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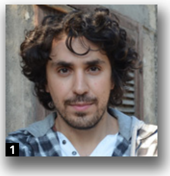
A novel decision-making support model based on value of time for public transport planning

1 **Gorkem Gulhan** PhD
Assistant Professor, Department of Urban and Regional Planning, Faculty of Architecture and Design, Pamukkale University, Denizli, Turkey (corresponding author: ggulhan@pau.edu.tr)

2 **Mustafa Ozuysal** PhD
Assistant Professor, Transportation Division, Department of Civil Engineering, Engineering Faculty, Dokuz Eylül University, İzmir, Turkey



Knowing exactly the value of time (VoT) for an individual may be a focus, resultant or definer in transportation planning. In a conventional transit planning paradigm, the decisions that have to be primarily implemented, along with the implementation programs, are determined through heuristic rather than analytical methods. Calculation of the VoT for each zone and scrutiny of these values through the correlation of transit surveys may be crucial in the process of determining investible zones. In the implementation process, the VoT for a zone may be evaluated as a primary selection indicator and thus efficient use of resources may be provided and sustainable development may be ensured. In this study, transit surveys were categorised and VoT estimates were then compared. The investments and interventions generated by evaluating the needs, complaints and expectations of transit users in different zones were sorted by considering the VoT. An analytical model was thus generated for transit planners, policy-makers and decision-makers to determine primarily investable zones in the implementation levels of urban transit planning. A case study revealed that reliability, driver behaviour, route and stop condition indicators provide consistency in selecting the zone priority.

Notation

F	Fisher test probability of the regression model
f_i	production function needed to produce commodity i
j	number of alternatives
P_{ni}	choice probability of alternative i by individual n
$\boldsymbol{T}_i$	vector of time inputs
U	utility function
$\boldsymbol{X}_i$	vector of market goods
y_{ni}	choice indicator of alternative i by individual n
β	maximum likelihood estimator

1. Introduction

Transportation planning is a process for ultimately determining transportation investments. Management of the investment stages is an essential part of sustainability or smart-growth policies. Transportation planning utilises the calibration of three crucial components: cost, comfort and time. With the exception of time, these components can be overlooked under any hypothesis. Consequently, a quantitative estimation of the value of time (VoT) and its contextualisation in lower levels of transportation planning by association with several techniques may allow transportation models to generate more accurate results. The VoT is a critical parameter in transport project appraisals owing to its dominating factor in terms of user benefits and is a key factor in the generalised cost when evaluating the time spent for each mode or route (Jiang and Morikawa, 2004). The VoT may be used in several stages of lower levels of transportation planning such as public transport planning. Public transport planning aims to enhance the quality of public transport service by utilising public transport surveys and inventory analyses. Large cities and metropolitan areas rely on public transport to provide efficient mobility and reduce emissions (Orth *et al.*, 2015). Policies and decisions are generated through transportation routines that are measured based on satisfaction surveys. Transportation investments are generated and resources are then used by considering the mentioned policies and decisions. The generation of well-directed decisions may lead to an optimal deployment of resources and sustainable urban growth. The aforesaid polices are also within the scope of smart-growth strategies.

De Serpa (1971) built the general concept of the VoT. The VoT is the amount an individual is willing to pay to reduce their travel time by one unit (Jara-Diaz, 2007). The usual procedure used to measure the VoT is to estimate discrete travel-choice models and calculate the rate of substitution between time and money from the estimated utility function (Jara-Diaz, 2007). The VoT is used as input in traffic forecasting models and a cost–benefit analysis (CBA) is typically estimated in stated-choice studies through which preferences are derived (Hanssen, 2011).

Many studies have found that the VoT varies with individual socio-economic environments (Bates *et al*., 2001; Bhat, 1998; Gunn, 2001; Hensher, 1997, 2001; MVA Consultancy *et al*., 1994; Wardman, 2001). Becker (1965) developed a general treatment for the allocation of time during all non-work activities. Johnson (1966) indicated that the value of non-work time equals the wage rate, owing to the absence of work time in the utility function. Vickrey (1969) discussed the effects of arriving at a destination within the desired time during traffic congestion. De Donnea (1972) found that models of consumer behaviour can contribute to an understanding of travel decisions. Small (1982) studied the possibility of rescheduling activities in order to undertake them according to a preferred schedule. Kono and Morisugi (2000) completed the first comparative static analysis on the VoT considering several factors. These studies have also been reviewed by Jara-Diaz (2007) and Mackie *et al*. (2001).

The paradigm of mean-variance includes a measure of variability, such as a direct standard deviation in the utility functions of individuals (Börjesson *et al*., 2012; Noland and Polak, 2002; Small *et al*., 2005). The VoT can be studied theoretically (Bates *et al*., 2001; Noland and Small, 1995) or empirically (Asensio and Matas, 2008; Bates *et al*., 2001; Börjesson and Eliasson, 2011). Fosgerau and Karlström (2010) indicated that the VoT is independent of the mean and spread of the travel time distribution. The VoT is generally used in the estimation of discrete travel-choice models (e.g. mode choice), but it can also be used for different levels of public transport planning.

The VoT is differentiated in different traffic analysis zones (TAZs) and conventional transportation planning overlooks the current situation in transport decision-making levels. People who assign more value to time should be prioritised in terms of transportation investments. However, a lack of analytical determination tools causes non-analytical decisions to be made in the decision stages of public transportation planning. Planning processes start analytically, with public transport surveys, and end with heuristic approaches. Analytical tools may lead to more accurate results, which may enable efficient use of resources and provide sustainability.

Previous studies have generally focused on the CBA of transportation investments in decision-making. CBA is a tool used to evaluate the potential socio-economic impact of public investment choices. Damart and Roy (2009) stated that, when choosing among alternative investment projects by using CBA, decision-makers reveal their priorities (based on the importance they assign to different projects) and these priorities must be perceived as legitimate. They also underlined the difficulty of striking the right balance between the expert knowledge produced by CBA methods and the knowledge produced by the participation of various stakeholders. Some efforts have been made to combine CBA-based findings with users' aspects (e.g. travel time savings), such as data envelopment analysis (Caulfield *et al*., 2013) and multiple-criteria group decision-making/aiding methodology (Zak *et al*., 2014). Besides being very complicated and time consuming for decision-makers, these techniques may not provide distinctive differences between alternatives when the investments do not differ in cost substantially. Some researchers have considered users' perceptions about public transportation alternatives, but the findings were not directly related to public transport regulations and investments. For instance, by analysing 16 aspects of interchanging bus and rail journeys, Stradling (2002) found separate factors representing psychological needs (saving effort), journey needs (saving time) and cost considerations (saving money). Stradling stated that all journeys require the expenditure of physical, cognitive and emotional efforts and focusing on sources of satisfaction and dissatisfaction should assist the marketing of public transport as alternatives to car use.

