Integrated Modeling Approach for the Transportation Disadvantaged

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Abstract: Transportation models have not been adequate in addressing severe long-term urban transportation problems that transportation disadvantaged groups overwhelmingly encounter, and the negative impacts of transportation on the disadvantaged have not been effectively considered in the modeling studies. Therefore this paper aims to develop a transportation modeling approach in order to understand the travel patterns of the transportation disadvantaged, and help in developing policies to solve the problems of the disadvantaged. Effectiveness of this approach is tested in a pilot study in Aydin, Turkey. After determining disadvantaged groups by a series of spatial and statistical analyses, the approach is integrated with a travel demand model. The model is run for both disadvantaged and nondisadvantaged populations to examine the differences between their travel behaviors. The findings of the pilot study reveal that almost two thirds of the population is disadvantaged, and this modeling approach could be particularly useful in disadvantage-sensitive planning studies to deploy relevant land use and transportation policies for disadvantaged groups.

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Introduction

The ability to access personal or public transportation is fundamental for everyone to connect with employment opportunities, shopping, health and educational services, and the community at large. However certain groups lack the ability to provide their own transportation or have difficulty accessing available public transportation (Department of Transportation 2003). The "transportation disadvantaged" (DA) populations are those who personally experience difficulties or are unable to transport themselves or are unable to purchase transportation due to physical or mental disability, income status, age, etc. (Raje 2003).

Determining disadvantaged populations and comparing their characteristics with nondisadvantaged (NDA) groups are extremely important for sound transport and urban policy making. One of the major deficiencies is the unavailability of a comprehensive and holistic way in determining DA groups and measuring their disadvantage levels. Existing transportation planning models (TPMs) do not provide policy makers with the degree of disadvantage levels of a locality, and have been inadequate in addressing severe long-term transportation problems that DA groups overwhelmingly encounter (Simpson 1994; Banister 2002; Kenyon et al. 2002). Policy makers would only be able to propose relevant remedies or polices if they have accurate disadvantage ratios and indicators. Therefore the aim of this paper is to develop a modeling approach to integrate disadvantage analysis into TPMs, and to explore the differences in travel behaviors between transport DA and NDA groups.

This research views disadvantage as a multifaceted term, meaning that a person is likely to be DA in a variety of ways (e.g., physically disabled, elderly, without a motor vehicle, and disadvantage caused by location). This research identifies severely DA groups through a cluster analysis, and it describes a modeling approach and validation rather than presenting a case study. The proposed approach provides planners with an effective modeling and simulation tool that identifies the DA and improves their conditions. Disadvantage indices are useful for policy development and are important data input for policy analysis simulations. To develop such indices, characteristics of DA are needed to be defined carefully. The ultimate purpose of the approach is to equate the conditions of those DA to NDA by supporting the development of efficient policy actions through simulations and continuous monitoring of the situation of the DA. The modeling approach developed in this study is tested in a pilot study and proved that it effectively detects DA and NDA groups with the techniques proposed.

This paper addresses the following primary research question: how can an integrated modeling approach be developed—sensitive to the DA in determining their characteristics, spatial concentrations, travel patterns, and were they exposed to a severe disadvantage level—and could it be used as a decision/policy support tool?

The paper is structured in five parts. The following section reviews the literature on transportation DA. "Integrated Transportation Modeling Approach" introduces the proposed integrated transportation modeling approach. "Discussion of the Findings" demonstrates and discusses the implementation of the model in a pilot study. "Conclusions" concludes with the overall findings of the research.

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Transportation Disadvantaged

The DA groups are generally identified as those people whose range of travel alternatives is limited, especially in the availability of easy to use and inexpensive options for trip making (Transit Cooperative Research Board 1999). The negative impacts of transportation on the DA have not been effectively considered in the modeling studies, as these models do not take qualitative, social, and ethical parameters into account (Banister 2002; Kane and Mistro 2003).

Transportation models are increasingly under attack for being biased against nonmotorized traffic modes and socially DA groups (Murray 2003), and for failing to inform policy makers with accurate information on the DA. In recent years, a strong demand has arisen for an equitable access to transport for the DA. Garret and Wachs [in Sheck (1997)], Church et al. (2000), Deakin (2001, 2003), and Yigitcanlar et al. (2005) point out the ethical responsibility of modeling studies toward social issues and view "accessibility" and "social equity" among the key issues for land-use and transportation planning.

Mobility impairment and a low level of accessibility to urban services and transportation facilities are among the growing problems contributing to the escalation of inequity (Wu and Hine 2003; Yigitcanlar et al. 2006). Until recently the conventional TPMs have only preserved this status quo. Pennycook et al. (2001) note that distances to services have increased over the last 2 decades together with the rapid growth of suburbia. According to Webber (1982), there is an inequity problem between people with and without an automobile, and those without access to an automobile are even deprived of access to the economic and social life of the city.

However, there is still a struggle to define the disadvantaged in a more explicit way. It has been concluded that the precise definition is impossible, since many dimensions of disadvantage cannot be compartmentalized and handled with the existing travel modeling techniques (Lyons 2003). In describing who the DA might be the Transit Cooperative Research Board (1999) and Kenyon et al. (2002) succinctly elucidate reasons for disadvantage and the factors influencing immobility as: access to automobiles, demographic factors, and availability of public transportation.

Similarly in the report by the Social Exclusion Unit (2003), disadvantage is explained by three factors: no access to transport facilities as a result of social exclusion; due to poor transportation provision; and adverse impacts on socially excluded areas, such as air pollution and accidents. The impact of social isolation on travel behavior is well documented by Porter (2002) and Lucas (2004).

However, exclusion does not solely relate to poverty or disability. Poor people still may have cars, or live in an accessible area and, thus, their poverty may not cause them to experience transport exclusion. Disabled people can have high accessibility to transport if they are supplied with or made accessible to resources by other means. The exclusion can become much wider and multidimensional such as physical, temporal, economical, spatial, and psychological (Hine and Mitchell 2001; Schonfelder and Axhausen 2003). One would be DA in certain periods of time, or in some certain places. Demographic dimension also adds to this as the numbers of disabled and elderly people are increasing in almost all nations (Brail et al. 1976; Blaser 1996; Deakin 2003). Hine and Grieco (2003) argue that a combination of poor accessibility with low levels of mobility and low levels of sociability intensifies exclusion. Thus, these intensities can be used as a measure in identifying the DA.

