[c]*Lecturerr of Highway and Airport Engineering, Faculty of Engineering, Zagazig University, Egypt*
[d]*Teaching Assistant of Highway and Airport Engineering, Faculty of Engineering, Zagazig University, Egypt*

ARTICLE INFO

Article history:

Received 29 March 2022
Received in revised form
15 June 2022
Accepted 23 July 2022
Available online 23 July 2022

Keywords:

Transportation planning
Travel Demand model
Four-step demand model
Trip assignment model application

ABSTRACT

The transportation planning process is considered a point of interest in the field of urban sustainable development. After many years of development and knowledge, it was found that transportation modelling has a fundamental role in transportation planning. There are many types of transportation models that represent the travel behavior in the study area. The traditional travel demand model is one of the most widely used in transportation planning modelling. Mainly there are four stages in the traditional travel demand model. These stages are trip generation, trip distribution, mode choice, and trip assignment. The trip assignment model is the result for the previous three stages and could estimate the traffic flow on network links. This paper represents the traditional travel demand model so-called "four-step model" and its structure as well as the validation methods for the trip assignment model. The overview also includes the applications of the traffic assignment model, considering it the final stage of the travel demand model, in the sustainable development of urban cities.

1. Introduction

Transportation planning models are considered an essential tool in the decision-making stages. It could be depicted as mirroring the way individuals view the world and make movements, whether (passenger movement) or (freight transport) [1]. Furthermore, transportation planning encourages travel demand forecasting as it provides technical support for estimating traveler behavior in the short or long time of estimation [2]. There are many types of travel demand models and could be differentiated according to the sequence of choices into (Trip-based model) and (Activity-based model) [3]. The trip-based model takes into consideration that the choice of each trip end is independent of the other trips choice in the same trip journey. In contrast, the activity-based models focus on the primitive reason for travel and types of activities as there is an interrelationship possibility of trips called (tours or chains) [4]. The traditional four-step model (FSM) is an example of trip-based transportation modeling. FSM includes four main stages: trip generation, trip distribution, mode choice, and route choice (trip assignment). The traffic assignment model is the final stage in defining a complete model for transportation data description. The assignment model takes the matrix of movements from origin zones to destination

* Corresponding author. Tel.: +2-01032597871
E-mail address: aelsaed@eng.zu.edu.eg

zones and loads it onto the convenient network. The results from the assignment models are the private transport models as vehicles per links and public transport models as passenger trips. Most of the procedures for trip assignment models are empirical and depend on traffic and route conditions. Application of assignment models on a large scale of study areas becomes more complicated, thus using simulation techniques by computer software saves time and effort in the assignment process [5]. In the following topics, a review of the traditional FSM including trip assignment step and the applications of trip assignment model is presented.

2. History of traditional FSM

Transportation in history has been influenced by the newest innovations, development, and acquisition of human life knowledge [6]. Transportation planning started in the United States of America in terms of regional transportation planning to provide regulation funding for the infrastructure project constructed in the states. Before the Second World War in 1945, transportation planning was a simplified tool without full representation of transportation behavior. After the end of the Second World War, the widespread of vehicles and transportation networks has led to the need for transportation modeling to overcome the complexity of transportation movement representation [7]. Transportation modeling is a systematic representation of the real world-traveling behavior and land use activities as existing [8]. Transportation models were widely used in the early years to verify that enough highway capacity was adequate to serve the rising demand for automobile trips with very little effort in dealing with other transportation modes [9]. The trip-based model technique was the first approach to be used in transportation modeling and applied in Chicago as a case study [10]. Then, the framework of the traditional four-step approach was suggested by Manheim [11] and is still used today. The four-step model has been widely used in the transportation planning field of science and applications. Although it has some drawbacks in describing travel behavior; it is considered an essential tool in the history of transportation demand modelling. The reason for using this model is the logical sequence of the model steps [12]. FSM consists of four successive steps; trip generation, trip distribution, mode choice, and finally trip assignment [13].

3. Limitations of traditional FSM

FSM, which is based on the trip-based technique, has some drawbacks that lead to an invalid representation of travelers' behavior [14]. Horowitz [15] was one of the first to recognize the limits of the FSM concept. After that, many authors investigated the weakness of FSM and its limitations [16, 17, 18]. The main disadvantage of using the traditional FSM is the discontinuity of steps and the independence of the model's parameters from each other. This may lead to an inability of describing travel behavior [19]. The limitations of the traditional four-step model could be summarized in main topics as shown below:

a. Disregard the activity participation decisions as a reason for demand function.

b. Ignoring the spatial and temporal interrelationship between activities and trips.

c. Inadequate substantial evidence related to alternate scenarios including information level and household dynamics.

4. Defining FSM procedures

The FSM provides a way to get equilibrium traffic flow on the network paths. The FSM is commonly used to estimate the travel demand in the study area. It depends on the logical sequence of travel movement representation. The FSM framework model is illustrated in Figure (1) by Garber et al. [20]. FSM consists of four main steps: Trip generation, trip distribution, mode choice, and trip assignment.

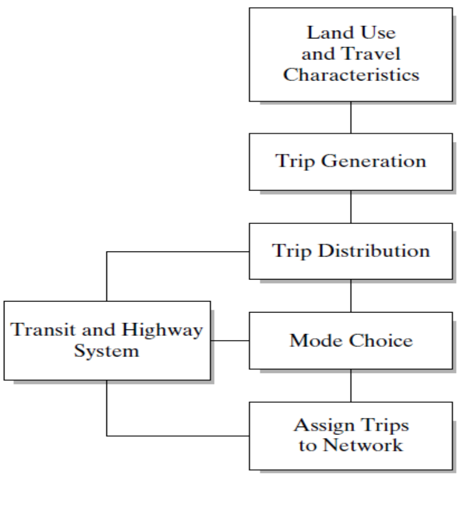

Fig. 1. FSM procedures

4.1. Trip Generation step

The objective of this step is to define the number of trips that are produced or attracted to each zone on the transportation systems [21]. These generated trips could be classified according to trip purpose into three categories: a) home-based work trips (HBW), b) home-based other trips (HBO), and c) non-home-based trips (NHB). In case of having one end of the trips at home then this trip is home-based. None-home-based trips have neither end of trips at home [22]. Production and attraction trip generation models are two products depending on trip ends. Indeed, the home-based trips with the end of the trip at home are always the production while the nonhome end is the attraction. In non-home trips, the origin of the trips is the production while the destination is the attraction [23, 24]. Trip production models are mainly used to have a complete definition of trips focusing on household and personal details. However, trip attraction models are highly recommended in the case of zonal analysis requirements [25].