The current study, when compared with other previous studies, suggests a more practical and visual technique (Pareto analysis) that is mostly constructed on users' perceptions of public transport alternatives that do not differ in cost substantially (e.g. public bus or paratransit)

The aim of this paper is to attempt to contribute to the current state-of-the-art methods of transit planning by introducing use of the VoT measure in the decision-making process. At attempt is also made to generate a method for presenting an opportunity to decision-makers to allow transportation investments to be managed more effectively and a sustainable transportation planning process to be generated. In transit planning, investment decisions are continuously generated; however, the main issue should be determination of the primary decisions and investments. In this process, several zones and investments should be prioritised; however, this is a non-analytical process. Through an evaluation of transit surveys, primarily investable zones were determined by comparing VoT estimates of the different zones. Thus, the social requirement of transit infrastructure was evaluated for a different method in transit planning.

The city of Tekirdag, which is located in the north-western part of Turkey, was selected as the study area. Many developing cities are trying to minimise the negative effects of the paratransit mode. Tekirdag is one of these cities, as the paratransit mode has a high usage and many negative effects on the urban transportation system. The findings of this study can thus be generalised to similar developing cities by performing the same methodology. A transportation satisfaction survey (TTP, 2015) of the city was used as the data source. Household data and public transport demand matrices were obtained from this survey.

2. Methodology and study area

2.1 Methodology

In many developing cities, public transportation services are supplied by two main transportation modes: public buses and paratransit. Paratransit is an auxiliary mode, having similarities to both mass transport in terms of meeting public needs and private travel in terms of providing demand-responsive services (Black, 1995; Kalpakcı and Ünverdi, 2016). Although paratransit is a promising mode, providing flexible and more cost-effective transport than its formal counterpart, it usually evolves to reach direct competition with formal transit systems, with the result that authorities view it as a (necessary) nuisance that should be formalised (Woolf and Joubert, 2013) because the paratransit mode requires a planned system for driver behaviours, route allocation and working conditions. Additionally, the use of a low-capacity system in areas of high demand causes traffic congestion and inefficient infrastructure usage. For this reason, to increase the effective use of paratransit systems, the overall mass transportation network should be carefully analysed and, in cases of no profit in terms of management or a general insufficiency of transport, paratransit systems should be adopted where required (Kalpakcı and Ünverdi, 2016). The data and methodology of this study were focused on a decision-support tool to be used when regulations are needed to convert a paratransit service into a public bus system.

As shown in Figure 1, the methodology consists of four main stages: (*a*) transit survey and assignment analysis, (*b*) VoT estimation, (*c*) comparison and binding and (*d*) decision- and policy-making. The transit survey conducted to obtain paratransit and public bus choice behaviours and the level of user satisfaction is described in Section 3.1. Although the travel times were obtained using the survey results, a basic public transport assignment was also applied using PTV Visum software (PTV AG, 2011) to make a distinction between the journey time and the ride time for each mode. Moreover, missing travel times, which can arise from a random choice of the survey participants that may not cover all of the origin–destination pairs, were also completed using the assignment results. A timetable-based assignment was conducted for the peak morning hours to generate conventional transit planning

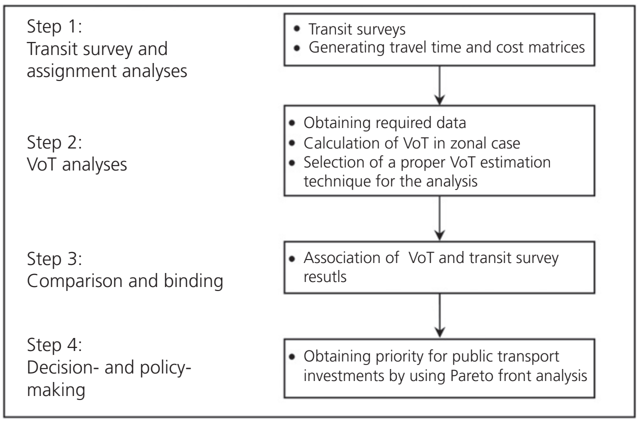


Figure 1. Flow chart of the methodology

indicators. The time between 07:00 and 09:00 was determined as the analysis period for this study. The peak hour period was selected as 2 h in order to obtain a better representation and thus estimation of transportation demand may be more accurate. Links, intersections, transit stops, transit routes and the origin–destination demand matrix of the zones were entered into the Visum transportation planning software. Current timetables of the bus and paratransit systems were obtained from the invention data of the current situation. The cost-related matrices were obtained from ticket prices and by measuring route lengths.

In the study area, operators generally implement fixed fares for both the public bus and paratransit routes. As an exception, a discount (from 2 TL (Turkish lira) to 1·75 TL (1 TL = £0·17)) is applied for paratransit rides shorter than 3 km and a higher fare (3·5 TL) is applied for the paratransit lines serving considerably farther districts (Kumbag and Barbaros). In addition, a 0·75 TL discount is implemented for student passengers on public transport lines. The route distances between each TAZ pair were used to obtain the unit cost of travel by dividing these fixed costs (by considering passenger type) by travel distance.

The importance of elapsed time for any type of choice, as well as in the choice of travel mode, has been empirically predicted by many different researchers. In 1965, Becker's pioneering work was one of the first economic studies to introduce a time dimension to the utility function of consumers (Becker, 1965). Becker emphasised that when decisions are taken by individuals regarding non-work activities, the VoT plays an important role. Although consumption is the purchasing of market goods, time is also a necessary variable for the consumption of such goods. Therefore, Becker defines commodities as a function of both market goods and time. Individuals are the producers of commodities. When an individual decides to travel by bus, both the purchase of a bus ticket and the time spent form a commodity. A commodity i may be defined as

1. $$Z_i = f_i(\boldsymbol{X}_i, \boldsymbol{T}_i)$$

where f_i is a 'production function' needed to produce commodity i, $\boldsymbol{X}_i$ is a vector of market goods and $\boldsymbol{T}_i$ is a vector of time inputs.