Hine and Grieco (2003) describe the general characteristics of various DA groups and the socioeconomic or transport groups they belong to. Kenyon et al. (2002) advocate three aspects of analysis to deal with the DA issues of individuals (e.g., mobility impaired), groups (e.g., poor, elderly), and communities (e.g., clusters, neighborhoods). They also argue that disadvantage is rather scattered. Wu and Hine (2003) provide seven different deprivation domains which are: income, employment, health and disability, education, geographical access to services, social environment, and housing. Litman (2002) examines the equity-based studies, and concludes that working with four user and six travel cost categories for a comprehensive equity-based transportation study is most appropriate. However, none of the above studies have clearly stated how various classifications would help to improve the conditions of the DA, though some studies have attempted to make this connection, which are discussed in the next section.

Disadvantaged in Transportation Planning Models

Brail et al.'s (1976) study is the first inquiry on the demand estimation for the DA in a TPM. It is argued that the traditional demand estimation techniques were ineffectual for these groups due to their particular transportation patterns and needs. In this study special "disadvantage coefficients" were sought, but the problem of overlapping categories occurred and caused double counting in the trip estimation analysis.

More recent studies focused on technology integration—intelligent transportation systems (ITS), geographical information systems (GIS)—with transportation modeling (Arampatzis et al. 2004; Thill et al. 2004; Wang 2005), where technology did not help much in integration of the disadvantage issue into TPMs. According to Cervero [in Barter and Raad (2000, Vol. 3], "there is no technology that can redress the social injustices inherent in a sprawling and auto-centric landscape."

There may be many groups with different transportation disadvantages, which can appear in various forms, such as: family size and conditions, dependency on a family member, personal characteristics, location-based, travel comfort, travel time, travel cost, transfers, speed and physical travel conditions, vehicle performance, security and safety, physical barriers and difficulties, and dissatisfaction with transportation services. Transit and peak captives may even be added because of their dependency on a single mode of transportation and travel time. Travel behaviors may also show variety in different cultures (Cervero and Mason 1998) and from one DA group to another. Therefore, developing an overall travel demand configuration for transportation modeling would be beneficial in addressing the problems of the DA.

Integrated Transportation Modeling Approach

In this study a new modeling approach is developed to determine DA and their travel behavior in order to focus and address their transport related problems. The model contains three stages, which are: (1) collecting and processing data; (2) determining DA population; and (3) comparing the DA and NDA populations (Fig. 1). The first stage of the model focuses on data collection and processing. The second stage of the model consists of a series of cluster analyses to clearly define DA groups. The final stage

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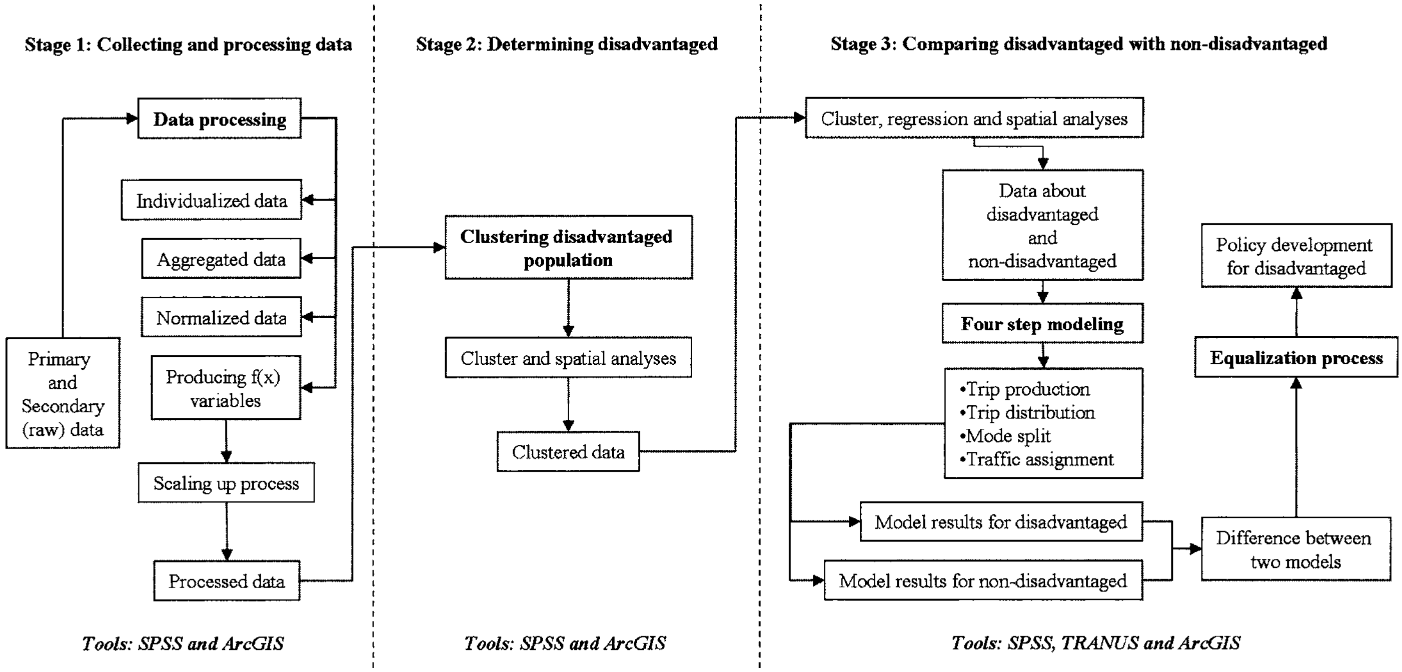

Fig. 1. Flowchart of model

involves comparison of DA with NDA population in terms of their travel behaviors.

