Improving the performance of urban public transport systems: case study of Denizli, Turkey

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Abstract

In this study, current problems in urban public transport system of Denizli, Turkey have been analyzed using such indicators like accessibility, comfort, capacity usage ratio and travel time. For this purpose, a wide range of properties of urban public transport (UPT) network and opinions of users have been collected by surveys and picked up from the field. An addition, bus / paratransit routes, frequencies and transfer facilities have been analyzed for the base case. Public transport properties have been defined by the public transport assignment using VISUM 12.01 software.

UPT analyses and corresponding scenarios have been proposed and performed by timetable-based assignment. A system-based assignment has been performed to determine the content of the scenarios. Solutions have been proposed to overcome the public transport problems in Denizli, Turkey. It was proposed that paratransit service routes should be removed from the Central Business District (CBD), bus / paratransit service frequencies have been re-arranged to manage public transport demand and various operational regulations have been offered. Based on findings, current bus vehicles are out of efficient usage and it has been verified by UPT surveys. Frequencies and headways on the buses in urban and rural areas have been increased by new regulations and these regulations have been arranged by pursuing mentioned public transport indicators.

Keywords: *Public transport, accessibility, timetable-based assignment, VISUM.*

1 Introduction

Public transport provides a better process of evolution and growth for cities, therefore sustainable development should include UPT service provision. Public transport modes usually consist of buses, paratransit vehicles, trolleybuses, trams, trains, rapid transit and ferries. Paratransit system may be used in areas of low-demand exists, for people who need a door-to-door service and in integrated transport networks for accessing high capacity modes in some developing cities such as Denizli. The growing demand of the use of private cars serving urban mobility implies the high-social costs in terms of human lives. Safety and environmental problems are the main chronicle problems of car usage in cities. Cipriani et al. (2012) stated that such a high social cost can be faced by introducing management policies and design frameworks aiming at shifting the modal split towards the public transport, which makes a better use of land, air and energy sources than individual transport mode. Important transport problems are often occurred in Central Business Districts (CBD) when transportation systems, for a variety of reasons, cannot satisfy the requirements of trip demand.

Traffic congestion in urban areas is one of the most important transportation problems in CBDs. Many UPT systems are used over or under capacity because of inaccurate planning and network design. To overcome the UPT problems and to analyze the current network, robust UPT planning is needed. UPT planning may be carried out by assignment process. UPT assignment is an important tool to specify the current problems and to generate successful designs.

Various types of techniques have so far been used for travel demand forecasting and UPT assignment. Nowadays, UPT assignment models have become more complicated in order to describe passengers' route choices as detailed and correctly as possible. The basic needs for a UPT assignment are the Origin-Destination (OD) matrices, the road network properties and the UPT routes. Assignment in transport planning requires to examine the entire network and its connections between all traffic zones. Planners have to consider the previous decisions about network before design process. For an efficient UPT planning, each plan about the city especially transportation master plans (TMP)s, have to be considered.

UPT planning can be a part of a TMP simultaneously; the projections and providences have to be considered as an object at the planning stage. This unity of TMP and UPT provides consistent and reasonable purposes since the impacts of TMP will be considered at the planning process. The relation between UPT and TMPs brings environmental benefit and possibility to serve mobility needs for people within the scope of accessibility. Benenson et al. (2011) presented the main factors that affect the use of UPT, such as land use planning, local government policy extent of economic resources implementation of modern technologies, and social tendencies. Land use planning and accessibility are important design criteria for UPT planning and UPT network design.

Accessibility can be considered as an important indicator or a designing criteria for the UPT planning process. Hansen (1959) and Engwicth (1993) showed that accessibility refers to the ease of reaching goods, services, activities and destinations, which together are called opportunities. It can also be defined as the potential for interaction and exchange. Interest in sustainable development has under routed the importance of accessibility as a main indicator to assess transport investments, urban policy, and urban form. A paradigm shift is growing in transportation planning and UPT planning which strikes out for accessibility. This can also be described as a shift from mobility-oriented analysis to accessibility-based analysis. Accessibility based planning tends to consider lots of different factors, finds out different solutions, incentives to change travel behavior, and brings out more accessible CBDs. Thus there is a need of considering accessibility at different levels of UPT to gain more accurate results and long-lasting decisions during planning the UPT systems.