Individuals maximise their utility function U, given by

2. $$\begin{aligned} U &= U(Z_1, \ldots, Z_m) = U(f_1, \ldots, f_m) \\ &= U(X_1, \ldots, X_m; \quad T_1, \ldots, T_m) \end{aligned}$$

The VoT estimation technique applied in this study is based on the hypothesis of a discrete-choice analysis. The VoT, a trade-off between travel time and travel cost based on a travel demand model obtained through a utility maximisation approach, has been used to assign a monetary value to the travel time saving in the evaluation of alternative projects (Ben-Akiva and Lerman, 1985; Bruzelius, 1979).

To obtain a trade-off between travel time and cost components, the coefficients of ordinal utility functions for public bus and paratransit modes were obtained by using the maximum likelihood estimation of a mode-choice model of binary logit type. In a logit model, the choice probabilities are functions of the explanatory variables (time and cost) and the corresponding parameter β. The likelihood parameter for any observation can be obtained by using the observed choices of individuals and the choice probability of individual n according to the initial form of the utility function. If the parameter y_{ni} indicates whether an alternative was chosen, it can be written in an equivalent manner as

3. $$L = \prod_{i=1}^{j} (P_{ni})^{y_{ni}}$$

where j is the number of alternatives. y_{ni} is 1 for the chosen alternative and zero for all other alternatives. Equation 3 shows that it is possible to make a special expression for the probability of every individual in the case of a sample choice case when all alternatives are available to choose. This is called the likelihood function $L(\beta)$, which is calculated by multiplying the choice probabilities for the observed choices of all individuals

4. $$L(\beta) = \prod_{n=1}^{N} \prod_{i=1}^{j} (P_{ni})^{y_{ni}}$$

where β indicates the maximum likelihood estimator maximising this function, N is the number of individuals. Maximising the likelihood function is equivalent to maximising the logarithm of the likelihood function. Taking the logarithm of this expression yields the log-likelihood function LL(β), given by

5. $$\mathrm{LL}(\beta) = \sum_{n=1}^{N} \sum_{i=1}^{j} y_{ni} \ln P_{ni}$$

The log-likelihood function is globally concave (Train, 2009). Thus, it becomes easier to find the vector of parameters β that maximises the log-likelihood function by finding the first-order condition for each parameter

6. $$\frac{\partial \mathrm{LL}(\beta)}{\partial \beta} = \sum_{N=1}^{N} \sum_{i=1}^{J} (y_{ni} - P_{ni}) x_{ni} = 0$$

For easier interpretation, it is possible to manipulate this expression as

7. $$\frac{1}{N} \sum_{N=1}^{N} \sum_{i=1}^{J} y_{ni} x_{ni} = \frac{1}{N} \sum_{N=1}^{N} \sum_{i=1}^{J} P_{ni} x_{ni}$$

In this equation, the left-hand side represents the observed average value of the explanatory variable vector x of the sampled decision-makers, whereas the right-hand side represents the average of x for the predicted choices of the sampled decision-makers. Therefore, the maximum likelihood estimates for β are those that make the predicted average of each explanatory variable equal to the observed average in the sample (Train, 2009).

For the third stage of this study, the obtained VoTs are first examined to ensure logical inferences. Informal tests of the coefficient estimates according to previous expectations regarding the sign and relative values of the coefficients are necessary and widely applied procedures in practice (Ben-Akiva and Lerman, 1985). The VoTs are expected to be positive significant. Various versions of cost and time indicators were examined to assess this expectation. Besides, their combinations with and without a constant term were applied in log-likelihood estimations. The selected estimation was then combined with the transit quality of service indicators obtained from the transit survey.

For the final stage of the modelling process, priority decision support for public transport investments was constructed by implementing a Pareto optimality analysis, which is a graphical representation of the allocation of resources. For the optimal point found using this technique, it is impossible to reallocate resources in order to make any preference criterion better without worsening at least one other preference criterion. The optimal design method of the proposed approach involved an investigation into the most efficient choice by utilising a multi-objective evaluation of the quality indicators and variables, with the purpose of investigating the various alternatives for the most efficient solution. Therefore, a decision-maker can decide whether to accept the proposed solution.

2.2 Study area

Tekirdag is on the routes of the international transit highways E84 and D100. It has connections with significant metropolitan areas such as Izmir and Istanbul. It has railway connections to Europe and a seaway network. The city has an international airport that can be accessed by paratransit vehicles. The number of private cars per thousand people is 117, which is slightly under the Turkish average (121). The city has about 200 000 motor vehicles, which is 1·13% of Turkey's total, and it is ranked as the 22nd city in Turkey based on number of vehicles.

Suleymanpasa is a seaside area in the centre of Tekirdag province which has industrial areas, a harbour and tourist centres in the surrounding region. In addition, it has a strong spatial position because it is near Istanbul (TTP, 2015). The city has a macro form that progresses along the seaside on an east–west axis. There are also high-capacity roads to the north, which generate routes to the peripheral areas. The macro form of the city and the main land uses are shown in Figure 2. The population of Suleymanpasa is 196 031 and it is approximately prorated in terms of gender. It has annual population growth of 5% and it is the second most populous town in Tekirdag province after Corlu. The city is characterised by high income, and social life is improving. The urban texture is generally reinforced concrete, with many multi-storey buildings although there are also two-storey buildings on the boundaries of the town.

There are 16 districts in Suleymanpasa, each having a population of 2000–20 000 people. These districts are defined as TAZs in this study. The district has been enhanced by several administrative interventions, but the zones of interest are the main ones in the centre, which have a transit network and links, as shown in Figure 3. There are 16 transit lines, 70 semi-private buses and 296 paratransit vehicles for public transportation.

As shown in Figure 2, the study area is a coastal city and the transit lanes are thus frequently in radial form. It is also typical for bus lanes to be radial. In such cases, it is expected that paratransit lanes will act as feeder lanes. However, the macro form of the city is unsuitable for these types of integrations because the interior distances are insufficient for a feeder design. Currently, the paratransit lanes act as bus lanes, meaning that they are also in radial form, and thus paratransit lanes may be transformed into bus lanes.