The proposed model accommodates a sequential four-step modeling approach for two main reasons. First, it provides an opportunity for an easy integration of the disadvantage analysis into the TPMs, that the method can be conveniently conducted by any expert who already governs the basic process of the traditional approach. Second, it facilitates rendering the necessary outputs out of the assignment stage, which must follow ordinarily all other steps, to be used in policy-making analyses through simulations.

In dealing with the problems of the DA, authorities need to know the extent, ratio, and types of disadvantage occurring. The outcome of the model would guide them through the policy-making process for improving the travel conditions of the DA. Hence, the method could be used as a tool for monitoring disadvantage levels in a transportation system. Through simulations, disadvantages can also be projected for each designed scenario packages.

This model is tested in a pilot study to find out whether it runs validly and serves as a useful tool for improving the conditions of the DA groups. The city of Aydin, a food-processing center in Western Turkey, is selected as a pilot study area. The population of Aydin in 2000 was 135,365. The population was large enough and the urban layout was not too complicated to run the model satisfactorily. The boundary of the pilot area is restricted to the urban footprint, which is comprised of 12 travel analysis zones.

Collecting and Processing Data

The data for the case study is gathered from three sources: municipal transportation dataset, 2000 census, and household travel surveys (HTS). The municipal transportation dataset includes road networks, public transport (PT) routes, PT stops, and time tables. Some of the data were not available in digital format. The available datasets are geocoded and entered into GIS. The 2000 census data have been provided by the State Institute of Statistics. A face-to-face survey is conducted with randomly selected households (based on municipal records) using a "stratified random sampling" technique. The survey is conducted with 326 households which represents 932 household members (0.7% sampling ratio).

The HTS is designed carefully to investigate both individual and household socioeconomic and travel characteristics. Questions related to households aim to reveal socioeconomic status of the households, such as car ownership, household size, and income. Questions related to individual household members aim to determine individual travel patterns to reveal disadvantage-related information. Respondents were asked to give detailed information about their daily travel behavior, such as trip destinations, travel comfort level, travel time, and costs. The reliability of the survey data is cross checked by reinterviewing randomly selected respondents.

Aydin's settlement structure is quite different from most of the developed country's cities. The city has a compact form, having only very limited dispersed suburbs. Wealthier groups reside in the suburbs surrounding the city center. The urban fringe is mainly home to low income groups. The eastern suburbs largely comprise the manufacturing and industrial precincts with limited residential areas, while the western suburbs comprise newly developed middle income residential quarters. According to 2000 census statistics (State Institute of Statistics 2003), Aydin has the following socioeconomic profile: 16% unemployed, 19% studying in a school or university, 25% preschool age, and 20% over 65 years of age. Service, manufacturing, and commercial sectors are the dominant economic activities among the urban economic activities (38, 17, and 16%, respectively). Census statistics also confirm the household travel survey findings. Table 1 presents some of the salient characteristics of the households within 12 zones.

The results of the HTS present the accessibility levels to various land-use destinations. These land-use destinations include

Table 1. Salient Household Characteristics

Zones	Household size	Motor vehicle ownership (%)	Unemployment (%)	Student (%)	Age under 7 (%)	Age over 65 (%)	Physically disabled (%)	Higher degree (%)	Secondary school graduate (%)	Primary school graduate (%)	Did not go to school (%)
1	3.93	38.92	28.07	15.95	28.24	9.41	1.06	3.41	23.06	68.24	5.29
2	3.63	48.56	29.14	17.25	26.87	49.25	0.30	4.03	50.45	29.85	15.67
3	4.58	32.78	17.58	13.95	36.26	34.85	1.82	6.36	36.82	43.94	12.88
4	3.51	46.75	15.96	21.21	7.14	15.71	3.43	9.29	32.86	54.29	3.57
5	3.76	38.64	20.33	18.63	13.41	9.76	0.85	2.44	18.20	69.00	10.37
6	3.64	42.39	20.52	19.69	43.53	24.71	0.47	2.24	31.29	54.12	12.35
7	4.21	38.00	14.18	27.77	24.51	22.55	0.39	2.84	15.78	69.61	11.76
8	5.63	33.11	21.31	13.29	23.08	39.42	2.50	0.58	29.92	45.00	24.50
9	3.68	38.66	13.34	19.75	48.58	8.22	1.51	2.74	28.08	60.27	8.90
10	3.45	35.52	8.69	12.91	20.75	13.21	1.70	6.23	5.17	82.00	6.60
11	3.85	38.46	7.72	16.69	31.00	9.88	0.37	7.90	10.25	80.00	1.85
12	3.14	48.26	8.49	23.51	20.31	17.19	1.56	2.97	15.00	76.56	5.47
Average	3.92	40.00	17.11	18.38	26.82	21.18	1.33	4.25	24.74	61.07	9.94

work, education, shopping, recreational activities, and sociocultural activities. The index values then converted into accessibility levels. The household accessibility levels of each zone to land-use destinations are listed in Table 2. The findings of the household travel survey reveal that Zones 5, 6, 8, and 9 are among the DA zones in terms of accessibility to the major land-use destinations.

Determining Disadvantaged Population

There are a large number of factors which contribute to transport disadvantage. NSW Ministry of Transport (2005) defines people as being DA with mobility, isolation, disability, and age-based criteria. Some researchers focused on the socioeconomic aspects of the public to determine social groupings that are most likely to suffer transport disadvantage (Denmark 1998; Wu and Hine 2003; Dodson et al. 2004). Buchanan et al. (2005, Vol. 14) noted that "[DA] include low-income people, the unemployed, beneficiaries, youth and children, women, the elderly, disabled people, outer urban dwellers, and ethnic minorities. Other categories of relevance are: households in low rent housing, households with low mortgage payments, and households that do not own a motor vehicle." However not everyone in each of these groupings is severely DA.

The research reported here developed a method for clearly determining people as being severely DA. It defines people with severe transportation disadvantage as those having a number of major disadvantages at the same time (see Table 3 for the listing of the major disadvantage categories). Therefore the second stage of the model consists of a series of cluster analyses to determine those who are DA.