This study therefore deals with UPT problems and brings out various proposals to overcome these problems by considering accessibility. UPT planning for Denizli, Turkey has been applied and various solutions have been proposed. Household surveys, OD matrices, TMP of the city and land use inventories have correspondingly been evaluated. Three stages carried out during planning and evaluating the UPT in the following way:

1) To carry out system-based assignment
2) To carry out timetable-based assignment
3) Planning the UPT

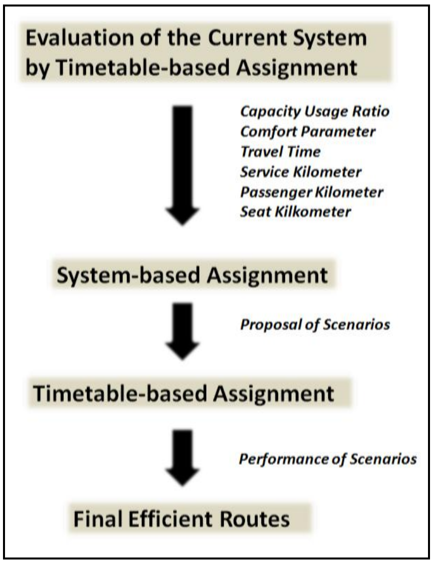


Figure 1. Operation chart for UPT planning process.

Base case has been analyzed and short term proposals have been offered. The efficiency of UPT network has been aimed to improve different combination of modifications. In the scope of this study base case has been analyzed by using VISUM 12.01 software. A timetable-based assignment has been performed to find link volumes on network. Average capacity of the bus routes, travel efficiency and comfort level indicators were found and evaluated in accordance with optimum UPT service level. Figure 1 shows the operation chart for UPT planning process.

A system-based assignment has been performed before the determination process of the scenarios. Scenarios have been offered in accordance with system-based assignment results. At solutions; some implementations like increasing bus frequencies restricting paratransit routes on CBD and association of UPT vehicles have been incorporated in various scenarios. Timetable-based assignment has been performed by using VISUM 12.01 software transport planning program. The demand corridors of the city have been confirmed by using system-based assignment and afterwards the results of the scenarios have been interpreted in the light of UPT efficiency indicators.

2 Analyses on public transport systems in Denizli, Turkey

Denizli is a city which is located at the Aegean Region of Turkey with a population of over 500.000 at the central district. It's a meso-scaled industrial and tourism city near the famous tourism area called Pamukkale and the city consists of 80 different zones. The transport demand has been supplied by private car, bus, paratransit, service vehicle and taxi modes. Traffic problems occur in recent years in the city of Denizli [DBM, 2010] since high density of private car use and relatively low UPT usage. The UPT demand in Denizli has been mostly supplied by bus and paratransit systems. Paratransit vehicles are the minibuses in capacity of 14 person per vehicle. The car ownership rate of the city is 22% and this value is two times higher than the average car ownership in Turkey.

Figure 1 shows the bus and paratransit routes which have a length of 1470 km in total. Paratransit system has been preferred more than the bus system because the paratransit vehicle services are more flexible than the bus services in terms of the departure frequencies and stops. Especially the movements of paratransit vehicles cause traffic and safety problems since they often move unbounded, pick up passengers without rules and move in arbitrary frequencies. In addition, the flexibility of the paratransit vehicle services may cause traffic congestion and safety problems in peak hours.

Figure 1. Current bus / paratransit routes with jointly used links.

2.1 Planning History and Inventory

TMP for Denizli was completed at 2010 [DBM, 2010]. In the TMP, a wide range of socio-economic and spatial data has been collected from the area for several analyses. Transport demand matrices were obtained from house hold surveys. The collected data are the followings:

- Route of the UPT routes,
- Direction information,
- Interval between bus stops,
- Location of bus stops,
- Density of passenger,
- Density of traffic,
- Occupancy rate,
- Departure time.