In 2015, a transit satisfaction survey with a capacity of 1500 respondents was conducted in the city, and trip generation and attraction ratios were obtained. It was found that home-to-work and home-to-school trips were predominant and that the ratios of pedestrian movement were high when coming to a stop and going towards the destination after the final stop. The transit survey showed that transit users were mostly satisfied with the operational conditions, the service quality of the stopping locations, routes, fares and other elements (TTP, 2015). A timetable-based transit assignment was conducted using Visum transportation planning software and travel time matrices were generated. Tekirdag province was selected as the study area since the trade-offs between car and urban transportation modes are near-zero and it thus provide a good opportunity to measure trade-offs between paratransit and public bus modes.

3. Transit survey and VoT analyses

3.1 Step 1: Analysis of transit planning and survey

The selected city is a middle-sized regular Turkish city that consists of industrial areas and tourism zones, and thus provides a good case in terms of adaption of the model to other cities. The survey size was determined according to the population of the city; the sampling ratio was set as 2%. The sub-national administration and the project team conducted a passenger survey and line analysis in 2015 (TTP, 2015). Passenger satisfaction levels, passenger holding capacity, the amount of stops, stop conditions and route characteristics were identified by means of this survey. Zonal trip generation and attraction values were measured. In total, 3500 surveys were conducted throughout Tekirdag, with approximately 1500

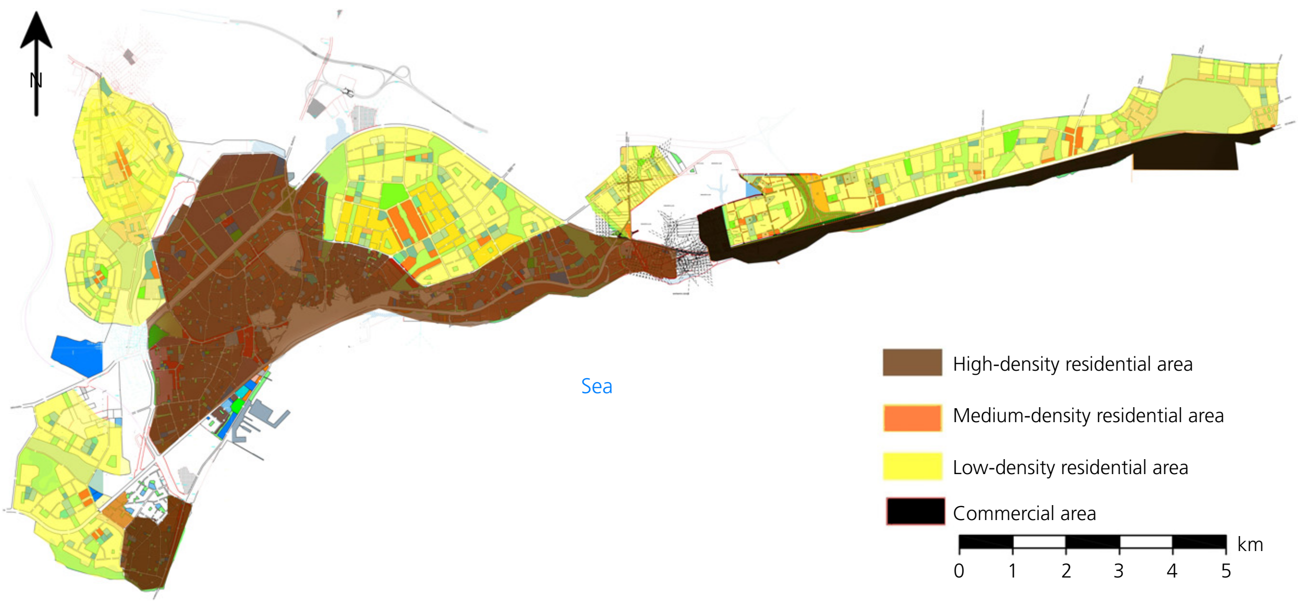
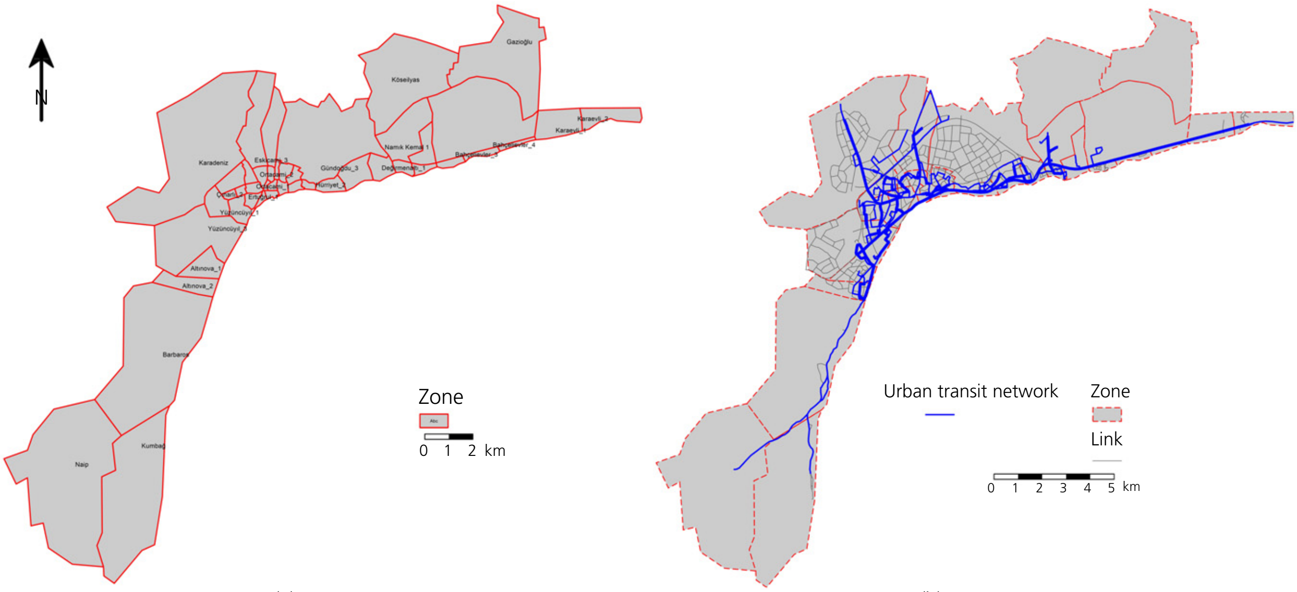