Cluster analysis is a statistical technique that is developed to group similar cases. Clustering algorithms are methods to divide a set of observations into groups so that the members of the same groups are more similar than members of different groups or clusters (Ripley 1999). The method of cluster analysis has been used widely in transportation planning, traffic accident analyses, traffic signal optimization, and ITS related studies as a data mining tool (Hauser et al. 2000; Smith and Saito 2001). Cluster analysis makes data manageable and helps analysts to construct a simple

Table 2. Household Accessibility Levels to Land-Use Destinations by Zones

Zones	Accessibility to work	Accessibility to education	Accessibility to health services	Accessibility to shopping	Accessibility to recreational activities	Accessibility to sociocultural activities	Zone average
1	Medium	High	Medium	Low	High	High	Medium
2	Medium	Medium	Low	Medium	Medium	High	Medium
3	Low	High	High	High	High	High	High
4	Medium	Medium	Medium	Medium	High	High	Medium
5	Low	Medium	Poor	Medium	Poor	High	Low
6	Poor	Medium	Low	Low	Poor	High	Low
7	Poor	High	Medium	High	Medium	High	Medium
8	Poor	Medium	Low	Medium	Poor	High	Low
9	Poor	Low	Low	Low	Low	High	Low
10	Low	Medium	Medium	Medium	High	High	Medium
11	Low	High	High	High	Medium	High	High
12	Low	High	Medium	Medium	Medium	High	Medium
Average	Low	Medium	Medium	Medium	Medium	High	Medium

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Table 3. Major Disadvantage Categories

Category	Category name	Notes
ACCESS	Accessibility	Determines the number of people with poor accessibility level to basic urban amenities
COM.PUB	Comfort level of public transit	Measures passenger density and comfort conditions of public transit
COM.VEH	Comfort level of private motor vehicle	Private motor vehicle comfort level (i.e., odor, air, condition, noise, cleanness, seat comfort)
IMPED.MP	Mode and peak impediment	Represents combined effect of mode and peak activity together with emphasis on the disabled
IMPED.PT	Public transit impediment	Indicates public transit conditions (i.e., physical conditions of bus stops, service frequencies, number of transfers)
IMPED.CU	Cumulative impediment	Represents the cumulative effect of basic impedance elements (i.e., travel time, cost, and distance to stop or car park)
INC.PER	Income level	Income per person
SCH.TRIP	Journey to school	Indicates travel conditions of students with various measures
VEH.AVA	Motor vehicle availability	Determines the number of people with no motor vehicle

mathematical relationship between causes and the phenomenon, and it identifies the most relevant elements that represent the group.

The following assumptions are considered in this study during cluster analysis: the analysis to provide objectively defined outcomes; the analysis to divide the population on the basis of nearest neighbor rule; all variables and the value scales to have equal weights in the clustering process; all variable values to be scaled so the yield upward values representing NDA and the downward values DA; and the zones to have homogeneous characteristics.

In cluster analysis, all data values are needed to be commensurate for comparability (Richardson et al. 1995). In this study more than 100 disadvantage variables are clustered around 11 major DA categories to form a generalized "disadvantage domain" (Table 3). For example, factors that are affecting PT usage (e.g., service frequencies, number of transfers, and physical conditions of PT stops) are combined into one generalized PT impediment variable. This clustering allowed us to run a model with only 11 variables, and helped minimize possible errors originating from individual variables.

Socioeconomic, cultural, geographic, and legislative characteristics of localities are very important in selecting correct variables to determine the DA. Therefore, some of the variables that are used in this pilot study (i.e., PT comfort and vehicle comfort) may not necessarily be the best suited to defining DA populations elsewhere.

Each observation value is translated to a scale value between 0 and 100, which this process is referred to as "scaling up process." The general principle in the scaling process is to scale all individual values to the highest value gained all throughout the data field. The frequency of scale values (Likert) in a single data column provides the importance of the variable concerned before the variable value in the function. In the process, first the weights of importance are assigned and a raw utility value is found, and then the highest value gained is calculated throughout the utility results of individuals. Similarly, if a maximum accessibility level is found for an individual to be 2.8 points, this was regarded as "100 points of access" and all other individual values are rated over this highest value.

The process of forming and scaling DA categories is undertaken in three steps: disaggregating household data into personal statistics, forming disadvantage categories, and generating utility directions.

All upward values mean positive utility results for a person, while downward values mean negative utility (disutility). It is necessary for clustering that all values are distributed between two clusters (DA and NDA) so the lower values fall into the DA category and higher ones fall into the NDA. It is assumed that all categories considered have an equal weighting.

There are two basic utilities of the clustering. These are: to which cluster an individual belongs, and the distance of the individual values to the center of the cluster, which is the degree of disadvantage for the variable. All data are reduced to 11 disadvantage categories and are prepared for the clustering process. Simple "*K* means" method of clustering in SPSS is applied to derive the data of those DA. No threshold value is introduced, and the data are divided by the software into two populations without any subjective intervention. Each individual belonged to the cluster whose center is closest to that in terms of Euclidian distance. This type of clustering is referred to in the literature as the "internal cohesion" clustering (Everitt 1993). For objectivity, no predefined threshold values are introduced in grouping the values. Simply, the procedure is used for splitting the sample population into two groups for the major disadvantage categories.

People with relatively low scores belonged to the DA, and the ones with high scores to the NDA categories. Consequently, the number of DA persons was 629 and NDA was 303. In the model, the DA and NDA are separated and evaluated independently. Additionally cluster centers provide an indication of the disparities (as a gauge for disadvantage) between the two clusters for each variable. Cluster center results point to the fact that disadvantage is largely due to a lack of motor vehicle access and poverty. This finding indicates that "vehicle availability" and "income" are the key policy variables in determining disadvantage. Therefore a local council needs to pay a great deal of attention to these two issues, while developing policies to address the problems of the DA.