After TMP, UPT planning for Denizli was completed at 2011 [DBM, 2011]. UPT surveys (3000 surveys for bus / 1500 surveys for paratransit mode) have been performed on vehicle. That is approximately the %4 of total trip stock.

2.2 The Planning Tool VISUM 12.01 Software

VISUM is a program for computer-aided transport planning which serves to analyze and to plan a transportation system. VISUM 12.01 public transport module allows a comprehensive analysis of UPT systems. The UPT demand between zones are distributed to links and routes. This dispersion can be specified by UPT assignment. System based or time table based assignment can be used for this specification. (VISUM 11.52, manual)

2.2.1 System-Based Assignment

System-based assignment helps to find desired paths and the expected routes if all conditions were appropriate. The basic network can be characterized with following sets of links;

-All links of the possible road network;
-Only those links which are traversed by UPT routes;
-Only those links which are traversed by active UPT routes

From the links of basic network; a graph is constructed which is the basis for a best-route search. Since individual routes are not distinguished, transfer stops with their respective transfer times cannot be included in the search. The system-based assignment calculates exactly one route for each pair of origin and destination zone, which consists of one origin and destination connector for the UPT as well as of links and their correspondingly turns, which are permitted for a public transport system (VISUM 11.52, Manual). This method is recommended for preliminary consideration at the level of determining new UPT routes. The method depends on assignment of the UPT demand to shortest paths and specifying link demands. This kind of assignment helps to find desirable paths in a given road network. (VISUM 11.52, manual)

2.2.2 Timetable-Based Assignment

A search method is called timetable-based if all services of UPT routes are taken into account with their precise departure and arrival times. Timetable-based method is suitable for assignments and the calculation of indicators, when a route network plan and a detailed timetable are available for the UPT. It takes the coordination of the timetable into account and thus ensure very precise results of the indicator data calculation.

The timetable-based method calculates connections for each OD pair. It is assumed that the passengers have timetable information available and choose their access time according to the departure on the first UPT route. During the search, the user can influence the kind of connections found in different ways by means of search impedance. For the connection search, two variants (branch & bound search and shortest path search) are offered that represent the different compromises between the number of alternatives on the one hand and the memory and computing time requirements on the other. During pre-selection of connections, the connections yielded by the search algorithm are analyzed by means of general criteria as to whether some of them are of a significantly lower quality and can thus be deleted. The independence of connections can be taken into account if required (VISUM 11.52, manual). Timetable-based method is efficient if there is a possibility for entering routes & timetables to the system. In this study, Branch & Bound search algorithm is used to consider all connection possibilities.

2.3 UPT Assignment for Current Situation

In urbanization process, population, industrialization and socio-economic growth are in an increasing acceleration correspondingly to the specialization and urban organizing. Spatial interaction is getting denser due to increase of car ownership and increase of traffic carload. The important problem in Denizli is the shape of land use status in terms of traffic. The land use does not provide a feasible network. Especially, the speedy flow is very low in CBD and historical core zones due to parking problems and irregular urbanization. Household surveys clearly show that people of the city prefer private car or UPT modes for the distances above 3 km per hour. 67% of all trips which are between 5-12 km are being traveled by UPT modes in Denizli. There are 32 active bus routes and 15 paratransit routes in the city. Timetable- based assignment is conducted by entering 15 paratransit routes and 32 bus routes into the software. Current bus vehicles were researched and it was identified that there are 3 types of bus vehicles such as 19 seated with maximum 50 passengers, 26 seated with maximum 70 passengers, and 36 seated with maximum 100 passengers, respectively.

The road network was introduced to the VISUM by entering the links, intersections, UPT stops, routes and demand matrices within 80 zones to perform UPT analyses. The OD demand matrix has been entered to the system for all UPT systems for morning peak period (07:00/09:00).

Timetable-based assignment is carried out to show whether the current UPT systems work efficiently or not. The headways of the UPT systems which are chosen as 2 minutes for paratransit vehicles and as the current timetable information for bus vehicles are used in the VISUM. Figure 2 represents the timetable-based UPT assignment results for morning peak.