Several factors influence the trip production or attraction to each of the transportation analysis zone (TAZ). These factors could affect personal trip production or personal trip attraction. The freight trip generation also has some factors that affect its trip production and attraction. The following Table (1) summarizes the factors according to the type of trip generation model [26,27].

Table. 1. Factors affecting trip generation [26,27]

Trip Generation model	**Factors affecting trips generation**
Personal trip production	• Personal income; • Car ownership; • Number of persons in each household; • Household structure; • Residential density; • Value of land; • Distance of TAZ from the central business district (CBD)
Personal trip attraction	• Available industrial and commercial space; • Zonal employment.
Freight trip production and attraction	• Available area of corporations; • Number of employees; • Number of sales.

Trip generation analysis models are devolved to estimate the travel trips generated in each TAZ for each trip purpose depending on socio-economic and land use activity data in the future. These models have a fundamental assumption that there are relationships between land use activities and the frequency of the generated trips [28]. Studies have developed three types of trip generation analysis models: (a) Growth factor method; (b) Linear regression analysis method; (c) Cross-classification method.

4.2. Trip distribution step

The objective of this step is to determine the trips between each pair of TAZs. Trip distribution is essential for understanding the human movements between TAZs in the study area [29]. The results of the trip distribution step could be classified as two types of outputs. The first type is having the human movement between TAZs in the shape of a matrix or a table that so-called "origin-destination" (O-D) matrix or table. The second type of trip distribution output is to have movement representation on a production-attraction basis. There are many methods of trip distribution steps. These approaches could be classified into two main categories: (a) Growth factor approaches; and (b) Gravity law approach [30].

Growth factor approaches (GFAs) are used in short time planning especially in updating existing origin-destination tables [31]. By necessity, these approaches require having a current O-D table from previous studies or survey data. There are five types of GFAs: (1) Uniform growth factor approach; (2) Average growth factor approach; (3) Detroit approach; (4) Fratar approach; and finally (5) Furness approach. Table (2) epitomize the difference between the GFAs' formulas.

Table. 2. Different types and formula for GFA

GFA	**Proposed formula**	**Definitions and notations**
Uniform growth factor	$T_{ij} = t_{ij} \times G$	• Tij is the estimated number of trips from zone I to zone j. • t_{ij} is the current number of trips from zone I to zone j. • G is the general growth factor for the study area.
Average growth factor	$T_{ij} = t_{ij} \times \frac{G_i + G_j}{2}$	• G_i is the origin growth factor of trips from zone I to zone j. • G_j is the destination growth factor of trips from zone *I* to zone *j*.
Detroit	$T_{ij} = t_{ij} \times \frac{G_i \times G_j}{G}$	
Fratar	$T_{ij} = t_{ij} \times G_i \times G_j \times \frac{L_i + L_j}{2}$	• L_i is the spatial factor for zone $I = \frac{t_i}{\sum_1^n t_{ij} \times G_j}$. • L_j is the spatial factor for zone $j = \frac{t_j}{\sum_1^n t_{ij} \times G_j}$.
Furness	$T_{ij} = t_{ij} \times G_i \times G_j \times A_i \times B_j$	• A_i and A_j are Furness parameters.

Although GFAs are simple and easy to understand and apply, they have limitations due to their assumptions and the type of data needed. GFAs need the same database as the original trip table, however, this type of data is expensive and needs more time. Furthermore, these approaches are highly dependent on the base year trip matrix and don't take into consideration the changes in the transportation cost due to development or network congestion [32]. Indeed, Fratar's approach was shown to be the most effective method of GFAs [33].

The gravity law approach is an approach that estimates each cell in the O-D matrix without the existence of current travel pattern as opposed to growth factor approaches. This approach uses the concept of Newton's gravitational law; therefore, it acquires its name from that. The first use of the gravity model was by Casey in 1955 [34]. After that, the studies investigated a more effective and simplified formulas till reaching the formula shown in Equation (1) [30,35,36].

$$T_{ij} = O_i \times D_j \times \left[\frac{f(C_{ij})}{\sum D_j \times f(C_{ij})}\right] \#(1)$$

Where,

O_i= Generated trips from zone I,
D_i= Attracted trips to zone I,
$F(C_{ij})$ = Generalized function (friction factor).

The friction factor (C_{ij}) is an independent factor that appraises the travel impedance between traffic zones including the travel cost or distance or travel time [32]. This function has several versions such as gamma function, exponential function, power function, and combined function listed in Equations (2) to (5), respectively. Early studies depended on the hand-fitting friction factor. Recently, Gamma function formation has had a good impression on its results of trip distribution [22].

$$f(C_{ij}) = \mathrm{a} \times \mathrm{C_{ij}}^{\mathrm{b}} \times \mathrm{e}^{\mathrm{c}\times C_{ij}} \#(2)$$

$$f(C_{ij}) = e^{(-bC_{ij})} \#(3)$$

$$f(C_{ij}) = C_{ij}^{-b} \#(4)$$

$$f(C_{ij}) = C_{ij}^{a} e^{(-bC_{ij})} \#(5)$$

Where,

A, b, c = Function coefficient

4.3. Mode choice step

Mode choice is the third step in the FSM. Recently, many authors have studied the mode choice behavior of the travel makers as it is the most complex step in travel demand modelling. The main objective of this step is to determine the number or percentage of zonal trips in terms of private or transit modes. Choosing travel mode is a gleaner process as it depends on many independent variables such as a person's income, car ownership, and many other variables. Many mode choice models depend on the logit theory and could be classified as three types of models mentioned below:

a. Simple multinomial logit,
b. Nested logit, and
c. Incremental logit (pivot point).