Determining types of disadvantage provides us with information about which variables are to be captured as "policy variables" and which sociodemographic groups to focus on. Table 4 presents the aggregated view of disadvantage categories by zones. These findings overlap with the socioeconomic data obtained from the HTS and the census.

The cluster results indicate that the city of Aydin accommodates a large number of DA. The reason for this high level DA ratio might be the urban form, PT configuration, and also socioeconomic characteristics of the residents. Aydin is a compact medium-size city with mostly concentric layout. However, the PT

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Table 4. Aggregated Disadvantaged Categories by Zones

Zones	ACCESS	DEPEND	EDU. FAM	IMPED. CU	IMPED. MP	IMPED. PT	INC. PER	PUB. COM	SCH. TRIP	VEH. AVA	VEH. COM	Number of disadvantaged categories
1	NDA	NDA	NDA	NDA	NDA	DA	NDA	NDA	NDA	NDA	NDA	1
2	NDA	NDA	DA	DA	DA	DA	NDA	DA	NDA	DA	NDA	6
3	NDA	NDA	DA	DA	DA	NDA	NDA	NDA	NDA	NDA	NDA	3
4	NDA	NDA	NDA	DA	NDA	DA	DA	NDA	NDA	DA	DA	5
5	DA	NDA	NDA	DA	DA	DA	NDA	NDA	DA	NDA	DA	6
6	DA	NDA	DA	NDA	NDA	DA	NDA	NDA	NDA	DA	DA	5
7	NDA	NDA	NDA	NDA	NDA	DA	NDA	DA	DA	DA	DA	5
8	DA	DA	DA	DA	DA	DA	NDA	NDA	NDA	DA	DA	8
9	DA	NDA	NDA	DA	NDA	DA	NDA	NDA	DA	NDA	NDA	4
10	NDA	NDA	NDA	DA	NDA	NDA	DA	DA	NDA	NDA	DA	4
11	NDA	NDA	NDA	NDA	DA	NDA	DA	NDA	NDA	NDA	DA	3
12	DA	NDA	DA	NDA	DA	NDA	DA	NDA	NDA	NDA	NDA	4
Number of disadvantaged zones	5	1	5	7	6	8	8	3	3	5	7	—

services are lacking. In addition, motor vehicle ownership, income, and employment levels are very low. Further, travel times exceeding 20 min are considered a disadvantage in Aydin, while 45 min of travel time could barely be considered a disadvantage in a large metropolitan city.

Fig. 2 presents DA zones as zone averages derived from the aggregated clustering results. Zones 2, 6, and 8 are noted as DA and are also characterized as low socioeconomic areas. Fig. 2 also illustrates various socioeconomic characteristics of the zones that are derived from the HTS and the census.

This analysis demonstrates that it is possible to determine zone clusters of the DA by the cluster analysis. In the case of Aydin, this study falsifies Hine and Grieco's (2003) argument that the DA are rather scattered. This analysis shows that there are relatively dense DA populated areas. The disadvantages are overwhelmingly contingent on low income, low motor vehicle ownership, large household size, poor accessibility, and low educational level.

Comparing Disadvantage with Nondisadvantage

TRANUS integrated land-use and transport modeling software is utilized for the transportation modeling of Aydin. TRANUS is powerful software, particularly when calculating complicated algorithms and handling mass information processing (Barra 1989). TRANUS requires aggregation of all data entries into a zone level for producing categorical results. The categories property of the software is used in handling the separate model runs. Further, it includes the evaluation part and performance indicators in which some scenarios could be evaluated (Modelistica 2005).

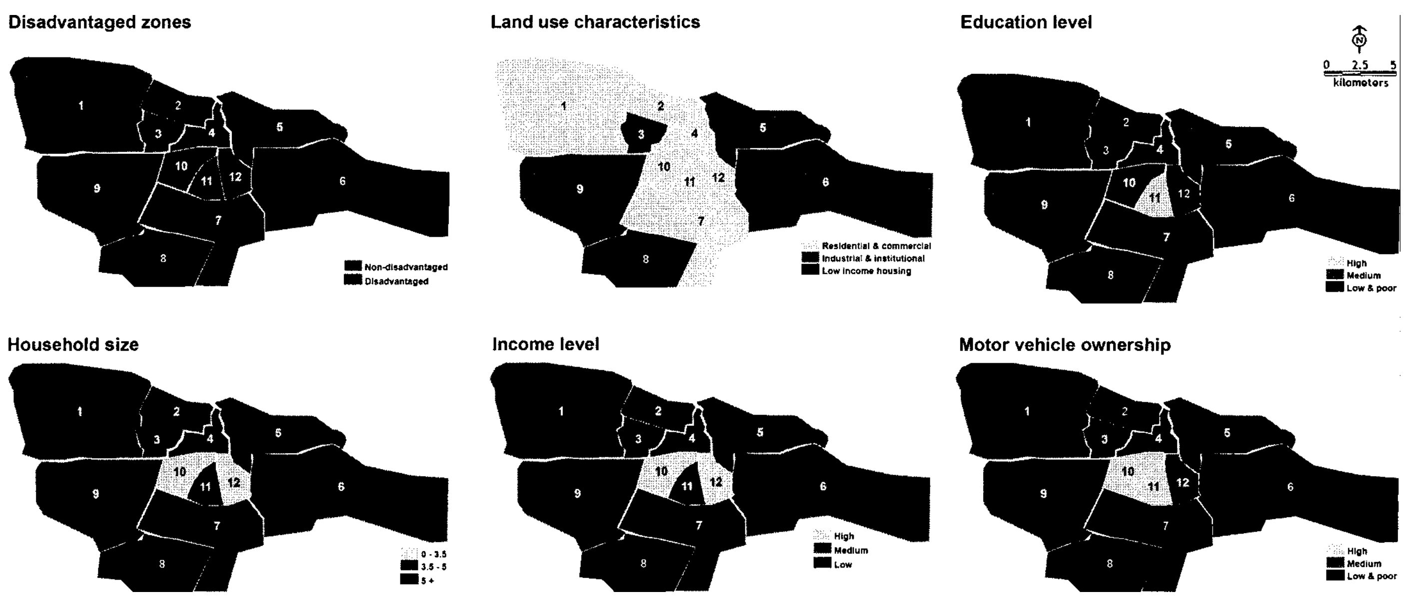

Fig. 2. Disadvantaged zones and their selected characteristics

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Table 5. Regression Model for Trip Production