Efficiency indicator on the existing network will be called **Travel Efficiency** (TE) and be the ratio of **Passenger Kilometer** (*PassBoard x in-vehicle distance from board till alight*) to **Service Kilometer** (*Departures x Journey Length*). An increase in this indicator means the route is getting more efficient, since proportionately more passenger kilometers per service kilometer are covered. An increase in Travel Efficiency does not always represent a better improvement because cost of the UPT services may reach excessive values. To prevent this unexpected situation we use Capacity Usage Ratio (CUR) as an efficiency indicator and defined in Equation 1. CUR is the rate of mean volume to total capacity per route. Mean volume is the passenger km and total capacity of cumulative seating and standing capacity of the vehicle combinations over all vehicle journey sections of the object. TE is an indicator which is related to CUR and this means that an increase in TE causes changes on CUR. The third indicator will be called **Comfort Parameter** (CP) and will be the ratio of **Passenger Kilometer** (*PassBoard x in-vehicle distance from board till alight*) to S**eat Kilometer** (*Number of seats x Journey Length*). A decrease in this indicator means the route is more comfortable, since proportionately more passenger kilometers per seat kilometer are covered. Equation 2 shows the Travel Efficiency and Equation 3 shows the Comfort Parameter.

$$CUR = \frac{MV}{TC} \tag{1}$$

$$TE = \frac{\sum PK}{\sum SRK} \tag{2}$$

$$CP = \frac{\sum PK}{\sum STK} \tag{3}$$

In equation 1, *CUR* represents the Capacity Usage Ratio, *MV* represents the mean volume of the route and *TC* represents the total capacity of respective route. In Equation 2, *TE* represents the Travel Efficiency, *PK* represents the Passenger-km and *SRK* represents the Service-km. In Equation 3, *CP* represents the Comfort Parameter, *PK* represents the Passenger-km and *STK* represents the Seat-km.

Household surveys show that UPT users dissatisfied about long travel times, low departure frequencies and overrated capacity ratios of vehicles. UPT users expect a better arrangement for bus frequencies and a regulation for UPT routes. Operation of different modes on same routes cause inefficient traffic conditions and these conditions induce various UPT problems. All these reasons are the main reasons which reduce the indicators Travel Efficiency and Comfort Parameter.

According to the timetable-based assignment, it was found that the passenger of 86.500 are carried in the morning peak period. The total volume of carried passenger by UPT systems was found approximately as 290.000 passenger/day with respect to 30% of daily trips occurred in the morning peak period.

In do nothing case, paratransit and bus systems make 36.480 service kilometer (total distance that has been travelled by bus and paratransit vehicles in peak hour). In the case of timetable-based assignment, efficiency and comfort parameters were considered to evaluate current UPT systems. ***TE*** was calculated as **42.60** for base case. This value has to be increased as far as possible for increasing the service capability of the UPT systems but pursuing *CUR* . ***CP*** is found as **1.82** and has to be decreased as far as possible for passengers to get better service but pursuing TE.

Figure 2. Timetable-based UPT assignment results for morning peak (07:00 - 09:00).

3 Suggestions for Management Strategies

In this section, a system-based assignment is performed by using UPT demand matrices. According to the system-based assignment, it is showed that a large amount of UPT demand grew out of CBDs and the development areas of the city play critical role on demand interaction with CBDs. The UPT systems at this region has to be rearranged by taking into account of the growing public transport demand because population densities and CBD areas are growing out day after day. System-based assignment is useful for pre-information for planners at the route/frequency rearrangement process. In addition, the assignment results have been considered to arrange frequencies, regulations and routes. The scenarios which have been proposed in section have been created by considering system-based assignment results.

System-based shows the amount of desired passenger travel on the routes if all the conditions are convenient. Assignment results indicate that development at CBD is fast and transportation demand to CBD is higher than the other parts of the city . Representative demands cannot be handled on the same routes since there become shifts on the route choices. It is clearly seen that there has to be a new arrangement for bus routes, new route regulations for paratransit routes and operational innovations like associations of transport vehicles. System-based assignment used as a base-case planning tool to various scenarios. Timetable-based assignment was used for obtaining of the proposed scenarios. Figure 3 shows the system-based UPT assignment results for morning peak (07:00 - 09:00).