Figure 2. Urban macro form of Suleymanpasa and main land uses



(a) (b)

Figure 3. (a) Study area and central districts; (b) transit network and links

Table 1. TSQIs for each TAZ

TAZ	Fare (TSQI_fare)	Frequency (TSQI_freq)	Route (TSQI_route)	Vehicle comfort (TSQI_veh)	Stop conditions (TSQI_stop)	Driver behaviour (TSQI_driver)	Reliability (TSQI_rel)
1 Altınova	2·543	2·500	2·957	2·870	2·848	3·022	3·044
2 Aydoğdu	2·721	2·750	2·951	3·192	2·990	3·097	3·115
3 Bahçelievler	2·500	2·500	3·000	3·500	1·500	3·000	4·000
4 Barbaros	2·750	2·750	2·750	2·750	2·750	2·750	2·750
5 Çınarlı	2·618	2·824	2·882	2·941	2·882	3·029	2·939
6 Değirmenaltı	2·439	2·474	2·807	3·035	2·807	2·912	3·058
7 Ertuğrul	2·692	2·769	2·923	2·962	3·000	3·038	3·043
8 Eskicami-Ortacami	2·583	2·952	2·925	3·038	2·861	3·108	3·100
9 Gündoğdu-Turgut	2·556	3·000	3·222	3·222	3·056	2·889	3·059
10 Hürriyet	2·577	2·701	2·859	3·070	2·657	2·934	3·054
11 Karadeniz	3·056	3·056	3·111	3·056	3·111	3·056	3·000
12 Kumbağ	2·500	2·500	2·500	2·500	2·500	2·500	2·500
13 Namık Kemal	1·889	2·333	2·333	3·000	2·667	2·667	2·444
14 Yavuz	2·357	2·750	2·750	3·000	2·821	2·893	3·080
15 Zafer	2·667	2·333	2·667	2·727	2·833	2·833	3·000
16 100-Yıl	2·343	2·914	2·942	3·000	2·729	3·000	3·111
Mean	2·549	2·694	2·849	2·991	2·751	2·920	3·019
Standard deviation	0·245	0·230	0·219	0·224	0·369	0·166	0·334

conducted in the study area, Suleymanpasa. Surveys were conducted during academic periods to obtain accurate results in terms of home–school based trips. There are two transit modes in the city (bus and paratransit) and satisfaction surveys were conducted for each. The origin and destination zones of transit users, the service quality and the operation performance of the transit system were measured. A total of 710 bus satisfaction surveys and 364 paratransit satisfaction surveys were conducted in the vehicles themselves or at transit stops.

For each of the 16 zones of the study area, transit service quality indicators (TSQIs) regarding fares, frequency, routes, vehicle comfort, stop conditions, driver behaviour and reliability were assessed in terms of satisfaction, with respondents' answers classified on a scale of 1 to 4 indicating 'very bad' to 'very good', respectively. Considering the mean TSQIs shown in Table 1, fares, frequency and stop conditions received the most unfavourable comments. In addition, the higher standard deviations for stop conditions and reliability indicated wider differences in opinion among the TAZs compared with the other TSQI observations.

3.2 Analysis of VoT

The VoT for the transportation network was calculated by using a binary logit type of discrete-choice model. To obtain proper coefficient estimates, the VoT was calculated for 16 combinations (C1–C16) using cost and time variables. Combinations of the intercept cost–time variables considered in the VoT calculation for the mode-choice analysis are listed in Table 2. Table 3 details the estimated VoT for each TAZ and each combination.

Because VoT estimation is based on a discrete mode-choice analysis, the mode-choice calculation capability of the combinations is essential. A lack of sampling or variable type that may not properly reflect each mode of choice behaviour in some of the zones may cause endless interrupted iterations in a maximum likelihood estimation of a certain mode-choice model. As can be seen from Table 2, the maximum number of successive mode-choice estimations was obtained for 12 TAZs using combinations C12 and C16. Because the time and cost variables are both disutility indicators, they are expected to have negative signs and consequently provide positive VoT estimations as the ratio of these coefficients. The maximum number of TAZs with this condition was provided by combination C12. In Table 2, ρ^2_{mean} is the average of ρ^2, which is an informal goodness-of-fit index measuring the fraction of the initial log-likelihood value explained by the model

8. $$\rho^2 = 1 - \frac{\text{LL}(\beta)}{\text{LL}(0)}$$

This value must lie between 0 and 1 and is analogous to R^2 used in a regression analysis. Prior studies have noted that ρ^2 should be evaluated carefully. The measure is most useful in comparing two specifications developed on exactly the same data (Ben-Akiva and Lerman, 1985). For this reason, selection of the best combination is not based on this mean measure, but reasonable values of ρ^2 are expected. Combination C12, with $\rho^2_{\text{mean}} = 0{\cdot}296$ is acceptable from this point of view.

It can be seen from Table 3 that Barbaros, Çınarlı, Gündoğdu-Turgut, Hürriyet and 100-Yıl TAZs provided a positive VoT for most of the combinations. These TAZs are similar in terms of demographic structure and their residents comprise a certain portion with a high income and high socio-economic level. The people living in these TAZs have private cars and usually do not use urban public transit for daily transport. On the other hand, Altınova, Bahçelievler, Ertuğrul, Eskicami-Ortacami, Karadeniz, Kumbağ and N. Kemal districts were the zones in which the VoT was almost meaningless. Combination C12 showed the greatest number of positive VoT values and VoT estimations of nearly zero for the remaining negative values, and thus provides a reasonable evaluation. Again, these TAZs are similar in terms of demographic structure (TTP, 2015): the people who live in these TAZs generally have low income and low socio-economic levels and do not have private cars, and thus use urban public transit for daily transport.