The first and second types are commonly used in the estimation and evaluating of mode shares by inserting new transit modes in an area that has no such service. While, the third type, incremental logit, is commonly used in the mode improvement strategies analysis. The three types are detailed and explained in the NCHRP report [22]. The multinomial and nested logit model structure is shown in Figure (2).

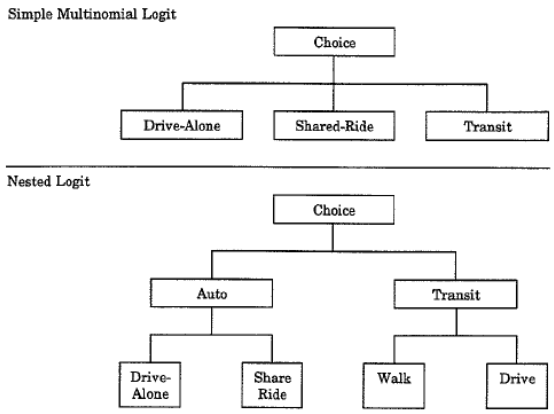

Fig. 2. Mode Choice Model structure

4.4. Trip assignment step

The final step in the traditional FSM is to determine the running routes that are estimated to be used and predict the number of vehicles in private transportation modes and passengers in transit transportation modes. The assignment process is the final output of the travel demand model (FSM). The assignment traffic results from loading travel demand trip between each TAZ on the network paths.

4.4.1 Link performance function

In essence, the congested network links have a major effect on the route choice for travelers. For any link, it has been generally noticed that the speed decreases as the flow increases to the point at which the flow is equal to the capacity of the link. After this point, the flow, and the speed decrease simultaneously whilst travel time increases [37]. This relationship is represented in an equation called "volume delay function (VDF)". VDF is used to express the travel time, or travel cost, on a network link as a function of the assigned volume on this link [38]. Usually, this function could be expressed as the result of multiplying the free flow time by the normalized congested function as shown in Equation (6). The most famous VDF was developed by the Bureau of Public Roads (BPR) [39] and has the formula shown in Equation (7).

$$t_{cu} = t_0 \times f\left[\frac{v}{c}\right] \#(6)$$

$$t_{cu} = t_0 \left(1 + \alpha \times \left[\frac{v}{c}\right]^{\beta}\right) \#(7)$$

Where,

t_{cu}= congested travel time,
$t_{0=}$ free flow time,
V= traffic volume,
C= capacity for each link,
α and β= parameters for calibration.

Indeed, the BPR formula is sufficiently good to be used in dealing with different link classes [40]. The basic BPR formula has used the default values of 0.15 and 4.0 for calibration parameters α and β, respectively [41]. These default calibration parameters could be used if there is a lack of information relevant to VDF parameters. Other contributions have been done to modify the basis BPR formula and test the modified BPR against field observations [42, 43].

Many other authors have proposed different formulations for VDF. In general, VDF is expressed as a relationship between travel time and flow on links. The following Table (3) lists the most common VDF proposed by researchers [44, 45, 46, 47].

Table.3. Different formulations for VDF

Author	Proposed formula	Definitions and notations
Smock (1962) [44]	$t = t_o \times e^{\left(\frac{V}{C}\right)}$	
Davidson (1966) [45]	$t = t_z\left[1 + J\left(\frac{X}{1-X}\right)\right]$	• t_z is zero flow time • J is the delay parameter • X represents (V/S) • S is the saturation parameter
Overgaard (1967) [46]	$t = t_o \times \alpha^{\beta\left(\frac{V}{C}\right)}$	α and β are parameters for calibration
Steenbrink (1974) [47]	$t = t_o\left[1 + \alpha\left(\frac{V}{C_s}\right)^{\beta}\right]$	• α and β are parameters for calibration • C_s is the steady state capacity

4.4.2 Trip assignment methods

Fundamentally, trip assignment methods can be widely classified into two classes: static trip assignment method and dynamic trip assignment method [48]. The static trip assignment method mainly focuses on the side of the transportation planning process that estimates the traffic loading on network links. one the other hand, the dynamic trip assignment method is used to develop time-varying traffic flow on network links to indicate the congestion levels vary with time. The dynamic trip assignment method gives attention to traffic control and management besides transportation planning [49].

Several trip assignment methods differ in the level of detail in dealing with route choice prediction. The most common methods are the all-or-nothing assignment method (AON), stochastic assignment method, and trip assignment with congestion method. AON is used to assign all trips, from origin to destination, to the best route connecting them. The best route is the route that has the least trip time, distance, or other impedance factors or has the least generalized cost. This method is probably reasonable in uncongested networks where there are few alternative paths and there is a large variety in travel costs [50]. The stochastic assignment method takes into consideration the variation in drivers' perceptions of travel costs [51]. Stochastic methods have two methods in determining assignment flow: simulation-based and proportion-based methods. The first method used the principles provided by Burrell [52] to introduce variability in travel costs. On the other hand, the proportion-based method allocates flows to second alternative routes from fixed proportions using logit-like expressions. Finally, trip assignment with congestion method takes into consideration the relation between the generalized travel cost and traffic flow of a link and then calculates both simultaneously till they are consistent with each other, and the equilibrium state takes place. The equilibrium technique requires several iterations of traffic flow assignments and the recalculation of link travel times. Regardless of, the extra iterations load, equilibrium methods are thought to be the most preferable to other assignment methods [5].

