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USING POTENTIAL ACCESSIBILITY MEASURE FOR URBAN PUBLIC TRANSPORTATION PLANNING: A CASE STUDY OF DENIZLI, TURKEY

ABSTRACT

Policy makers and planners evaluate the implementation of the urban public transport (UPT) planning studies in terms of some objective measures such as load factor, mean volume per trip, capacity usage ratio and total capacity. In some cases, improving these measures may lead an unforeseen decrease on accessibility to the opportunities in terms of UPT users. Thus, this study aims to evaluate Potential Accessibility (PA) as an efficiency measure in decision stage of UPT planning. It widely depends on fieldwork, surveys, data inventories and existing plans. In this context, a comprehensive UPT planning has been carried out through VISUM traffic simulation software by taking the PA into account, and a four-step UPT planning procedure has been proposed. The results showed that PA may alternatively be used as an evaluation instrument in decision stage of UPT planning while the objective measures are insufficient to represent the effectiveness of alternative scenarios.

KEY WORDS

urban public transport; potential accessibility; VISUM; transit assignment

1. INTRODUCTION

Mobility demand of people living in urban and metropolitan areas has continuously been growing due to the increasing socio-economic needs which lead to varied activities. Hence, people tend to use individual motorized transport modes in order to satisfy this ever-changing mobility demand [1]. Increasing trend of modal shift in favour of the private car results in adverse impacts on the environment and these impacts have to be reduced in order to make the transport sector more environmentally sustainable [2]. Modal substitution represents hence an important strategy of demand management for the achievement of sustainable transportation. This task can be accomplished by providing better modal options such as urban public transport systems characterized by high quality levels [3].

Providing high quality transit services is the basic goal that all Urban Public Transportation (UPT) agencies strive to achieve. To attain this goal, UPT agencies must design their services considering clear and defined principles. This requires service design standards and effective performance measurement system [4].

UPT service quality can be evaluated based on subjective and objective measures. Subjective measures are related to the transit user judgments, which are generally derived from user satisfaction surveys. Thus, the perceived quality of a UPT service may be evaluated in terms of the user opinions. In this context, some studies propose qualitative analyses based on simple statistical techniques [5-9]. Eboli and Mazzulla [10] state that the main disadvantages of this type of measure are the strong subjectivity of transit users' judgments and the failure to take non-users' perceptions into account. On the other hand, UPT service quality may be evaluated by a range of some quantitative measures which can be used for measuring the ability of a transit agency to offer services that meet customer expectations [11]. These performance measures are objective measures expressed as a numerical value, which may not provide information by itself about how “good” or “bad” a specific result is, and for this reason it has to be compared with a fixed standard or past performance [10].

The Transportation Research Board has investigated the service quality measures in terms of different UPT service aspects through the Transit Cooperative Research Program [11-13]. In these studies, five categories of service quality measures are defined: availability in terms of passengers’ ease of access and use of transit service, service monitoring, travel time, safety and security, and maintenance and construction. Bertini, El-Geneidy [14] have developed some tools that may help to determine the best performance measures for use by various entities within the UPT organization. It has been stated that with simple and directly measurable variables, it is possible to compare performance from day to day and from route to route in order to measure and improve UPT service quality. As can be seen so far, the studies, which have been dealt with evaluating UPT service quality, are widely based on either objective or subjective measures. However, a recent study, which was carried out by Eboli and Mazzulla [15], introduces a new methodology, which is based on the use of both passenger perceptions and transit agency performance measures involving the main aspects characterizing a transit service.

Apart from the subjective and objective measures, Santos [16] pointed out the accessibility required for an effective UPT service quality. The system accessibility, which is an important characteristic of a high UPT service quality, can be determined by the distance between users’ origin and the initial station and between the last station and the final destination [17]. The common definition of the accessibility is the potential of opportunities for interaction and it is generally recognized that the use of Potential Accessibility (PA) was first introduced by Hansen [18].