Independent variables	Nondisadvantaged		Disadvantaged	
	Coefficient	Significance	Coefficient	Significance
Education level	2.022	0.002	—	—
Income level	−0.040	0.016	—	—
Economic dependency	−0.039	0.007	—	—
Vehicle comfort	—	—	−0.046	0.113
Comfort level of public transit	—	—	−0.06	0.063
Economic dependency	—	—	0.026	0.042
Constant	3.131	0.000	5.977	0.043
Number of observations	—	303	—	629
R-squared	—	0.785	—	0.690

TRANUS accommodates a traditional four-step modeling process to estimate traffic volumes on major roadways (primarily freeways, arterials, and collectors). The four steps include: trip productions, trip distributions, mode split, and traffic assignment, which will be discussed in the following sections.

In this pilot study "journey to work" and "journey to school" are considered in determining travel patterns. The model is run for 12 traffic analysis zones. To compare the DA population with the NDA, both of their travel behaviors are determined by TRANUS. Trip productions and distributions for all modes (PT, private vehicle, and walking) are calculated and entered into TRANUS for the mode split. TRANUS is utilized for running the model and monitoring assignment results. Performance indicator results and simulations are also obtained for each category.

In terms of PT there is only one mode available at the pilot study area, which is the bus service. Bus services that run on 14 routes are operated by the transportation department of the Aydin city council. Network configurations and travel cost values are estimated by considering distances over the PT and road networks for each "trip production–trip attraction" pairs. Other aspects of the transportation system and the traffic assignment calibration specifications are outside the scope of this paper.

Trip Production

An ordinary least square multiple linear regression model is used to determine the most important factors in trip production for both DA and NDA. Regression analysis is a popular technique in determining factors influencing trip production (Southworth and Owens 1993; Cervero and Gorham 1995; Cervero and Kockelmann 1997; Hess et al. 1999; Krizek 2003). After various trials with different variables through correlation analysis, three variables are entered in the regression model. The variables with the highest R^2 value are the most effective factors in explaining the trip generation behavior. For NDA these variables are educational level, income level, and economic dependency, where the dependent variable is the number of daily trips per person. When these variables are run together in the regression model, the R^2 value is as high as 0.78. For the DA, the highest R^2 value (0.69) is achieved with the following variables: vehicle comfort, comfort level of PT, and economic dependency (Table 5). In the statistical analyses, error margins are assumed to be 5%.

The overall average daily trips per person for the NDA are 1.73, compared with 1.65 for the DA. Trip production results by zones for both DA and NDA groups are presented in Table 6.

Trip Distribution

A simple distance decay function, which is based on the singly-constrained gravity model, is used to determine trip distributions. Following the calibration process, obtained trip length distributions (TLD) are found to be fitting to the TLD curve of original origin–destination data for the beta calibration. Finally, the beta values became −1.22 and −1.12 for the NDA and the DA, respectively. [For DA: R^2: 0.978, significances: 0.578 (constant), 0.000 (TLD), standard error of estimate: 0.129, t test: −0.595 and −15.047. For NDA: R^2: 0.56, significances: 0.78 (constant), 0.051 (TLD), standard error: 0.83, t tests: −0.295 and −2.553. Acceptable significance level: 0.05.] This analysis confirms

Table 6. Trip Production by Zones for Nondisadvantaged and Disadvantaged

Zones	Nondisadvantaged				Disadvantaged			
	Model's trip generation rate (per person)	Survey's trip generation rate (per person)	Population	Trip production	Model's trip generation rate (per person)	Survey's trip generation rate (per person)	Population	Trip production
1	1.81	1.88	4,459	8,383	1.72	1.93	7,802	15,042
2	1.75	1.51	1,868	2,821	1.77	1.59	9,510	15,111
3	1.87	1.61	3,450	5,555	1.14	1.17	5,857	6,624
4	1.94	1.94	2,477	4,805	1.95	1.88	7,659	14,437
5	1.88	1.94	6,410	12,435	1.99	2.3	7,067	16,268
6	1.74	1.89	3,975	7,513	1.71	1.49	11,384	16,985
7	2.02	2.08	3,277	6,816	2.02	1.9	8,661	16,499
8	1.23	1.33	1,004	1,335	1.24	1.31	12,042	15,799
9	1.54	1.4	3,422	4,791	1.48	1.3	5,829	7,601
10	2.12	2.15	6,394	13,747	1.73	1.94	3,289	6,394
11	1.4	1.28	4,522	5,789	1.64	1.39	5,377	7,452
12	1.51	1.61	3,840	6,182	1.4	1.51	5,990	9,063
Total	1.72	1.73	45,098	80,171	1.64	1.65	90,267	147,275

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Table 7. Calibrated Trip Distributions for Nondisadvantaged and Disadvantaged