5. Travel demand model reliability

Since travel demand models are closed and eminent by mathematical relationships, the real-world demand depends on the population behavior which reflects an open system with many differences from the static mathematical relationships used in the models. Therefore, validation and calibration of travel demand models is an important process in making satisfying convergence between real-world and models [53]. After estimation of the travel demand model, this model should be tested before it applies to the field of application. Thus, calibration and validation processes take place after the estimation process and before the application stage as illustrated in Figure (3).

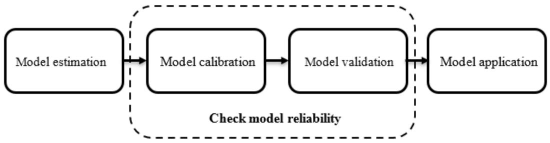

Fig. 3. Role of model calibration and validation

Model calibration modifies parameter values until expected travel within the region for the base year matches observed travel inside that region. These factors are expected to remain constant throughout time for forecasting considerations. Calibration is done in each of the four steps of the modelling process, and it usually happens after the model parameters have been determined. The validation process requires comparing the model expectation with data other than that used in the estimation process of the model. The validation step is an iterative process related to model calibration. It includes checking the model outputs against field data and modifying parameters until model results achieve an acceptable range of error [54].

5.1. Types of travel demand model validation tests

Four main types of validation checks could be specified. These types are (a) Base year comparisons, (b) Temporal comparisons, (c) Sensitivity checks, and (d) Reasonableness and logic checks [55]. Base year comparisons are probably the weakest validation tests because they are frequently performed on the same data that was used for model estimation. Splitting observed data into estimation and validation data sets might improve the utility of base year comparisons. Temporal comparisons are considered a strong validation approach since it involves estimating and calibrating a model using data from one year and then validating the model using data from a different period. Sensitivity testing applies the models with alternate input data or assumptions to test the ability of the model to simulate the travel behavior in different conditions related to the input demographic data, socioeconomic data, or transportation system. Reasonableness and logic tests comprise the type of checks that contrast estimated (or calibrated) model parameters with those predicted in other regions with similar models.

5.2. Aggregation levels for validation tests

The scale of model validation ranges from disaggregated data to aggregated data. At the level of disaggregated data, the model is compared to observed data on an individual scale. However, the level of aggregate data is performed on a larger scale than the level of disaggregated data as it is conducted on the zones and systems scale [56].

5.3. Sources of errors in travel demand model

There are many sources of errors that affect the travel demand models. Systematic analysis of errors provides a good estimation of the critical sources of errors [57]. These sources of error studies give a hand in the reliability of the model which affects the applications and investments in the study area [58]. From several sources of errors in the model's creations there are input data errors, model specification errors, and model aggregation errors [55].

5.4. Accuracy issues in travel demand model

The level of accuracy and purpose of the model influence the validation process. Time and resource availability control the level of accuracy and validation step [59].

5.5. Trip assignment model validation

As the trip assignment is the final product of the travel demand model. The assignment validations have frequently been utilized to represent a validation of the complete modelling process because the inputs to the assignment processes are based on the previous steps in the process [55]. This study focuses on the validation of the trip assignment model. The trip assignment model is validated in three levels: link specific, corridor, and systemwide. For systemwide validation levels, there are Vehicle Miles of Travel (VMT), Vehicle Hours of Travel (VHT), cordon volume, and screen line volume. VMT and VHT is an essential level of validation in the study areas which have agencies concerned with environmental protection issues where there are targets that should be fulfilled related to environmental problems [60]. So, VMT is an important criterion in trip assignment validation by comparing modeled VMT against VMT recorded from reports of the highway performances and traffic counting as the Highway performance monitoring system [61].

Traffic volume validation checks are conducted on each link or systemwide including screen lines and cordon [62]. Indeed, several measures could describe model reliability such as root mean square error (RMSE), percent root mean square error (%RMSE), scatter plot including (correlation coefficient (R), and coefficient of determination (R^2)) [54]. Other measures could be used such as mean absolute error ratio (MAE Ratio), and GEH statistics which could be preferred by some authors. Each of the previously mentioned measures is illustrated below beside the acceptable range for each measure.

- Root mean square error (RMSE)

RMSE is more widely used in the travel model validation process. This type of measure has the advantage of a long history of effectiveness and very well-understood criteria [41]. RME formula is shown in Equation (8) [63]. RMSE is usually applied by functional classification or facility type. Counts and model volumes should represent the same period, often one-hour duration.

$$RMSE = \sqrt{\frac{1}{n} \times \sum_{i=1}^{n} (M_i - C_i)^2} \#(8)$$

Where
Mi=Modeled volume for network links,
Ci=Counting volume for network links, and
N=Number of counted links.

- Percent root mean square error (%RMSE)

The same as RMSE, but this type of measure refers to the error between the modeled and counted volume as a percent. The following Equation (9) is used for calculating %RMSE. The acceptable range for RMSE and %RMSE is provided by [55] and listed in Table (4).

$$\%RMSE = \frac{RMSE}{\left(\frac{\sum_{i=1}^{n} C_i}{n}\right)} \times 100 \#(9)$$

Table.4. Target values for RMSE and %RMSE

Functional classification	Target value of RMSE	Target value of %RMSE
Freeways	<12500	<20%
Expressways	<7500	<30%
Principal arterials	<3750	<30%
Minor arterials	<3000	<40%
Collector	<2250	<70%
Systemwide links	-	<40%

- Scatter plot measures

Visual displays have been suggested as a method of representing data and have been widely used in many fields [64]. A Scatter plot is one of the most common data representations which shows the relation between the modeled and observed traffic volumes. The coefficient of determination (R^2), which is the square value of R, is calculated as the ratio of the variance in a dependent variable attributable to the variance in an independent variable as shown in Equation (10). In consequence, R^2 is thought to represent a measure of how much variation in the difference between traffic counts and model estimation volume. Indeed, reaching a regional R^2 of 0.88, has been proposed as an acceptable range for a valid trip assignment model [65].