Determining the performance of accessibility that has been a challenging problem and several measures have been developed and evaluated for the solution. Infrastructure-based, person-based, utility-based and the location-based measures are the mostly used types [19]. Both measures and their related components should be specified according to certain criteria in order to provide consistency between the problem and accessibility perspective. Accessibility and transportation have common components such as transport planning, geography, urban planning and UPT [45-47].

It is necessary to design UPT routes passing through an area by meeting the accessibility and efficiency requirements [20]. Mavoa et al. [21] have classified accessibility measures with respect to the UPT into three categories as access to transit stops, duration of public transit journey and access to destinations via UPT. Most studies on accessibility include UPT focus on physical access that represents the proximity to the transit stops [22-29]. However, it is important for users to know the places which can be subsequently reached by using UPT services, Origin-Destination (O-D) features and the time required to travel between the zones [30]. To the best of our knowledge, there are no studies in which the accessibility measure is utilized for UPT planning.

This study tries to make a contribution to the current state of the art of UPT planning by introducing the use of the PA measure in decision-making process. For this purpose, a four-step UPT planning process is proposed. In this process, various scenarios are built and evaluated in terms of the traditional and PA measures. It should be noted that the accessibility formulations and scenario building techniques, which are available in the literature, are utilized. Proposed process is applied to the real UPT network of a medium-sized industrial and tourism city in Turkey. In addition, the effects of the PA and UPT performance measures on the policy making level of UPT planning are compared.

The rest of this paper is organized as follows: the next section presents the current UPT features of the study area and methodology. Application and analyses are provided in Section 3. Section 4 ends with a conclusion and some suggestions for future directions.

2. METHODOLOGY AND STUDY AREA

2.1 Methodology

This study proposes a four-step UPT planning procedure considering the PA measure as an evaluation instrument, as shown in *Figure 1*.

In STEP 1, a timetable-based assignment is carried out through VISUM traffic simulation software for base case [31]. In this step the current UPT travel demand, service routes, vehicle capacities and timetable information of the UPT services are taken into account. Considering a regular-service bus system, four objective measures, which are occupancy of the vehicles, capacity usage ratio, mean volume per trip and total capacity, are employed to evaluate transit service quality.

Occupancy of the vehicles, which is expressed as a *load factor*, may be taken into account as an objective quality measure since some acceptable values have empirically been determined by Transit Cooperative Research Program [32]. The importance of vehicle loading varies by the type of service. In general an inner-city service may approach a load factor of 2.0 but more typically 1.5, while other services are in between

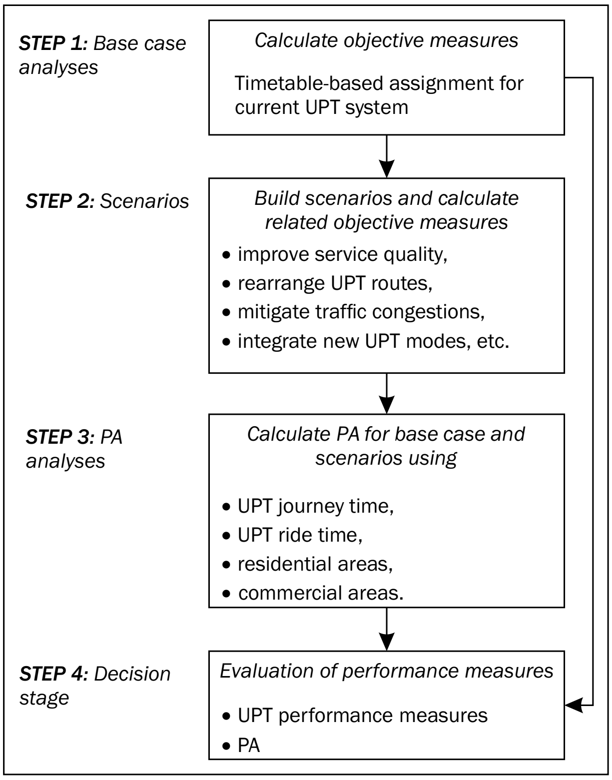

Figure 1 - Flowchart of the proposed UPT planning process.