As shown in Table 2, combination C12 included unit cost per kilometre and ride time variables, and did not include a constant term. The exclusion of a constant term can be inferred positively because a VoT estimation can be completely based on the time- and cost-related parameters. Because short trips,

Table 2. Variable combinations and estimation results considered in VoT calculation for mode-choice analysis

Combination	Intercept inclusion	Cost variable type[a]	Time variable type[b]	Number of zones with calculated mode choice	ρ^2_{mean}	Number of zones with positive VoT
C1	Yes	C	JT	7	0·149	5
C2	No	C	JT	10	0·050	5
C3	Yes	C	RT	7	0·168	5
C4	No	C	RT	11	0·110	5
C5	Yes	C	UJT	7	0·363	4
C6	No	C	UJT	10	0·333	3
C7	Yes	C	URT	7	0·632	4
C8	No	C	URT	8	0·631	3
C9	Yes	UC	JT	9	0·240	5
C10	No	UC	JT	10	0·031	6
C11	Yes	UC	RT	10	0·309	6
C12	No	UC	RT	12	0·296	7
C13	Yes	UC	UJT	8	0·190	2
C14	No	UC	UJT	9	0·156	3
C15	Yes	UC	URT	8	0·365	5
C16	No	UC	URT	12	0·490	3

[a]C = cost; UC = unit cost per kilometre
[b]JT = journey time; RT = ride time; UJT = unit journey time; URT = unit ride time

Table 3. VoT estimations obtained from combinations

TAZ		Combination																Number of combinations providing positive VoT
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	
1	Altınova	-2×10^{-7}	-5×10^{-7}	-2×10^{-7}	-5×10^{-7}	−0·310	−0·327	−0·473	−0·465	-1×10^{-7}	$-1{\cdot}1 \times 10^{-7}$	-1×10^{-7}	**$-1{\cdot}1 \times 10^{-7}$**	−0·084	−0·083	−0·117	−0·116	**0**
2	Aydoğdu	−0·059	−1·881	0·607	−0·868	−0·008	−1·982	−1·566	−1·228	0·070	0·047	0·530	**0·339**	−0·214	−0·123	−1·185	−1·425	**5**
3	Bahçelievler	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	**0**
4	Barbaros	0	0·096	0	0·102	−0·070	0	0·011	0	0	0·021	0	**0·023**	−0·030	0·416	0·028	0	**7**
5	Çınarlı	2×10^{-6}	1×10^{-6}	2×10^{-6}	1×10^{-6}	0·012	0·014	−3·290	−2·392	-7×10^{-7}	$-6{\cdot}9 \times 10^{-7}$	-7×10^{-7}	**$-6{\cdot}9 \times 10^{-7}$**	−0·131	−0·106	4·339	1·747	**8**
6	Değirmenaltı	−0·2671	−0·2808	−0·3457	0	0·128	0·33079	0·171005	0·0705948	−0·0863	0	−0·003	**$-3{\cdot}9 \times 10^{-3}$**	−0·02847	−0·02645	−0·007159	0	**4**
7	Ertuğrul	-4×10^{-7}	7×10^{-6}	-4×10^{-7}	7×10^{-6}	0	0	0	0	0	0	0	**0**	0	0	0	0	**2**
8	Eskicami-Ortacami	-1×10^{-5}	-5×10^{-6}	-1×10^{-5}	-5×10^{-6}	0	0	0	0	0	0	0	**0**	0	0	0	0	**0**
9	Gündoğdu-Turgut	0·130	3·467	0·112	0·243	0·666	0	1·717	4·578	0·064	0·973	0·083	**0·100**	0	−1·051	0·833	0	**12**
10	Hürriyet	0·043	0·047	0·010	0·010	0·106	0·111	0·052	0·060	0·021	0·026	0·041	**0·035**	1·711	2·703	0·520	0·662	**16**
11	Karadeniz	−0·059	0	−0·083	−0·086	−0·744	−0·662	−0·448	−0·430	0	−0·002	−0·001	**0**	−0·174	−0·362	0	0	**0**
12	Kumbağ	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	**0**
13	N. Kemal	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	**0**
14	Yavuz	0·278	−0·164	−0·345	−0·401	−0·217	−0·190	−0·833	−1·051	−0·273	0·456	0·718	**0·972**	−1·135	−0·749	−2·227	−3·257	**4**
15	Zafer	0·296	−0·047	0·216	−0·280	−0·137	−0·196	−0·388	−0·741	0·512	−6·087	0·152	**1·120**	−0·235	−0·285	0	−1·067	**5**
16	100-Yıl	-6×10^{-6}	-2×10^{-6}	-6×10^{-6}	-2×10^{-6}	−0·464	−0·448	−0·689	−0·644	9×10^{-7}	9×10^{-7}	9×10^{-7}	**9×10^{-7}**	0·058	0·344	0·082	0·210	**8**
	Number of positive VoT estimations	**5**	**5**	**5**	**5**	**4**	**3**	**4**	**3**	**5**	**6**	**6**	**7**	**2**	**3**	**5**	**3**	

Table 4. Regression analysis between TSQIs and VoT

Indicator	*β*	Standard error	*t*-statistic	*p*-value
TSQI_route	−2·187	0·472	−4·630	0·001
TSQI_stop	1·937	0·347	5·585	0·000
TSQI_driver	−2·596	0·661	−3·928	0·002
TSQI_rel	2·864	0·514	5·570	0·000
R^2	0·788			
Regression sum of squares	1·833			
Residual sum of squares	0·494			
F-value	11·118			
F-probability	0·001			

which may be defined as stopovers with paratransit, may result in high costs, the selection of unit cost per kilometre for the cost variable is also reasonable. Selection of ride time instead of journey time shows that the out-of-vehicle time may not be considerable when compared with the in-vehicle time. The model is based on a binary-mode-choice environment because of two crucial points that should be clarified for this case study. Firstly, the assumption that only two alternative modes are plausible since private car usage was confirmed as near-zero in the satisfaction surveys. It should be noted that, in Turkey, private car taxes and taxed fuel prices are among the highest in the world (Rodionova, 2016), so again taxi services are so rare that they may be neglected. Secondly, there is not a rail system transportation mode all over the city. Due to these reasons, only two travel modes were used to measure trade-offs and VoTs.