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (yi - \hat{y}_i)^2}{\sum_{i=1}^{n} (yi - \bar{y})^2} \#(10)$$

Where
n = number of measurements,
y_i =value of the i^{th} observation in the validation counts data,

$\bar{y}$ = the average value of the validation counts data, and
$\hat{y}_i$= the predicted value for the i[th] observation.

• Mean absolute difference ratio (MAD ratio)

The MAD ratio is widely used in many studies related to the structure of population and households (demographic studies) [64, 66, 67]. MAD ration could be calculated using the following Equation (11). JICA [68] has used the MAD ration to validate the trip assignment model for Greater Cairo. By using daily traffic counts with a traffic volume over 10,000 the MAD ratio was 0.34 which represents a good trip assignment model.

$$MAD\ ratio = \left[\frac{\sum_{i=1}^{n}(C_i - M_i)}{\sum_{i=1}^{n} M_i}\right]/n \#(11)$$

• GEH statistics

The GEH statistic acquires its name from Geoffrey E. Havers who developed it in 1970. Since then, this measure has been developed and studied by many authors [69, 70, 71, 72]. This type of validation measure is preferable since it overcomes the issue of having variations in traffic flows as some of them are very large (freeways) and some have lower traffic flows, (local links) [70, 73]. The formula used in determining GEH is shown in Equation (12).

$$GEH = \sqrt{\frac{(C_i - M_i)^2}{0.5(C_i + M_i)}} \#(12)$$

The acceptable range for GEH is proposed by [74, 75] and stated that the average GEH should be less than 5 for at least 85% of total counted links. According to the Australian Transport Assessment and Planning Guidelines [8], the average GEH should be less than 5 for at least 60% of total counted links.

6. Trip assignment model application in sustainable development

Transportation planning and management affect the development of the countries. It gives a hand in choosing the best way to construct new transportation areas and update the transportation movement in existing areas. Over and above that, infrastructure and highway facilities lean on the transportation planning output fulfillments. Trip assignment models are a tool used by transportation planners to simulate the transportation behavior in the study area. These models can calculate the effect of changes in the study area. Air pollution, congestion level, fuel consumption, and other criteria could be estimated and compared between the base and the proposed conditions.

Many authors used the trip assignment models in travel behavior estimation in cities. Ramadan et al. [72] developed an assignment model for the Anamorava region in the Republic of Kosovo and used the Tflow-fuzzy calibration method for model adjustment using PTV Visum software. Joni et al. [76] created the traffic assignment model for Palembang City, one of the main cities in Indonesia, and studied the effect of adding four connecting bridges in 2022 and five bridges in 2027 on transportation planning in the city. Evangelos et al. [77] constructed a trip assignment model in the Greater Nicosia Area, Cyprus, using the macroscopic and microscopic combination in the transportation analysis by applying static and dynamic assignment side to side.

Indeed, Transportation modelling has been used in estimating the effect of transportation systems on the environment. Yi Wang et al. [78] have proved the relation between transportation projects and environmental sustainability through building assignment models and estimating the impact on the environment. Assignment models for passenger and freight, as well as private modes, have been studied for a case study in Poland to estimate the amount of emission in the study area [79]. On other hand, the traffic assignment model is used to estimate the effect of traffic flow on pavement performance and maintenance investments [80].

The modes of transportation systems are included in the studies of transportation planning and modelling. For example, Jiancheng Long et al. [81] proposed a methodology to predict and model the taxi movement using dynamic taxi traffic assignment in the case of having private cars, occupied taxis, and vacant taxis loaded in a dense network. Joschka Bischoff et al. [82] studied the effect of mode shifting from private cars to autonomous taxis in the study area; of Berlin. Also, many authors have taken into consideration the combining of two or more transportation systems as multimodal scenarios. Xiaohua et al. [83] constructed a tri-level traffic assignment model for multi-modal transportation planning. Public transportation assignments have a vital role in the complete travel description. Public transportation model was studied and modeled using PTV Visum in Hyderabad city to evaluate the current situation and estimate the future proposed scenarios in the public transportation movement [84]. Oded Cats et al. studied the on-board congestion related to transit modes and have used the transit assignment model to estimate its effect using PTV Visum and BusMezzo tools [85]. For railway transit mode, many studies are concerned with railway system management and planning. One of these studies investigated the influence of changing the ticket price of railway transit on the total passengers using this mode [86]. Gao et al. [87] studied the problem of ticket fare clearing related to urban transit systems by proposing a technique for estimating the proportion of passengers on each railway path. Guangming Xu et al. [88] devolved a dynamic assignment model related to the Beijing Metro network to determine the space-time distribution flow for transit railway passengers. Air traffic assignment model has been considered a planning tool for the estimation of air traffic movement. For instance, Vinh Ho-Huu et al. [89] studied the effect of air traffic movement on environmental pollution as well as fuel consumption by using an assignment model. Indeed, the effect of air traffic assignment appears directly in vicinity areas. Emir Ganić et al. [90] examined the effect of departure and arrival routes on the population near the airport aside from air pollution, especially the amount of CO2. In the naval field of science, the assignment model has a major effect on decision-making for assignment problems related to seaports. Cagˇatay Iris et al. [91] proposed a methodology for solving crane assignment problems in the terminals of seaports. Giada Venturini et al. [92] used the assignment model for optimizing the assignment process related to container shipping terminals to reduce time and fuel consumption.

In the field of parking studies, Adam et al. [93] have studied the concept of the parking search route and formatted the stochastic user equilibrium assignment model for expected parking probability.