Figure 3. System-based UPT assignment results for morning peak (07:00 - 09:00).

Three different scenarios are proposed to increase the efficiency of the services of the UPT systems. The public transport OD matrix used for scenarios is determined as the sum of bus and paratransit demand matrices for the morning period (07:00 - 09:00) which is the dense time slice of the day with 30% of all trips. Table 1 shows the scenarios which are examined in timetable-based assignment.

Table 1. UPT features of the scenarios.

Scenarios	Proposals
Analyses	Base Case Analysis (BCA)
1	BCA + Bus Frequency Arrangement (BFA)
2	BCA + BFA + CBD Restriction to paratransit
3	BCA + BFA + CBD Restriction to paratransit + Association of Paratransit Vehicles

Scenarios;

Scenario 1 Increase on the bus departure frequencies on base case;

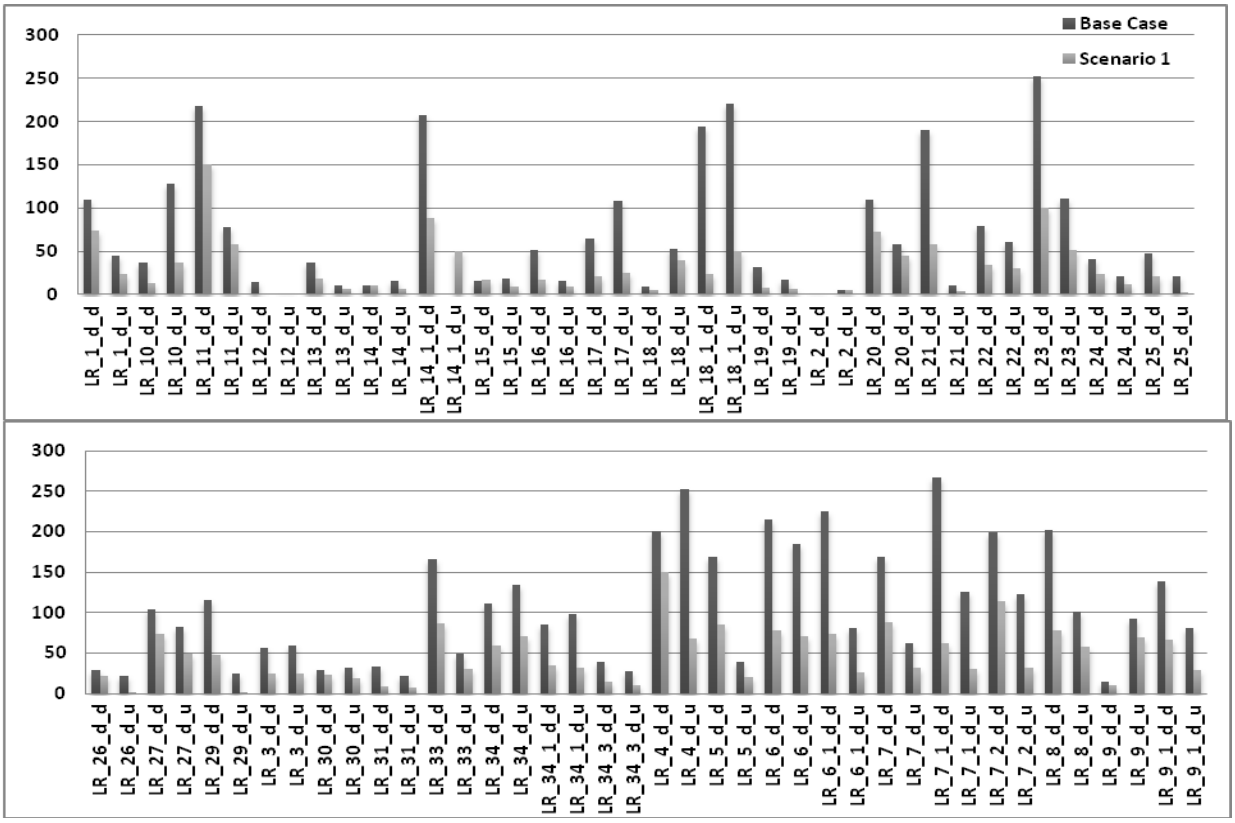
To increase the efficiency of UPT system; the frequencies and headways of the buses have been calculated with Maximum Loading Method which is based on the passenger analyses at the bus trips. Maximum Loading Method is the bus frequency arrangement method which have been defined by Ceder (2002) for improving bus services at UPT. Ceder (2002) defined various frequency assignment methods for arrangement of bus frequencies. General evaluation and measuring studies were performed on vehicle as:

$$F_j = \frac{\bar{P}_{mj}}{\gamma_j \times c} \tag{4}$$

Where, F_j represents the frequency of the bus departure for the respective route, $\bar{P}_{mj}$ represents the maximum observed passenger number on the headway, γ_j represents the loading factor at time interval ($0 < \gamma_j \leq 1.0$) and c represents the vehicle capacity (sitting + standing). "j" is the time interval indicator and has been accepted as 1 and γ_j has been accepted as "**0.6**" in the rearrangement process in Equation 4.

The new frequencies showed that the vehicle fleet has to be extended. According to the scenario 1, the number of passengers carried on the bus line routes is increased by 8%. Table 2 shows the bus route capacity usage ratios for current analysis and for scenario 1. Shortenings were created at the pattern of Line Routes/lineroute numbers/ directions up (d_u) and directions down (d_d).

Table 2. Bus route capacity usage ratios (%) for base case and scenario 1.



*CUR*s of the base case analysis show the boarding desire for routes. The routes which exceed the limit show high boarding demands for respective routes. Because of the some inadequate conditions the passengers go towards for other routes and other modes. Table 2 shows the high boarding desire for current capacities per route and the absorbed demand for each route with scenario 1.

Scenario 2 Restriction of paratransit vehicle entrance to CBD zone;

A core zone which attracts a large amount of trips and is the departure station of the bus & paratransit routes at the heart of the city called Bayramyeri, in Denizli Turkey. Traffic congestion and delays are the problems in the zone. Respective zone attracts a high trip demand since it is a commercial zone and is the historical core zone of the city. Land use of the area is not convenient for a easy travel in the zone because of unplanned urbanization. The roads are narrow and the traffic demand is relatively high. There are parking problems and the speed of the traffic is very slow. In these conditions, there occur traffic congestions and various transportation problems.

Household surveys and TMP indicates that paratransit vehicles have negative impacts on traffic in this zone. A pedestrian can access every part of the zone by walking in the range of 400-800 m and it is an accessible walking range.

Therefore, the restriction of paratransit vehicle entrance to Bayramyeri may lead to decrease the congestion and promote pedestrian mode. Passengers may be capable of accessing to the regulated paratransit routes by 7-8 minutes walking time. Figure 4 shows the regulated paratransit routes which are designed for the CBD entrance restriction. Paratransit vehicle restriction area has been determined by taking walking distance (250m-500m) into account. Assignment results showed that, while the number of passengers using the paratransit system decreases about 29%, there is an increase about 36% for bus services.