[32]. The average load factor $\bar{\lambda}$, for a regular-service bus system can be calculated using Eq. (1).

$$\bar{\lambda} = \frac{1}{m}\sum_{i=1}^{m}\frac{\sum_{j=1}^{f_i} p_i^j}{f_i \cdot s_i} \tag{1}$$

where p_i^j represents the maximum number of passengers observed on the jth departure of the ith bus route, f_i is the number of departures during the analysis period for the ith bus route and s_i is the number of seats in the transit vehicle while m represents the number of bus routes serving on the UPT network. The load factor is crucial importance in terms of the passengers' perspective since its higher values decrease the quality of service by leading more standees in the vehicles. The second objective measure is the average capacity usage ratio, $\bar{\gamma}$, that can be expressed as given in Eq. (2).

$$\bar{\gamma} = \frac{1}{m}\sum_{i=1}^{m}\frac{g_i}{h_i \cdot c_i},\ (i = 1,2,\ldots,m) \tag{2}$$

where g_i is the total passenger-kms covered, h_i is the total service-km covered and c_i is the total capacity that represents the cumulative seating and standing capacity of the vehicles on the ith route for overall journeys in the analysis period. Mean volume per trip $\bar{\delta}$, and total capacity supply C, which are the third and fourth measures, are formulized as given in Eqs. (3) and (4), respectively.

$$\bar{\delta} = \frac{1}{m}\sum_{i=1}^{m}\frac{g_i}{h_i},\ (i = 1,2,\ldots,m) \tag{3}$$

$$C = \sum_{i=1}^{m} c_i,\ (i = 1,2,\ldots,m) \tag{4}$$

In Eq. (4), C represents the total capacity which is the total seating and standing capacity of the vehicle combinations overall vehicle journey sections.

In STEP 2, various scenarios are proposed to overcome UPT related problems such as high capacity usage ratios, insufficient service frequencies, and traffic congestion that may arise from the UPT vehicles especially in Central Business Districts (CBDs). These problems may occur separately or simultaneously in urban areas. Thus, alternative scenarios could be applied to different combinations of these problems.

In order to provide acceptable timetables for the UPT services, departure frequencies f_i, may be calculated with Ceder's [33] maximum loading method as given in Eq. (5).

$$f_i = \frac{p_i}{\lambda_c \times s_i},\ (i = 1,2,\ldots,m) \tag{5}$$

where p_i represents the maximum number of passengers carried during the analysis period, λ_c is the critical load factor, and s_i is the number of seats in the vehicle for the ith bus route. Note that the value of λ_c may be accepted as 1.80 based on the standards provided by Transportation Research Board [32]. After building scenarios and calculating required service frequencies, the objective measures are recalculated based on Eqs. (1)-(4).

In STEP 3, the PA values, which have been frequently used to estimate the accessibility of residential, commercial, recreational and educational areas, are calculated for base case and scenarios [34, 35]. It can be expressed as the sum of all zones' accessibilities and has the following form [18]:

$$PA = \sum_i A_i = \sum_i \sum_j D_j d_{ij}^{-\alpha} \tag{6}$$

where A_i is the accessibility measure (hectare (ha)/min) of zone i to all opportunities D_j in zone j, d_{ij} is the impedance factor between zones i and j, and α is the parameter that reflects the impedance of distance. PA measure estimates the accessibility of opportunities of a zone to all other zones where fewer and/or more distant opportunities provide diminishing influences [36]. It denotes the "range of choice" offered by the land-use transport system in the form of a sum of potential destinations [37]. The opportunities, which cause trip generation and attraction, are related to the land use type of the destinations, in which the residential and commercial activities have occurred. The impedance may be considered as direct/indirect distance between zones or journey/ride time using a particular UPT system.

In STEP 4, the base case and scenarios are evaluated in terms of the objective measures and PA. From this point of view, this step may be named as the decision stage.

2.2 Study area

Denizli is located in south-western part of Turkey and it has a population of over 500,000 in central district. It is a medium-scaled industrial and tourism city around the famous tourist area called Pamukkale. The city consists of 80 zones which have been considered as traffic zones. The zonal layout of the city is given in *Figure 2*.