Zones	1	2	3	4	5	6	7	8	9	10	11	12	Trip production
(a) Nondisadvantaged population													
1	0	1,175	2,548	1,959	196	1,685	30	30	196	196	196	196	8,393
2	98	0	100	501	301	301	200	15	301	200	401	402	2,821
3	30	821	0	1,088	411	616	616	206	411	206	370	780	5,555
4	25	346	743	0	519	519	519	26	743	51	225	1,089	4,805
5	914	318	318	2,550	0	1,912	1,594	48	1,275	318	1,115	2,071	12,435
6	256	372	496	2,233	744	0	496	38	744	248	695	1,191	7,513
7	131	254	190	1,778	762	889	0	19	127	254	1,079	1,333	6,816
8	9	9	120	241	120	96	180	0	138	120	180	120	1,335
9	47	285	1,428	1,428	43	43	572	43	0	572	285	43	4,791
10	87	586	2,931	2,052	1,173	88	1,173	88	1,173	0	1,759	2,638	13,747
11	24	171	1,029	1,595	1,029	171	171	171	171	171	0	1,081	5,788
12	224	237	474	1,185	474	711	474	36	711	117	1,540	0	6,182
Trip attraction	1,847	4,575	10,377	16,609	5,771	7,012	6,025	721	5,989	2,455	7,846	10,945	80,171
(b) Disadvantaged population													
1	0	1,092	5,459	2,730	546	3,275	101	100	546	819	273	101	15,042
2	713	0	713	2,853	1,427	713	713	130	1,427	1,427	2,497	2,497	15,111
3	97	1,577	0	2,789	97	87	1,052	99	526	97	97	97	6,624
4	156	1,691	1,945	0	846	2,537	1,270	156	1,100	254	846	3,637	14,437
5	1,772	590	109	2,952	0	2,362	2,952	110	1,180	109	1,477	2,657	16,268
6	759	140	1,518	5,316	1,518	0	1,518	140	759	761	1,899	2,658	16,985
7	78	78	424	2,096	1,274	2,463	0	78	424	424	2,761	3,398	16,499
8	787	144	784	1,574	1,574	1,259	2,360	0	1,809	1,574	2,360	1,574	15,799
9	153	835	1,669	835	153	154	1,669	153	0	1,669	157	153	7,601
10	149	149	807	807	807	807	149	149	149	0	1,211	1,211	6,394
11	90	489	90	2,445	1,468	90	90	489	489	489	0	1,225	7,452
12	570	563	109	1,689	563	1,689	111	103	1,125	281	2,259	0	9,063
Trip attraction	5,324	7,348	13,626	29,085	10,272	15,447	11,985	1,707	9,534	7,903	15,836	19,207	147,275

that the DA travel slightly further than the NDA. The outcomes of the trip distributions for the NDA and the DA are listed in Table 7.

The overall trip production and distribution figures that are calculated by the model are close to the Transport Dept.'s trip production and distribution projection results. However it was not possible to check the stability and reliability of the same figures for the DA and NDA as such data have never been collected or estimated by the municipality or any researcher.

Mode Split

The utility approach (binomial logit) is used to calculate the proportions of modal choices. The general utilities for modes (public/private) of transport categories (NDA/DA) are derived through regression analyses, seeking relationship between the combined impediment variable, and the type of mode traveled as the dependent variable. The R^2 value for NDA is 0.78. The utility function for the DA could be explained solely by the combined impediment variable, where R^2 is 0.72 with coefficients being almost identical with the NDA (Table 8).

The calculations for mode split and assignments are run on TRANUS, therefore there was no need to employ logit method in finding mode split figures. TRANUS requires overall observed modal preferences to be entered into its system. Modal preferences are also calculated by considering the network and system characteristics (distance, PT services, and capacities). The modal

Table 8. Regression Model for Mode Split

Independent variables	Nondisadvantaged			Disadvantaged		
	t statistic	Coefficient	Significance	*t* test	Coefficient	Significance
Combined impediment	6.013	6.013	0.000	5.097	5.097	0.000
Constant	−4.278	—	0.000	−5.149	—	0.002
Number of observations	—	—	303	—	—	629
R-squared	—	—	0.783	—	—	0.722

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Table 9. Trip Production Differences between Nondisadvantaged and Disadvantaged

Zones	Trip generation of total population	Trip generation of nondisadvantaged	Trip generation of disadvantaged	Difference between nondisadvantaged and disadvantaged	Trip attraction rate for the disadvantaged
1	23,425	8,383	15,042	−6,659	0.64
2	17,932	2,821	15,111	−12,290	0.84
3	12,179	5,555	6,624	−1,069	0.54
4	19,242	4,805	14,437	−9,632	0.75
5	28,703	13,435	16,268	−3,833	0.57
6	24,498	7,513	16,985	−9,472	0.69
7	23,315	6,816	16,499	−9,683	0.71
8	17,134	1,335	15,799	−14,464	0.92
9	12,392	4,791	7,601	−2,810	0.61
10	20,141	13,747	6,394	7,353	0.32
11	13,240	5,788	7,452	−1,664	0.56
12	15,245	6,182	9,063	−2,881	0.59
Total	227,446	80,171	147,275	−67,104	0.65

preferences in favor of PT were 0.43 for the DA and 0.37 for the NDA population. That is, the DA is more prone to use PT than NDA.

Traffic Assignment

Quantifying traffic assignments is required for completing the final step of the modeling and also for determining performance indicator results for user disutility levels. The assignments are calculated automatically by TRANUS.

Discussion on Findings

The purpose of this paper is to determine and compare travel behaviors of the DA and NDA. The research findings are significant enough and the model could have a considerable contribution in the policy-making process. The DA group's ratio to the whole population is 64%. In trip production, the most DA zones (DA ratio above 65%) are 2, 4, 6, 7 and 8 (Table 9). Policy makers of Aydin municipality need to address the accessibility and mobility problems of the DA in these zones. Yet, the parametric differences between the NDA and the DA groups are slim, as in the beta values of trip distribution. This is probably because of the inflexible data of regular trips that both the NDA and DA equally have to endure. There is also a significant difference between the modal choices. The PT mode is 43% for the DA and 18% for the NDA.

Detailed cell results in the mode split stage are examined at the final stage of this study. Values over the general rate of 0.65 are assumed as severe DA cells. There are five zones (2, 4, 6, 7, 8), which should be targeted as the policy zones. Such differential rates of the base year would be especially useful in the absence of data for future studies (Tables 9 and 10). Private mode preference among the DA is quite low (2%) while it is very high (98%) for public mode, that is to say they are highly dependent on public mode, where the public mode dependency of NDA is much lower (77%). If less mobility is perceived as a disadvantage, the trip rate should be heightened for the DA, or other compensatory solutions need to be developed.