7. Conclusions

This paper aims to illustrate the usage of traffic assignment in transportation planning sustainability since it is the more essential and aggregate step of transportation planning modeling steps. The traffic assignment process is the fourth step in the travel demand model which is called the four-step model. The four-step model mainly consists of four successive stages: trip generation- trip distribution- mode choice- traffic assignment. The trip generation process is the first process and is used to estimate the number of generated and attracted trips for transportation zones. The most common methods for trip generation are growth factor methods, cross-classification method, and linear regression analysis method. The second step includes the distribution of generated trips on other TAZs which is called the trip distribution step. The distribution process depends on the friction factor or impedance of travel between TAZs. There are several methods for trip distribution such as growth factor methods and gravity law methods. Growth factor methods have limitations due to their required input data and assumptions. Mode choice is the third step and after conducting it, the travel pattern for each transportation mode could be determined. Mode choice has several techniques such as simple multinomial logit, incremental logit (pivot point), and nested logit. Finally, the trip assignment step is conducted to assign the flow pattern on the transportation network. The assignment process could be done using all-or-nothing, stochastic, and trip assignments with congestion methods. The link performance function is an important relationship to determine the effect of traffic congestion on traveler route choice.

The traffic assignment model validation tests are a crucial step to ensure a good representation of travel behavior in the study area. Vehicle Miles of Travel and Vehicle Hours of Travel are systemwide validation measures used to compare field and estimated values in areas concerning environmental protection issues. For traffic count validation tests, there are several measures such as Root mean square error (RMSE), Percent root mean square error (%RMSE), coefficient of determination (R2), and mean absolute difference ratio (MAD ratio), and Geoffrey E. Havers (GEH) indicator. GEH indicator is recommended since it overcomes the problem of having high variation in traffic flows.

The traffic assignment model, as a final stage in the travel demand model, has shown a major influence on sustainable transportation planning. Several studies used the results of the traffic assignment model in estimating the effect of the proposed transportation project. Other studies used the traffic assignment model to give decision-makers tools for long-term transportation planning. Different types of public transportation systems could be investigated such as buses, railway transit, and even air traffic and naval field. These applications give traffic assignment models and travel demand models as all an importance in sustainable transportation planning.

References

[1] De Dios Ortúzar J. and Willumsen L. G., "Modelling transport", John Wiley & Sons, 2011.

[2] Heyns W. and Van Jaarsveld S., "Transportation Modelling in Practice: Connecting Basic Theory to Practice", Transportation- Land Use and Integration: Applications in Developing Countries, vol. 100, 2017, pp. 3-27.

[3] Cascetta E., "Transportation systems analysis: models and applications", Springer Science & Business Media, 2009.

[4] Arentze T., Timmermans H., Hofman F., and Kalfs N., "Data needs, data collection, and data quality requirements of activity-based transport demand models", Transportation research circular, 2000, pp. 30-33.

[5] Rojo M., "Evaluation of Traffic Assignment Models through Simulation", Sustainability, vol. 12, No. 14, 2020.

[6] Lee N. E., Travel and transport through the ages. Cambridge University Press, 1955.

[7] Johnston R. A., "The urban transportation planning process", The geography of urban transportation, vol. 3, 2004, pp. 115-140.

[8] Transport I. C. "T1 travel demand modeling: Australian transport assessment and planning guidelines", 2016.

[9] Meyer M. D., "Transportation planning handbook", John Wiley & Sons, 2016.

[10] Weiner E., "Urban transportation planning in the United States: an historical overview", US Department of Transportation, 1997.

[11] Manheim M. L., "Fundamentals of Transportation Systems Analysis", Vol. 1, 1979.

[12] Transport I. C. "T3 Wider economic benefits: Australian transport assessment and planning guidelines", 2016.

[13] Kutz M., "Handbook of transportation engineering", McGraw-Hill New York, 2004.

[14] Chu Z., Cheng L., and Chen H., "A review of activity-based travel demand modeling", CICTP, 2012, pp. 48-59.

[15] Horowitz J. L., "Travel and location behavior: state of the art and research opportunities", Transportation Research Part A: General, vol. 19, No. 5, 1985, pp. 441-453.

[16] Moeckel R., Kuehnel N., Llorca C., Moreno A. T., and Rayaprolu H., "Agent-based simulation to improve policy sensitivity of trip-based models", Journal of Advanced Transportation, 2020, DOI. 10.1155/2020/1902162

[17] Rasouli S. and Timmermans H., "Activity-based models of travel demand: promises, progress and prospects", International Journal of Urban Sciences, vol. 18, No. 1, 2014, pp. 31-60.

[18] Bhat C. R. and Koppelman F. S., "Activity-based modeling of travel demand," in Handbook of transportation Science: Springer, 1999, pp. 35-61.

[19] McNally M. G., "On the formation of household travel/activity patterns: A simulation approach", University of California (Irvine), 1986.

[20] Garber N. J. and Hoel L. A., "Traffic and highway engineering", Cengage Learning, 2009.

[21] Oyedepo O. and Makinde O., "Regression model of household trip generation of Ado-Ekiti township in Nigeria", European Journal of scientific research, vol. 28, No. 1, 2009, pp. 132-140.

[22] Martin W. A. and McGuckin N. A., "Travel estimation techniques for urban planning", National Academy Press Washington, vol 365, 1998.

[23] Ashenagar J., "Comparative assessment of trip generation category analysis and regression modelling techniques," Universiti Teknologi Malaysia, 2010.

[24] Rahman R. A., "Modelling of Trip Generation Based on School Attraction," Universiti Teknologi Malaysia, 2009.

[25] Hensher D. A. and Button K. J., "Handbook of transport modelling" , 2000.

[26] Mathew T. V. and Rao K. K., "Introduction to Transportation engineering", Civil Engineering–Transportation Engineering, 2006.

[27] Moussa H., "Development of a Trip Generation Model for Gaza City", MSc Thesis in Infrastructure Engineering (Islamic University), 2013.

[28] Victor D. J. and Ponnuswamy S., "Urban transportation: planning, operation and management", Tata McGraw-Hill Education, 2012.

[29] Lenormand M., Bassolas A., and Ramasco J. J., "Systematic comparison of trip distribution laws and models", Journal of Transport Geography, vol. 51, 2016, pp. 158-169.