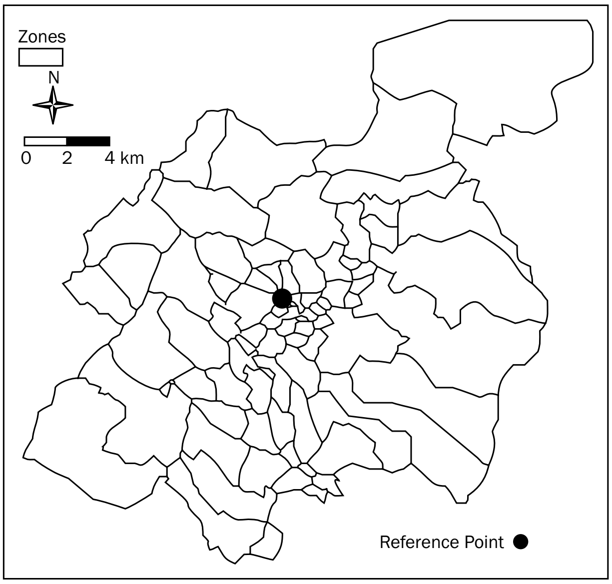

Figure 2 - Zonal layout of Denizli, Turkey

According to Gulhan et al. [38], transport demand is supplied by private cars, buses, paratransit, private service and taxi modes. Traffic problems tend to increase due to the high private car usage and relatively low UPT usage [39]. The car ownership rate of the city is 22%, and this value is two times higher than the average car ownership rate in Turkey. The peak hour trips (07:00 - 09:00 a.m) represent about 30% of the total trips which has been obtained by household surveys [38].

Gulhan et al. [38] stated that paratransit services are preferred over bus system in the city since they are more flexible in terms of the departures and transit stops. As a matter of local authority policy, paratransit mode has an importance on providing employment although it has some disadvantages. Paratransit drivers decrease traffic safety with selfish driving behaviours and it is very difficult to control this problem due to the high number of paratransit vehicles. To decrease the number of paratransit usage, UPT users may be stimulated to use bus services by increasing the service quality.

The irregular urbanization in the city brings various traffic problems. Especially, the average traffic flow speed is quite low in CBDs and historical core zones due to on-road parking and irregular urbanization [38]. The users prefer private car or UPT modes for the distances exceeding 3 km and 67% of all trips between 5-12 km are made by UPT modes. Three types of bus vehicles (i.e. small, medium and large size) with 19, 26 and 36 seat capacity are used with maximum capacity of 50, 70 and 100 passengers, respectively. The capacity usage ratio is obviously too high considering the quality of service conditions and it has to be reduced. Paratransit vehicles have 14 seats and they are not allowed to carry any standing passengers. The average speed of bus and paratransit systems have been obtained as 25 and 15 km/h, respectively from [39]. The UPT users are dissatisfied about long travel times, low departure frequencies and overloaded vehicles.

3. METHODS AND DATA ANALYSIS

3.1 Step 1: Base Case Analyses

In order to calculate UPT performance measures for the current UPT system, a timetable-based assignment is performed for the morning peak period between 07:00-09:00 a.m. For this purpose, the road network is introduced to the VISUM by entering the links, intersections, UPT stops, UPT routes and OD demand matrix for 80 zones. The current timetable information for bus and paratransit systems is used in the assignment process. *Figure 3* represents the resulting passenger volumes for the morning peak period. As can be seen in *Figure 3*, the UPT link flows are higher around the central parts of the study area than those obtained at the outskirts. Considering the modes in the UPT system, the average load factor may be calculated by modifying Eq. (1) as follows:

$$\bar{\lambda} = \frac{\sum_{i=1}^{m} \frac{\sum_{j=1}^{f_i} p_i^j}{f_i \cdot s_i} + \sum_{k=1}^{n} \frac{\sum_{j=1}^{f_k} p_k^j}{f_k \cdot s_k}}{m+n}, \quad (i = 1,2,\ldots,m;\ k = 1,2,\ldots,n) \tag{7}$$