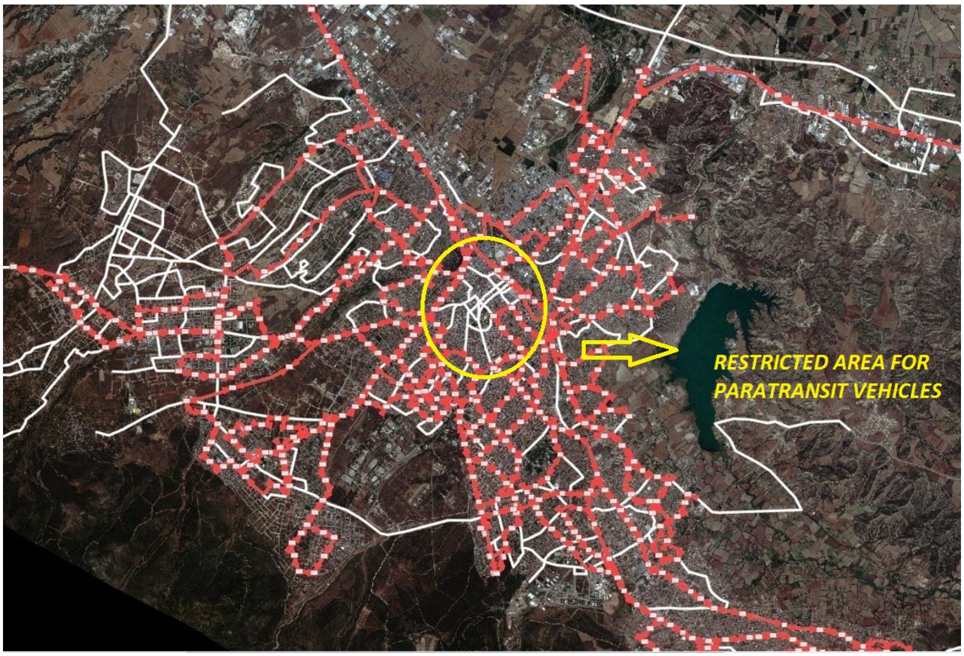


Figure 4. Restricted area for paratransit vehicles.

Scenario 3 ***Association of paratransit vehicles as an addition to scenario 2;***

In this scenario, the negative effects of 676 paratransit vehicles to city traffic have been tried to be decreased. For this purpose, association of 3 paratransit vehicles (14 passenger capacity per vehicle) to 1 paratransit vehicle (42 passenger capacity per vehicle) is carried out. At the same time, paratransit vehicles entrance to CBD was restricted and bus departure frequencies have been regulated as the same frequencies at scenario 1. The results showed that there is decrease of 36% at the passenger number carried by paratransit routes and increase of 48% at the passenger number carried by bus routes when compared with base case.

Table 3. Indicators for analyses and scenarios.

Scenarios	Travel Efficiency	Comfort Parameter
Base Case	42.60	1.82
1	18.17	0.81
2	21.82	0.93
3	24.97	0.98

Table 3 indicates that there is an important decrease at Comfort Parameter. It indicates that scenarios have a better comfort system for passengers. Decrease on travel efficiency is the result of improvement of *CUR*s because increase of frequencies and vehicles cause decrease on *TE*. Table 3 shows that results of scenario 1, 2 and 3 are similar at the standpoint of UPT. The impacts of scenario 2 and 3 are mostly about traffic and operational improvements.

4 Conclusions

In this study, current problems on UPT system of Denizli, Turkey have been analyzed based on parameters such as accessibility, comfort, travel time, operational conditions etc. Current public transport properties have been defined by the public transport assignment using VISUM 12.01 software and after consideration of the base case improvements for UPT have been researched.

Solutions have been proposed to overcome the public transport problems in Denizli. Different scenarios have been analyzed in different combinations. It was proposed that paratransit service routes should be removed from the CBD of the city. In addition, bus service frequencies have been re-arranged to manage public transport demand in a more comfortable way. Some operational improvements for bus and paratransit vehicles have been constituted. These proposals have been examined by timetable-based assignment process and the results have been considered via UPT efficiency indicators.

Three different scenarios have been analyzed without base case analysis; *CUR (Capacity Usage Ratio)*, *TE (Travel Efficiency)* and *CP(Comfort Parameter)* indicators have been evaluated in the name of total efficiency. The results clearly show that all scenarios have improvements on UPT service quality. Scenario 1 was the bus frequency rearrangement and *CUR* results showed that capacity usage of the bus mode is closer to optimum *CUR* value. Scenario 2 was the restriction of CBD to paratransit routes. The restriction area has been defined in the scope of pedestrian accessibility. Scenario 3 was the association of UPT vehicles as an addition to scenario 2. *TE* and *CP* results show that scenario 1, 2 and 3 have similar impacts on UPT.

CBD restriction and association of paratransit vehicles cause changes on general traffic and operation conditions. Those effects do not cause direct changes on UPT but cause indirect changes via changes on current traffic. Efficiency indicator examinations have to be increased as possible as to obtain more accurate results since an improvement on UPT has various effects on the UPT network and on the other features of the traffic like journey time, ride time, walking time to bus stops and etc.

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