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Impact of utility-based accessibility measures on urban public transportation planning: A case study of Denizli, Turkey

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ABSTRACT

As it is considerably difficult to identify specific changes by using a single numeric parameter, improvements gained by a new urban public transport (UPT) facility or by an operation policy is still a challenge in the decision-making process with respect to transportation planning. Although some indicators such as service quality, capacity usage ratio, service kilometers, passenger kilometers or seat kilometers are used by planners and policy makers, these indicators may not always reflect the total gain of trip makers: to access a facility providing a specific utility. Thus, this study aims to evaluate accessibility measures as performance indicators in the UPT planning process. Three scenarios that consist of timetable regulation, central business district restriction and integration with bus rapid transit are investigated using accessibility perspective in addition to the conventional indicators obtained by using VISUM™ travel demand modeling software. The results show that the first scenario leads to a more effective UPT system in terms of accessibility. Hence, a more distinctive measure is obtained for the decision stage of UPT planning.

Introduction

Urban public transport (UPT) planning is one of the most important parts of urban transportation planning and it provides sustainable development for cities. Thus, providing convenient planning strategies in which the travel behaviors of users are well-modeled has become a primary issue due to the influence of public access to UPT systems. Planners conduct UPT assignments to model travel behaviors of UPT users on the way from origins to destinations. The resulting traffic volumes for lines can be evaluated as an indicator for describing the service quality of the network (Friedrich, Hofsäß, & Wekeck, 2001). There are several conventional indicators such as cost, travel time, quality of service and number of transfer stations that are used by planners in the decision stages of UPT planning. As transportation science adds to its fields of interest, several concepts are articulated within the UPT planning field. Accessibility, which refers to the ease of reaching goods, services, activities and destinations (Engwicht, 1993; Hansen, 1959), has gained importance in transportation science in recent years and is one of those frequently articulated concepts (Caschili & De Montis, 2013; Monzon, Ortega, & Lopez, 2013; Ratner & Goetz, 2013) and it is increasingly employed in UPT planning.

Accessibility can also be defined as the ease by which people can reach and/or attain desired facilities, products and activities (Bhat et al., 2000). Accordingly, it may have considerable potential for the application in travel demand models as it is focused on the expected utility of transportation activities. While there are many studies, the foundation of the concept is similar in terms of components, measures and perspectives. Land-use, transportation, temporal and individual components are the main elements of accessibility components that planners utilize and specify fundamental in obtaining accessibility measures (Geurs & Ritsema van Eck, 2001). Infrastructure-, people-, utility- and location-based measures are the most common types of measures used (Geurs & Van Wee, 2004). Accessibility measures and components should be consistent with the accessibility criteria to match the right problem to the correct perspective. Geurs and Van Wee (2004) have defined four basic criteria for social and economic evaluations: theoretical basis, operationalization, interpretability–communicability and usability. A utility-based measure depends on the degree to which accessibility is evaluated as an output of various access alternatives. Utility-based measures reflect the advantages for people to gain access to various places. The utility term that is derived from the utility functions and used for discrete choice analysis is indirectly used to represent passenger perspective. While transport planning, geography, urban planning and UPT have other common components, the most important is that of accessibility. Accordingly, accessibility and UPT have a substantial relationship and have

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been investigated in several studies (Mavoa, Witten, McCreanor, & O'Sullivan, 2012).

Access to services and the accessibility of UPT have always been focal service issues (Murray, 2003) and most studies on accessibility include a UPT focus on physical access to the transit stops (Biba, Curtin, & Manca, 2010; Currie, 2010; Furth, Mekuria, & San Clemente, 2007; Gutierrez & Garcia-Palomares, 2008; Hsiao, Lu, Sterling, & Weatherford, 1997; Kimpel, Duecker, & El-Geneidy, 2007; Lovett, Haynes, Sunnenberg, & Gale, 2002; Zhao, Chow, Li, Ubaka, & Gan, 2003). Mavoa, Witten, McCreanor, and O'Sullivan (2012) classified accessibility measures with respect to UPT into three categories: access to transit stops, duration of public transit journeys and access to destinations. Access to a stop point means access to a UPT service. It is also important that the users know the various destinations they can access by using UPT services, the origin–destination (OD) features and the time required to travel between the zones (Lei & Church, 2010). Access to different opportunities or locations, another component of accessibility, can be achieved by building on spatial accessibility measures. There are different types of travel times that can be evaluated as measures of access. Accordingly, evaluating journey time or access time without considering ride time may result in overlooking the measure of service frequency. However, accessible and efficient services are vital features of well-utilized UPT systems (Murray, 2003).

Measuring UPT performance is an essential factor as it allows planners to evaluate and compare the success and potential of individual operators (Costa & Markellos, 1997). Previous UPT planning studies consider accessibility measures as the methodology and perspective, but it may be useful to evaluate them as performance indicators (Benenson, Martens, Rofe, & Kwartler, 2010; Curtis, 2011; Mavoa et al., 2012; Pitot, Yigitcanlar, Sipe, & Evans, 2006). As a change in the performance of the UPT system may not be observed by considering conventional UPT indicators alone, doing so may lead inaccurate decisions. Benenson et al. (2010) stated that the increasing interest in sustainable development has emphasized the importance of accessibility as a key indicator. Thus, it is important to measure the level of accessibility provided by UPT alternatives to support the process of UPT planning and decision making (Lei & Church, 2010). Therefore, evaluating accessibility in UPT planning may provide more accurate decisions.