where m and n are the number of bus and paratransit routes, respectively. Maximum acceptable load factor is 1.00 for paratransit mode due to the restriction of standing passengers in paratransit vehicles. Similarly, average capacity usage ratio, mean volume per trip and total capacity supply may be expressed as given in Eqs. (8)-(10), respectively:

$$\bar{\gamma} = \frac{\sum_{i=1}^{m} \frac{g_i}{h_i \cdot c_i} + \sum_{j=1}^{n} \frac{g_j}{h_j \cdot c_j}}{m+n}, \quad (i = 1,2,\ldots,m;\ j = 1,2,\ldots,n) \tag{8}$$

$$\bar{\delta} = \frac{\sum_{i=1}^{m} \frac{g_i}{h_i} + \sum_{j=1}^{n} \frac{g_j}{h_j}}{m+n}, \quad (i = 1,2,\ldots,m;\ j = 1,2,\ldots,n) \tag{9}$$

$$C = \sum_{i=1}^{m} c_i + \sum_{j=1}^{n} c_j, \quad (i = 1,2,\ldots,m;\ j = 1,2,\ldots,n) \tag{10}$$

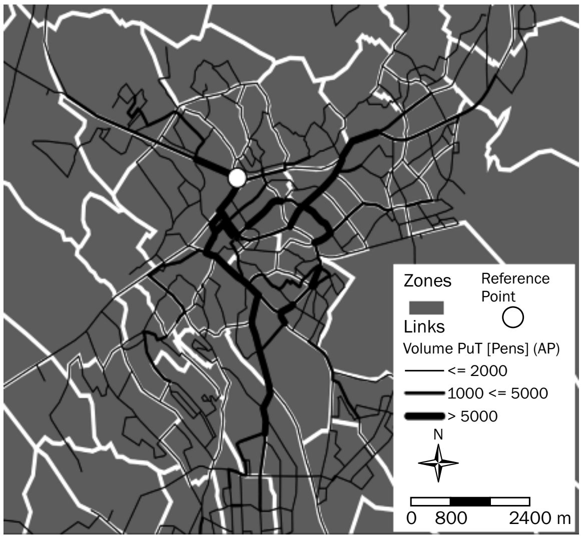

Figure 3 - Link volumes resulting from the UPT timetable-based assignment for the morning peak period

Values of the objective measures for base case are calculated using Eqs. (7)-(10) and given in *Table 1*.

Table 1 - Objective measures for base case

	$\bar{\lambda}$	$\bar{\gamma}$	$\bar{\delta}$	C
Bus	1.91	0.44	2,675	40,570
Paratransit	0.86	0.47	405	40,642
General	1.45	0.45	3,081	81,212

For the base case, the average values of the load factor are found as 1.91 for the bus system. It is obvious that some bus routes serve with load factors higher than 1.80. Thus, service frequencies of these bus routes should be rearranged. *Table 1* also shows that the average load factor, capacity usage ratio, mean volume per trip and total capacity supply are found 1.45, 0.45, 3,081 and 81,212, respectively.

3.2 Step 2: Scenarios

The results obtained through the base case solution reveal that the value of $\bar{\lambda}$ is 1.91 which is higher than the acceptable value of 1.80. Therefore, three different scenarios have been built considering the UPT planning decisions taken by the local authority as shown in *Table 2*.

Table 2 - Three scenarios for the UPT system of Denizli, Turkey

Scenarios	
1.	UPT timetable rearrangement (UPTR)
2.	UPTR + CBD entrance restriction (CBDR)
3.	UPTR + CBDR + BRT (Bus Rapid Transit) mode integration

As can be seen in *Table 2*, scenarios are sequentially developed and evaluated in terms of the objective measures in the following way.

Scenario 1: UPTR

Physical and operational design of an urban transit system was usually investigated from the routing point of view, frequencies and fleet size [40]. In this context, the departure frequencies of the bus and paratransit systems are rearranged based on Eq. (5). Considering some bus routes that have attracted very low travelling demand, the maximum departure period is accepted as 30 minutes for the bus system [41].