[30] Cascetta E., Pagliara F., and Papola A., "Alternative approaches to trip distribution modelling: a retrospective review and suggestions for combining different approaches", Papers in regional Science, vol. 86, No. 4, 2007, pp. 597-620.

[31] Abdel-Aal M. M. M., "Calibrating a trip distribution gravity model stratified by the trip purposes for the city of Alexandria", Alexandria Engineering Journal, vol. 53, No. 3, 2014, pp. 677-689.

[32] Rasouli M., "Trip distribution modelling using neural network", Curtin University, 2014.

[33] Brokke G. E. and Mertz W. L., "Evaluating trip forecasting methods with an electronic computer", Highway Research Board Bulletin, vol. 203, 1958, pp. 52-75.

[34] Casey H., "Applications to traffic engineering of the law of retail gravitation", Traffic Quarterly, vol. 9, No. 1, 1955, pp. 23-35.

[35] Celik H. M., "Sample size needed for calibrating trip distribution and behavior of the gravity model", Journal of Transport Geography, vol. 18, No. 1, 2010, pp. 183-190.

[36] de Grange L., Fernández E., and de Cea J., "A consolidated model of trip distribution", Transportation Research Part E: Logistics Transportation Review, vol. 46, No. 1, 2010, pp. 61-75.

[37] Suh S., Park C.-H., and Kim T. J., "A highway capacity function in Korea: measurement and calibration", Transportation Research Part A: General, vol. 24, No. 3, 1990, pp. 177-186.

[38] Spiess H., "Conical volume-delay functions", Transportation Science, vol. 24, No. 2, 1990, pp. 153-158.

[39] Bureau P., "Traffic assignment manual for application with a large, high speed computer", US Department of Commerce, vol. 37, 1964.

[40] Branston D., "Link capacity functions: A review", Transportation research, vol. 10, No. 4, 1976, pp. 223-236.

[41] Horowitz A., Creasey T., Pendyala R., and Chen M., "Analytical travel forecasting approaches for project-level planning and design", Vol. 756, 2014.

[42] Horowitz A. J., "Delay/volume relations for travel forecasting based upon the 1985 Highway Capacity Manual", Vol. 24, 1991.
[43] Moses R., Mtoi E., Ruegg S., McBean H., and Brinckerhoff P., "Development of speed models for improving travel forecasting and highway performance evaluation", Florida Dept. of Transportation, 2013.
[44] Smock R., "An iterative assignment approach to capacity restraint on arterial networks", Highway Research Board Bulletin, No. 347, 1962.
[45] Davidson K., "A flow travel time relationship for use in transportation planning", Australian Road Research Board (ARRB), vol. 3, No. 1, 1966.
[46] Overgaard K. R., "Urban transportation planning'traffic estimation", Traffic Quarterly, vol. 21, No. 2, 1967.
[47] Steenbrink P. A., "Optimization of transport networks. London; New York", Wiley, 1974.
[48] Chow A. H., "Trip Assignment–a literature review", California PATH (UC Berkeley), vol. 29, 2007.
[49] Saw K., Katti B., and Joshi G., "Literature review of traffic assignment: static and dynamic", International Journal of Transportation Engineering, vol. 2, No. 4, 2015, pp. 339-347.
[50] Dial R. B., "A probabilistic multipath traffic assignment model which obviates path enumeration", Transportation research, vol. 5, No. 2, 1971, pp. 83-111.
[51] Daskin M. S., "Urban transportation networks: Equilibrium analysis with mathematical programming methods, JSTOR, 1985.
[52] Burrell J. E., "Multiple route assignment and its application to capacity restraint", Proceedings of Fourth International Symposium on the Theory of Traffic Flow, 1968.
[53] Wegmann F. and Everett J., "Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee", Centre for Transportation Research (University of Tennesse), 2008.
[54] Systematics C., "Travel Model Validation and Reasonableness Checking Manual", Travel Model Improvement Program (Federal Highway Administration), 2010.
[55] Systematics C., "H-GAC Activity-Based Model – Model Validation Plan Report", Travel Model Improvement Program (Federal Highway Administration), 2013.
[56] Yasmin F., Morency C., and Roorda M. J., "Macro-, meso-, and micro-level validation of an activity-based travel demand model", Transportmetrica A: Transport Science, vol. 13, No. 3, 2017, pp. 222-249.
[57] Yang C., Chen A., Xu X., and Wong S. C., "Sensitivity-based uncertainty analysis of a combined travel demand model", Transportation Research Part B: Methodological, vol. 57, 2013, pp. 225-244.
[58] Richmond J. E., "New Rail Transit Investments-A Review", Harvard University, 1998.
[59] Systematics C., "Model Validation and Reasonableness Checking Manual", Travel Model Improvement Program (Federal Highway Administration), 1997.
[60] Waxman H. A., "An Overview of the Clean Air Act Amendments of 1990", University of California, vol. 21, 1991, p. 1721.
[61] Federal H. W. A., "Highway performance monitoring system field manual", US Dept. of Transportation Washington, 2010.
[62] Bass P., Perkinson D. G., Keitgen B., and Dresser G. B., "Travel forecasting guidelines", Texas Transportation Institute, 1994.
[63] Boyce D. E., Zhang Y.-F., and Lupa M. R., "Introducing feedback into four-step travel forecasting procedure versus equilibrium solution of combined model", Transportation Research Record, vol. 1443, 1994, p. 65.
[64] Dent J. B., "Systems simulation in agriculture", Springer Science & Business Media, 2012.
[65] Ismart D., "Calibration and adjustment of system planning models", Federal Highway Administration, 1990.
[66] Smith S. K., "Tests of forecast accuracy and bias for county population projections", Journal of the American Statistical Association, vol. 82, No. 400, 1987, pp. 991-1003.
[67] Siegel J. S., "Development and accuracy of projections of population and households in the United States", Demography, vol. 9, No. 1, 1972, pp. 51-68.
[68] Japan I. C. A. (JICA), "Transportation Master Plan and Feasibility Study of Urban Transport Projects in Greater Cairo Region in the Arab Republic of Egypt (CREATS – Cairo Regional Area Transportation Study)", vol. 3, 2001,
[69] Shankar K. R., Prasad C., and Reddy T., "Evaluation of area traffic management measures using microscopic simulation model", Procedia-Social Behavioral Sciences, vol. 104, 2013, pp. 815-824.
[70] Friedrich M., Pestel E., Schiller C., and Simon R., "Scalable GEH: A Quality Measure for Comparing Observed and Modeled Single Values in a Travel Demand Model Validation", Transportation Research Record, vol. 2673, No. 4, 2019, pp. 722-732.
[71] Feldman O., "The GEH measure and quality of the highway assignment models", Association for European Transport Contributors, 2012, pp. 1-18.
[72] Ramadan DURAKU V. A., Nikola KRSTANOSKI, "Building and Calibration Transport Demand Model in Anamorava Region", Tehnicki vjesnik - Technical Gazette, vol. 26, No. 6, 2019.
[73] Chitturi M. V., Shaw J. W., Campbell IV J. R., and Noyce D. A., "Validation of origin–destination data from bluetooth reidentification and aerial observation", Transportation Research Record, vol. 2430, No. 1, 2014, pp. 116-123.
[74] Transport I. I. , "Project Appraisal Guidelines for National Roads (Construction of Transport Models)", Standards and Research Section, 2016.
[75] Transport A. G., " Highway Assignment Modelling", Division Department for Transport (London), 2020.
[76] Arliansyah J., Prasetyo M. R., and Kurnia A. Y., "Planning of City Transportation Infrastructure Based on Macro Simulation Model", International Journal on Advanced Science, Engineering and Information Technology, vol. 7, No. 4, 2017.
[77] Mitsakis E., Aifadopoulou G., Salanova Grau J. M., Chrysohoou E., and Morfoulaki M., "Combination of Macroscopic and Microscopic Transport Simulation Models: Use Case in Cyprus", International Journal for Traffic and Transport Engineering, vol. 4, No. 2, 2014, pp. 220-233.
[78] Wang Y., Szeto W. Y., Han K., and Friesz T. L., "Dynamic traffic assignment: A review of the methodological advances for environmentally sustainable road transportation applications", Transportation Research Part B: Methodological, vol. 111, 2018, pp. 370-394.
[79] Jacyna M., Wasiak M., Kłodawski M., and Lewczuk K., "Simulation Model of Transport System of Poland as a Tool for Developing Sustainable Transport", Archives of Transport, vol. 31, No. 3, 2014, pp. 23-35.
[80] Mao X., Wang J., Yuan C., Yu W., and Gan J., "A Dynamic Traffic Assignment Model for the Sustainability of Pavement Performance", Sustainability, vol. 11, No. 1, 2018.
[81] Long J., Szeto W. Y., Du J., and Wong R. C. P., "A dynamic taxi traffic assignment model: A two-level continuum transportation system approach", Transportation Research Part B: Methodological, vol. 100, 2017, pp. 222-254.
[82] Bischoff J. and Maciejewski M., "Simulation of City-wide Replacement of Private Cars with Autonomous Taxis in