3.3 Relationship between satisfaction survey and VoT

Several TSQIs and VoTs were calculated and multiple regression analysis was conducted to obtain the TSQIs most related to VoT. Through determination of the TSQIs most correlated with the VoT, the decision-support tool combining these public transport measures can be simplified. Table 4 lists the standard error, *t*-statistic, *p*-value and *β*-value for each variable along with the R^2 value, the regression sum of squares, the residual sum of squares, the *F*-value and the *F*-probability of the regression model. The table shows that the model has a high R^2 value and thus there is a strong relation between the VoT and satisfaction surveys. The indicators based on stop conditions and reliability were found to be positively effective explanatory variables for VoT, with relatively high *t*-statistics. It can thus be said that the VoT is important for users even if the stop conditions and reliability indicators are commented on positively. On the other hand, the indicators relating to the route and driver behaviour were found to have a negative correlation with the VoT. In other words, the VoT increases in TAZs where the route and driver behaviour are viewed negatively. The spatial distributions of the VoT and route, stop conditions, driver behaviour and reliability TSQIs are shown in

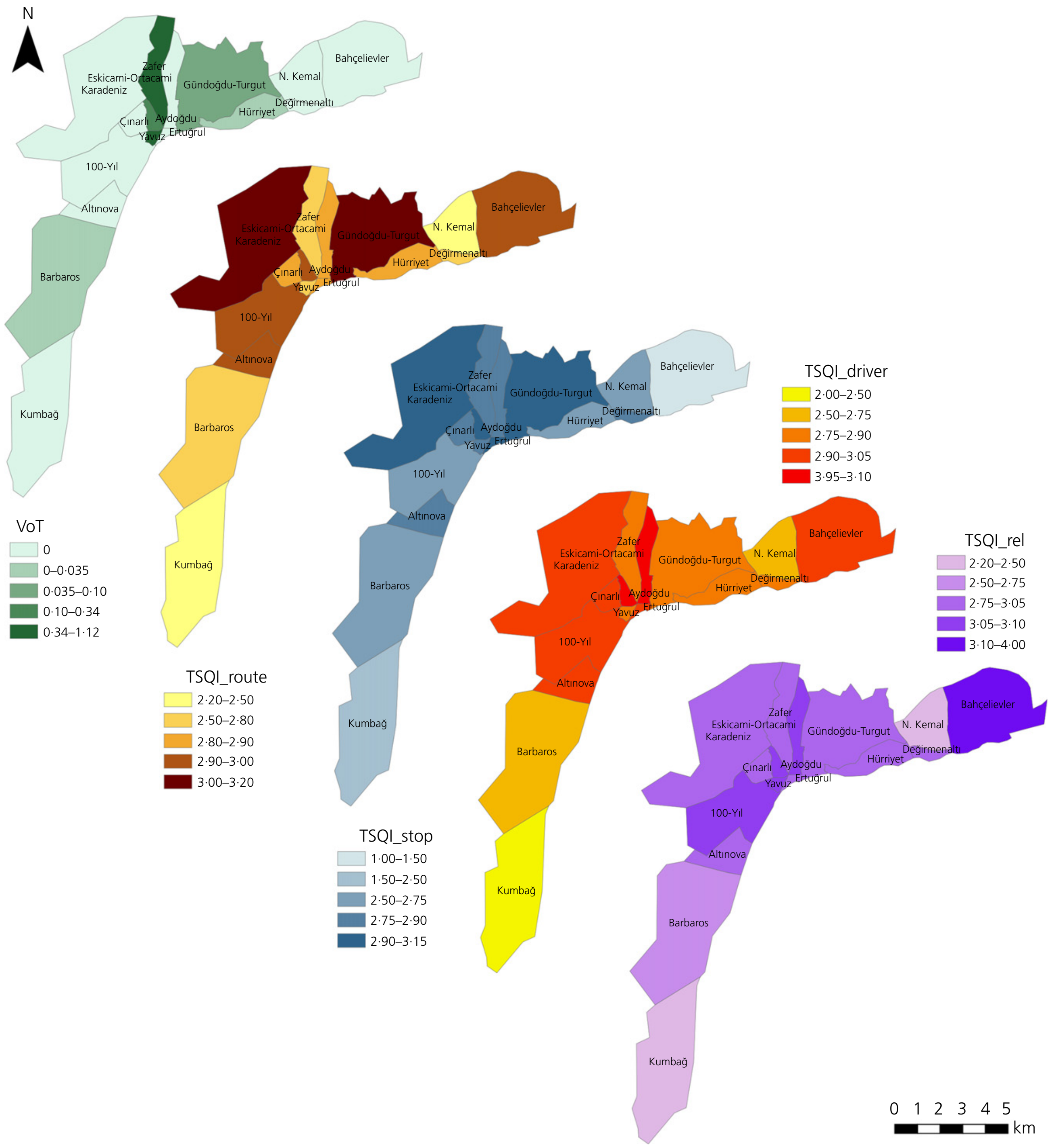


Figure 4. Spatial distribution of VoT and TSQI values

Figure 4. The class limits in Figure 4 were determined according to the natural breaks suggested by Jenks (1967) who used a data clustering method to determine the best arrangement of values into different classes. This is achieved by minimising the average deviation of each class from the class mean while maximising the deviation of each class from the means of the other groups. It can be seen from Figure 4 that the VoT estimations were high for the city centre, which has congested land use, narrow streets and high-priced residential buildings. The satisfaction levels regarding route and stop conditions were relatively high for the north-west part of the analysis zone. Satisfaction in terms of driver behaviour and reliability showed

a more homogeneous distribution, although somewhat greater in the east. The north-west part of the city has not been overbuilt and the eastern region of the city is focused on tourism. The western parts of the city, which are low-income areas, showed less satisfaction for all the TSQIs.

A decision-maker may determine primary problems by evaluating a regression analysis. However, it is not possible to determine the primary zone for intervention and the problems there concurrently. An optimisation dialectic should be thus generated to discover which types of problems occur and in which zones. A Pareto front optimality approach was generated to find a compromise solution and the variables used in the Pareto front solution were obtained using a regression model.

3.4 Decision and policy making

For a decision-support tool based on the proposed methodology, a Pareto front optimality approach, which is a graphical search method based on defining the edge of optimal values in binary relationships, is proposed. In a policy-making process, when the choices indicate similar benefits, the policy-maker may have difficulty in determining the best solution. In this case, the decision-maker may take advantage of different Pareto solutions to determine the optimal one. In this study, maximisation of the VoT results and minimisation of the TSQI indicators was considered to find TAZs in which the VoT spent using public transport is considered important and user satisfaction is low at the same time. The Pareto front solution for binary scatter plots of the VoT and the selected TSQIs according to multiple regression analysis is given in Figure 5.