Scenario 2: UPTR+CBDR

The core zone, which is called Bayramyeri, includes CBDs and attracts a large number of daily trips. The main problems in Bayramyeri are the traffic congestion, which arises from high number of paratransit vehicles, and selfish driving behaviours of paratransit vehicle drivers that decrease traffic safety especially during the peak hours [42]. The spatial size of the zone is convenient for pedestrian mobility. Pedestrians can access parts of the zone within the range of 400 m which is an acceptable distance for accessing the UPT services by walking [43]. Therefore, the restriction of paratransit vehicle entrance to Bayramyeri may decrease congestion and promote pedestrian mode. The restricted area for paratransit vehicles is given in *Figure 4*.

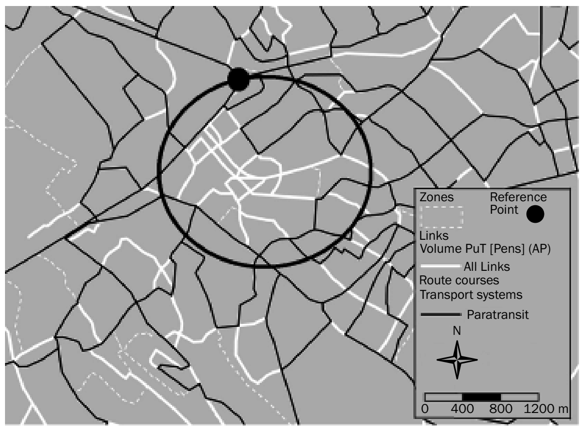

Figure 4 - Restricted area for paratransit vehicles

Scenario 3: UPTR + CBDR + BRT

A large amount of UPT demand grew out of CBDs in the city and the development areas of the city play a critical role on trip generation to CBDs. The BRT route and stop locations are taken from [38] and given in *Figure 5*. Note that the BRT and bus services are considered as different transit modes in the analyses since they serve with different vehicle capacities and operating speeds.

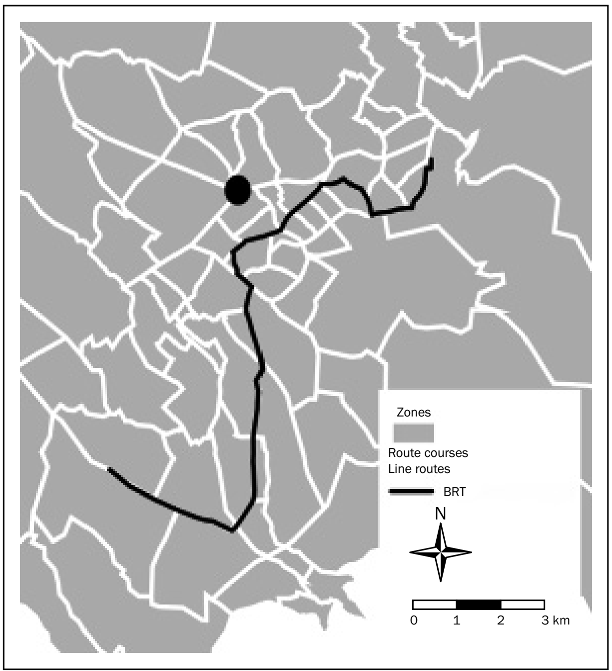

Figure 5 - BRT line and stops

Values of objective measures that are calculated using Eq. (1) for each scenario are given in *Table 3*.

Table 3 - Objective measures for scenarios

		Scenario 1	Scenario 2	Scenario 3
$\bar{\lambda}$	Bus	1.21	1.38	1.30
	Paratransit	0.66	0.71	0.65
	BRT	-	-	1.48
	General	1.00	1.09	1.03
$\bar{\gamma}$	Bus	0.27	0.28	0.25
	Paratransit	0.36	0.37	0.34
	BRT	-	-	0.21
	General	0.30	0.32	0.29
$\bar{\delta}$	Bus	1697	1802	1666
	Paratransit	309	325	299
	BRT	-	-	73
	General	2,006	2,127	2,038
C	Bus	67,820	84,380	89,090
	Paratransit	51,156	29,092	30,268
	BRT	-	-	8,750
	General	118,976	113,472	128,108