Berlin", Procedia Computer Science, vol. 83, 2016, pp. 237-244.

[83] Yu X., Wang H., Ge Z., and Guo J., "Traffic assignment model for combined mode with travel condition constraints", International Journal of Modern Physics B, vol. 34, No. 04, 2020.

[84] Krishna G. V. and Chattaraj U., "Analysis of Urban Public Transportation Network in Hyderabad: Telangana," presented at the International Conference on Civil Architectural and Environmental Sciences (Puri, Odisha), 2020.

[85] Cats O. and Hartl M., "Modelling public transport on-board congestion: comparing schedule-based and agent-based assignment approaches and their implications", Journal of Advanced Transportation, vol. 50, No. 6, 2016, pp. 1209-1224.

[86] Lin D.-Y., Fang J.-H., and Huang K.-L., "Passenger assignment and pricing strategy for a passenger railway transportation system", Transportation Letters, vol. 11, No. 6, 2019, pp. 320-331.

[87] Shengguo G. and Zhong W., "Modeling passenger flow distribution based on travel time of urban rail transit", Journal of Transportation Systems Engineering and Information Technology, vol. 11, No. 6, 2011, pp. 124-130.

[88] Xu G., Zhao S., Shi F., and Zhang F., "Cell transmission model of dynamic assignment for urban rail transit networks", PLoS One, vol. 12, No. 11, 2017.

[89] Ho-Huu V., Ganić E., Hartjes S., Babić O., and Curran R., "Air traffic assignment based on daily population mobility to reduce aircraft noise effects and fuel consumption", Transportation Research Part D: Transport and Environment, vol. 72, 2019, pp. 127-147.

[90] Ganić E., Ho-Huu V., Babić O., and Hartjes S., "Air traffic assignment to reduce population noise exposure and fuel consumption using multi-criteria optimisation", 26th International Conference Noise and Vibration, 2018, pp. 69-76.

[91] Iris Ç., Pacino D., Ropke S., and Larsen A., "Integrated Berth Allocation and Quay Crane Assignment Problem: Set partitioning models and computational results", Transportation Research Part E: Logistics and Transportation Review, vol. 81, 2015, pp. 75-97.

[92] Venturini G., Iris Ç., Kontovas C. A., and Larsen A., "The multi-port berth allocation problem with speed optimization and emission considerations", Transportation Research Part D: Transport and Environment, vol. 54, 2017, pp. 142-159.

[93] Pel A. J. and Chaniotakis E., "Stochastic user equilibrium traffic assignment with equilibrated parking search routes", Transportation Research Part B: Methodological, vol. 101, 2017, pp. 123-139..