As shown in Figure 5(a), the Pareto front was obtained for zone 13 (N. Kemal) and zone 15 (Zafer) for VoT–TSQI_route relationships. The line between these critical TAZ points indicates that the TAZs other than zones 13 and 15 had moderate values of satisfaction and VoT and can thus be ignored in the first stage of new investment in the public bus system, whereas zones 13 and 15 should take priority. The order of priority between these zones is related to a trade-off between VoT and route satisfaction. The satisfaction difference was about 14% between the two zones, but the VoT results were also very different. Therefore, zone 15 (Zafer) may be selected as the zone where the level of transit satisfaction needs to be improved. Zone 15 was also found in the other binary Pareto front edges, which proves the consistency of the approach. As shown in Figure 5, zone 4 (Barbaros district) for satisfaction in driver behaviour and reliability and zone 10 (Hürriyet district) for satisfaction in stop conditions and driver behaviour were also prominent. If the highest negative t-statistic of route satisfaction in the regression analysis is taken into account, zone 13

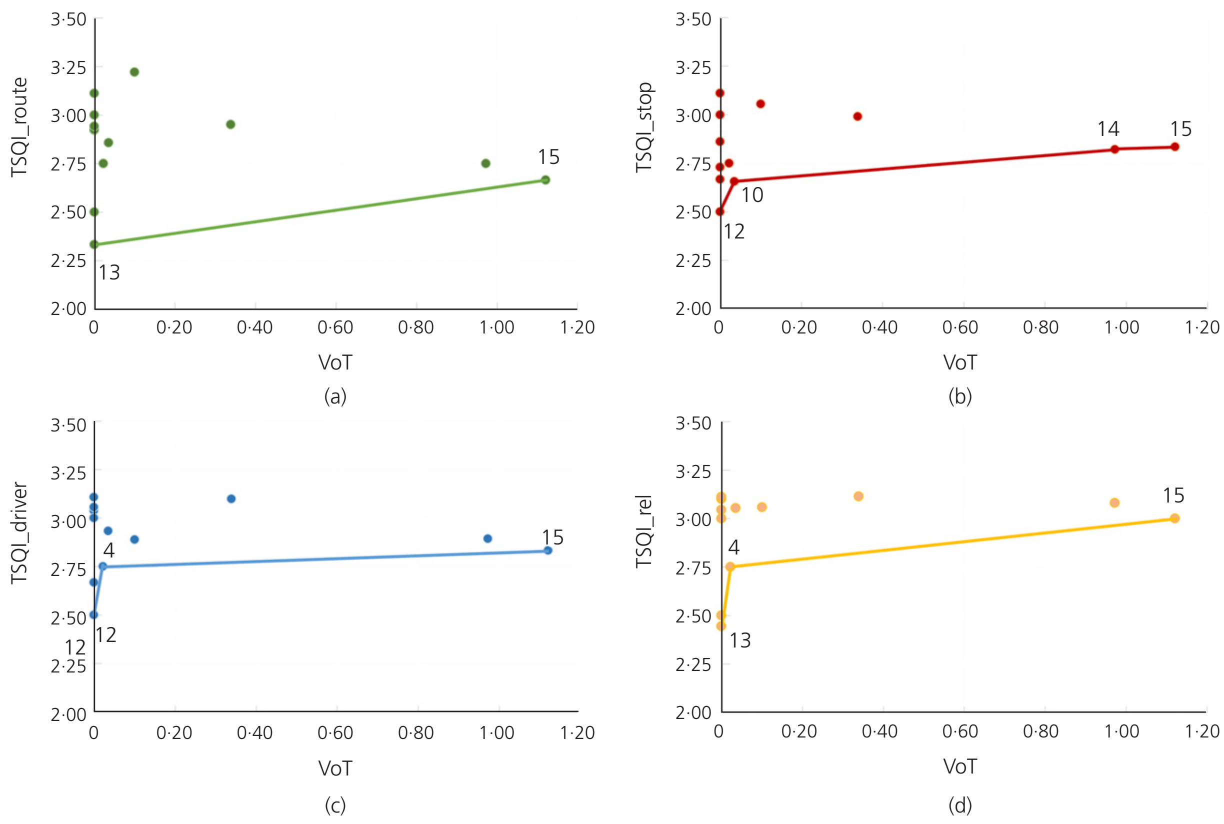


Figure 5. Pareto front solution between satisfaction survey variables and VoT results: (a) VoT–TSQI_route; (b) VoT–TSQI_stop; (c) VoT–TSQI_driver; (d) VoT–TSQI_rel

(N. Kemal district) can be considered as the second TAZ that requires investment in public transport. Zone 14 (Yavuz district) also appeared on the Pareto front of the VoT–TSQI_stop scatter plot. Zones 10, 13 and 15 show considerable VoT when compared with zone 4. Zone 4 may be determined as the optimum solution since it was obtained as a Pareto solution twice in four paradigms. In terms of transit stops, zone 10 may also be interpreted as the best solution. In conclusion, the mentioned zones were found to be those where a higher VoT was assigned and it may thus be instructive to choose these zones first in terms of transportation investment.

4. Discussion and conclusions

It is hoped that this study will contribute to current state-of-the-art methods for preventing flagrant wastes of resources by considering the VoT in the process of transportation planning. Considering VoT measures in transportation planning leads to more sustainable planning paradigms as zones that require transportation investments and urgent intervention are identified. In the proposed methodology, a conventional planning process is conducted and the decision-making part of the process is supported based on VoT results. It should be mentioned here that the findings of this study are case-specific, although a similar methodology could be applied for other local investigations. Using the proposed methodology, zones requiring urgent intervention in terms of public transport investment can be identified. In addition, new bus lines with a high quality of service could be designed to serve between zones in a prioritised manner.

The trade-off between Pareto fronts of the TSQIs may be determined according to multiple regression analysis. Otherwise, calculation of VoTs for diversified election models may be conducted in order to determine the most efficient choice for investment.

In further studies, more accurate estimations of the VoT may be obtained by using household travel survey data, which may have a greater number of samples and more homogeneous sampling than direct satisfaction surveys. The VoT can be utilised and interpreted at each sublevel of transportation planning, such as trip generation, trip distribution and mode-choice levels.

It should also be noted that a binary-choice model may be insufficient to measure the VoT in cities where private car use is high. In such cases, a multinomial-choice analysis should be conducted. In addition, the TSQI measures used in this study pertain to the study area. Thus, when using the same method in different regions, the Pareto front criteria should be independently determined.

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