It can be seen in *Table 3* that Scenario 1 provides the lowest load factor with an average value of 1.00. On the other hand, the average capacity usage ratio in Scenario 3 is lower than the others. From another point of view, Scenario 2 may provide a more efficient UPT system with the highest value of mean volume per trip. Additionally, it can be seen that there is a significant increase of total capacity supply for all scenarios in comparison with the base case while Scenario 3 provides the highest capacity reserve. It may be concluded that each scenario may be considered as the best in terms of different objective measures. At this point, it may be useful to investigate the scenarios in terms of PA.

3.3 Step 3: PA Analyses

Employing PA as an evaluation instrument may help UPT planning process while the projections or scenarios do not provide clear results. In addition, it may be possible to evaluate land use and transportation interaction in UPT planning since respective interaction is the key component of trip generation. In the calculation process of PA, there are two notions called opportunity and distance which are open concepts for interpretation. Opportunity represents all types of possible spatial destination modes which differ according to the standing point of perspective. Similarly, the notion of distance represents all types of impedance.

This study takes the distance into account as UPT journey and ride times. Inter zonal journey and ride time matrices have been obtained by a timetable-based assignment process and they have been used for determining PA. The opportunity factor has been handled as residential and commercial areas since they are the main trip attraction types of land use. The spatial sizes of residential and commercial areas have been taken from the Municipality of Denizli [39]. Gulhan et al. [44] stated that the parameter of distance impact has been found as 1.00 by a sensitivity analysis for the study area. The total PA for the city, which is accepted as the sum of zones' PA values, has been calculated using Eq. (6) and the results are given in *Table 4*.

As can be seen in *Table 4*, the PA values in Scenario 1 are clearly higher than those obtained for the base case and other scenarios.

Table 4 - PA values for base case and scenarios (ha/min)

	Base Case	Scenario 1	Scenario 2	Scenario 3
Journey time & residential area	9,399	9,612	9,082	8,845
Ride time & residential area	15,148	15,568	14,950	14,365
Journey time & commercial area	4,475	4,531	4,316	4,195
Ride time & commercial area	9,025	9,111	8,708	8,460

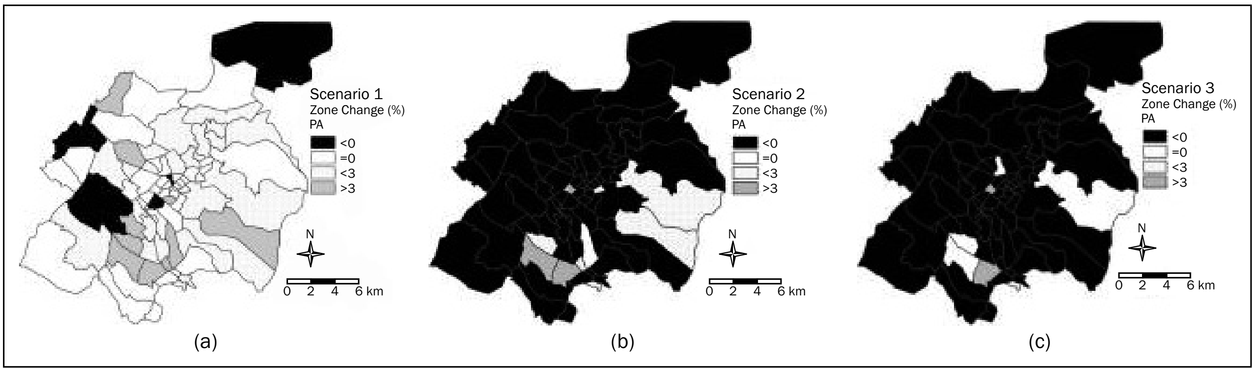

Figure 6 - Change of zonal PA values for journey time and residential areas in three scenarios in comparison with the base case

3.4 Step 4: Decision Stage

It may be briefly stated that the UPT system of Denizli needs to be improved in terms of service quality by considering the current vehicle loading levels. In this context, three scenarios have been developed to improve the service quality and relax the traffic conditions in the CBDs. However, the objective measures used for these scenarios may be insufficient to make a decision since their values are quite similar as can be seen in *Table 3*. Therefore, evaluating the PA measure at various levels may help us in decision making. The changes of zonal PA values in comparison with the base case are given in Figs. 6.a-6.c for Scenarios 1, 2 and 3, respectively.