This paper makes a contribution at the decision-making level regarding current state-of-the-art UPT planning by using accessibility measures. Although both accessibility formulations and scenario building techniques have been used before, there is still a significant gap in using accessibility measures in the decision-making stages of UPT planning. Thus, this study aims to evaluate accessibility measures as performance indicators in the UPT planning process. For this purpose, a five-step UPT planning model is proposed. In the first step, a timetable-based assignment is conducted for the base case, while in the second step, several scenarios are proposed to overcome UPT problems. In the third and fourth steps, generated scenarios are analyzed with respect to conventional indicators and utility-based accessibility (UBA). The fifth step involves a general consideration and evaluation of the results. The city of Denizli, which is located in the southwestern part of Turkey, is selected as the study area and the transportation master plan (TMP, 2010) of the city is used as a data source. Household surveys, public transport demand matrices and land use inventories are obtained from the transportation master plan (TMP, 2010). The base case for the UPT system is analyzed in terms of conventional indicators and three scenarios are then conducted with respect to the combinations of different service frequencies, vehicle capacities and operational adjustments by using the VISUM travel demand modeling software (see VISUM, 2011 for details). The results are evaluated with respect to UBA and four conventional indicators as functions of passenger kilometers, service kilometers, vehicle capacity and maximum number of passengers observed in the UPT vehicles.

The general structure of the study is organized as follows: The current UPT features of the study area are presented and the VISUM travel demand model and methodology are defined in section 'Method and study area'. Accessibility with UPT analyses for improvement is provided in section 'UBA and UPT planning analyses'. Section 'Discussion and conclusions' presents a general evaluation and recommendations for UPT decision makers and planners.

Method and study area

Method

The aim of this study is to offer an effective UPT planning model and to present possible measures to be implemented at the decision-making level by considering UBA components. For this purpose, a stepwise process is proposed in Fig. 1.

Fig. 1 indicates that the proposed model consists of five steps. At the first step, conventional indicators are obtained by a timetable-based assignment that is conducted by using the VISUM travel demand model. The mathematical expressions of these conventional indicators are given in

$$Q = \frac{\sum_{i=1}^{m} \frac{P_{i\max}}{F_i \cdot s_i} + \sum_{j=1}^{n} \frac{P_{j\max}}{F_j \cdot s_j}}{m+n}, \quad (i = 1,2,\ldots,m;\ j = 1,2,\ldots,n) \tag{1}$$

$$U = \frac{\sum_{i=1}^{m} \frac{pk_i}{sk_i \cdot c_i} \times 100 + \sum_{j=1}^{n} \frac{pk_j}{sk_j \cdot c_j} \times 100}{m+n}, \quad (i = 1,2,\ldots,m;\ j = 1,2,\ldots,n) \tag{2}$$

$$\bar{\delta} = \frac{\sum_{i=1}^{m} \frac{pk_i}{sk_i} + \sum_{j=1}^{n} \frac{pk_j}{sk_j}}{m+n}, \quad (i = 1,2,\ldots,m;\ j = 1,2,\ldots,n) \tag{3}$$

$$C = \sum_{i=1}^{m} c_i + \sum_{j=1}^{n} c_j, \quad (i = 1,2,...,m;\ j = 1,2,\ldots,n) \tag{4}$$

In Eq. (1), Q represents the parameter of service quality, $P_{\max}$ is the maximum number of passengers observed during the analysis period, F is the frequency of the bus/paratransit departures, s is the number of seats in the service vehicle and m and n are the number of bus and paratransit routes, respectively. In Eq. (2), U represents the capacity usage ratio (%), pk is the total passenger kilometers covered on the related bus/paratransit route, sk is the total service kilometers covered during the analysis period and c is the total capacity that represents the cumulative seating and standing capacity of the vehicles on the related route for overall journeys in the analysis period. $\bar{\delta}$ represents the mean volume per trip, which is formulized by Eq. (3). C represents the total capacity, which is the total seating and standing capacity of the vehicle combinations for all vehicle journey sections, which is formulized by Eq. (4). Note that a decreasing value of service quality, which provides more comfortable journeys with more seating and fewer standing passengers, may lead to inefficient operational conditions as service frequencies are increased.

In the second step, several scenarios are proposed to overcome excessive use of UPT vehicles, service frequency problems, traffic problems in central business district (CBD) induced by paratransit vehicles, as defined by Ceylan, Murat, Haldenbilen, and Cengiz (2004) and the lack of various modes in main axes. For this purpose, a new timetable chart, a new areal restriction for paratransit vehicles and a bus rapid transit (BRT) mode are offered. With respect to BRT, Rodriguez and Targa (2007) stated that BRT is increasingly popular throughout the world and it is utilized in