As can be seen in *Figure 6*, Scenario 1 features a general increase of zonal PA values in comparison with the base case. Scenarios 2 and 3 decrease zonal PA since journey time, which is needed to reach paratransit services, increases due to the longer walk times in CBDs. Thus, it may be useful to evaluate PA as a selection or design instrument in UPT planning. It may be emphasized that using PA as an evaluation instrument helps to reveal advantages of Scenario 1 in decision stage of UPT planning process for planners and policy makers.

4. CONCLUSION

UPT planning decisions are usually made in terms of service quality based on some measures such as loading factor, capacity usage ratio, trip volumes by policy makers and planners. When these measures have approximately similar values considering various scenarios, the authorities may not have a decision instrument. Thus, searching for useful performance measures becomes an important issue in the UPT planning field.

This study proposes a four-step UPT planning process, in which PA is employed as an evaluation instrument for decision stage of the UPT planning. In the proposed process, the current UPT system is analyzed in terms of the objective measures and some scenarios are built to overcome the UPT-related problems. Finally, the scenarios are evaluated in terms of the objective measures and PA.

In order to show the effectiveness of PA in the decision stage of UPT planning, the proposed process has been applied to the real UPT network of a medium-sized industrial and tourism city named Denizli, Turkey. The transportation master plan of the city has been evaluated as a data source and the UPT-related problems have been identified. In order to solve the existing problems, three scenarios have been proposed based on the assignment results which have been obtained by VISUM traffic simulation software. In the calculation process of PA, opportunities have been represented with residential and commercial areas while journey and ride times have been used as the distance parameters. The PA values have been calculated for the base case and the scenarios.

The results showed that the best service quality is achieved with Scenario 1 while Scenario 3 gives the lowest capacity usage ratio. However, Scenario 1 provided a significant increase of zonal PA while other scenarios have decreased in comparison with the base case. Therefore, it may be said that using PA as a decision instrument may support planners on taking better UPT planning decisions.

A future study may investigate the effects of land-use changes in the future by combining the proposed process with a suitable land-use planning approach.

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ÖZET

TOPLU TAŞIMA PLANLAMASINDA POTANSİYEL ERİŞEBİLİRLİK ÖLÇÜTÜNÜN KULLANIMI: DENİZLİ, TÜRKİYE ÇALIŞMASI

Planlamacılar ve karar vericiler Toplu Taşıma Planlarını (TTP) uygularken yükleme faktörü, ortalama seyahat başına yolculuk, kapasite kullanım oranı ve toplam kapasite gibi bazı objektif göstergeleri kullanmaktadır. Bazı durumlarda, bu göstergelerdeki artış, toplu taşıma kullanıcılarının fırsatlara olan erişiminde kestirilemeyen düşüşlere sebep olabilir. Bu nedenle bu çalışma, Potansiyel Erişebilirliği (PE) TTP'nin karar verme süreçlerinde verimlilik ölçütü olarak kullanmayı amaçlamaktadır. Çalışma, saha uygulamalarına, anketlere, envanterlere ve mevcut planlara dayanmaktadır. Bu kapsamda, PE dikkate alınarak kapsamlı bir TTP, VISUM programı yardımıyla gerçekleştirilmiş ve dört aşamalı TTP prosedürü önerilmiştir. Sonuçlar, objektif göstergelerin alternatif senaryoların verimliliklerini göstermede yetersiz kaldığı zamanlarda, PE'nin TTP'de değerlendirme enstrümanı olarak kullanılabileceğini göstermiştir.

ANAHTAR KELIMELER

toplu taşıma planlaması; potansiyel erişebilirlik; VISUM; trafik ataması

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