Findings of the ratio analysis for PT and private trips to all trips are listed in Table 11. Shaded cells in the table represent DA trip distributions. Analyzing these results could be useful for planners in detecting weak PT links in these zones. Also, it could be helpful to take action in improving PT conditions, especially if people who reside in these zones are heavily transit dependent. Further, through simulations, this model can be used to test future transportation infrastructure investments (e.g., new roads, PT routes) aiming to minimize disadvantage. Intraurban performance indicators and trip numbers by mode for the DA are provided in comparison to the NDA population in Table 12. Modal shifts can also be monitored in the simulations as a sustainability indicator to detect whether there is any significant modal shift occurring toward more PT use.

By analyzing the results of the model, policy makers can quickly and easily identify how much improvement is needed for the DA, and where to deploy new policies. Where pockets of disadvantage exist, the demand responsive systems based on modest ITS technology can be utilized to improve transportation for the most severely DA (Hine and Grieco 2003). In the simulations, the measuring device simply is the performance in achievement to the values of NDA. The purpose, then, ultimately becomes making those DA reach up to the NDA, i.e., equalizing (process) the DA. By having the DA ratios/indicators, the analyst will be able to propose relevant remedies and polices to equate the DA to the NDA.

Sample Simulation

The model is run through several simulation scenarios to demonstrate its capability in scenario testing to improve the conditions of the DA. For example, one of the simulation scenarios focuses on the improvement of the PT services. The previous findings

Table 10. Mode Split Differences between Nondisadvantaged and Disadvantaged

Categories	Category ratio of public	Category ratio of private	Ratio to total population: Public	Private	All
Nondisadvantaged	0.77	0.23	0.28	0.08	0.36
Disadvantaged	0.98	0.02	0.62	0.014	0.63
Total population	0.90	0.10	1	1	1

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Table 11. Disadvantage Proportions for Private and Public Modes by Zones

Zones	1	2	3	4	5	6	7	8	9	10	11	12	Trip generation rate
(a) Disadvantaged rates for public trips													
1	—	*0.54*	**0.82**	*0.54*	**0.93**	*0.71*	*0.7*	*0.7*	**0.93**	**0.95**	**0.86**	0.24	*0.7*
2	**0.94**	—	**0.94**	**0.9**	**0.82**	*0.51*	*0.68*	**0.75**	**0.82**	**0.97**	**0.94**	**0.84**	**0.84**
3	*0.62*	**0.78**	—	**0.98**	0.09	0.09	**0.94**	0.17	*0.54*	0.17	0.3	*0.62*	*0.61*
4	*0.73*	**0.97**	*0.7*	—	*0.51*	**0.98**	*0.67*	*0.74*	*0.58*	**0.82**	**0.81**	**0.82**	**0.77**
5	**0.95**	**0.88**	0.15	*0.62*	—	*0.65*	**0.97**	*0.56*	0.48	0.15	*0.71*	*0.68*	*0.68*
6	**0.91**	0.15	**0.96**	**0.85**	*0.75*	—	**0.96**	*0.66*	0.42	**0.92**	**0.92**	**0.8**	**0.79**
7	*0.65*	0.11	*0.74*	**0.79**	*0.59*	**0.89**	—	*0.67*	**0.92**	*0.59*	**0.83**	**0.75**	**0.75**
8	**0.93**	*0.72*	*0.65*	*0.65*	**0.97**	**0.96**	**0.98**	—	**0.97**	**0.97**	**0.98**	**0.97**	**0.9**
9	*0.62*	**0.9**	0.45	0.29	*0.63*	*0.62*	**0.95**	*0.63*	—	**0.95**	0.18	*0.63*	*0.58*
10	*0.65*	0.2	0.25	0.28	*0.58*	0.4	0.11	*0.65*	0.11	—	0.36	*0.51*	0.34
11	*0.7*	**0.93**	0.05	*0.71*	*0.65*	0.1	0.25	**0.93**	**0.93**	**0.93**	—	*0.56*	*0.57*
12	**0.93**	**0.93**	0.15	*0.74*	*0.65*	**0.98**	0.15	*0.71*	0.48	**0.88**	*0.73*	—	*0.7*
Trip attraction rate	*0.72*	*0.59*	0.49	*0.61*	*0.6*	*0.57*	*0.61*	*0.6*	*0.6*	*0.69*	*0.63*	*0.62*	**8.22**
(b) Disadvantaged rates for private trips													
1	—	0.08	0.25	0.1	*0.52*	0.19	0.17	0.15	*0.52*	*0.62*	0.36	0.03	0.17
2	*0.55*	—	*0.56*	0.37	0.25	0.08	0.15	0.18	0.26	*0.72*	*0.54*	0.27	0.3
3	0.08	0.21	—	**0.78**	0.01	0.01	0.6	0.01	0.08	0.01	0.03	0.08	0.12
4	0.2	*0.69*	0.16	—	0.07	0.8	0.15	0.18	0.09	0.29	0.24	0.22	0.2
5	*0.63*	0.37	0.01	0.1	—	0.12	*0.74*	0.1	0.07	0.01	0.16	0.12	0.13
6	*0.5*	0.01	*0.65*	0.34	0.17	—	*0.64*	0.15	0.05	*0.5*	*0.5*	0.24	0.24
7	0.13	0.01	0.21	0.24	0.1	0.4	—	0.1	0.44	0.1	0.25	0.18	0.19
8	*0.57*	0.14	0.14	0.14	*0.68*	*0.63*	**0.75**	—	*0.74*	*0.7*	**0.77**	*0.7*	0.43
9	0.15	0.43	0.05	0.03	0.08	0.09	*0.59*	0.08	—	*0.6*	0.01	0.14	0.09
10	0.12	0.02	0.02	0.03	0.1	0.06	0.01	0.12	0.01	—	0.03	0.06	0.04
11	0.14	*0.53*	0	0.15	0.12	0.01	0.03	*0.53*	*0.53*	0.42	—	0.06	0.09
12	*0.53*	*0.53*	0.01	0.15	0.11	**0.76**	0.01	0.18	0.06	0.33	0.12	—	0.13
Trip attraction rate	0.3	0.25	0.17	0.2	0.19	0.26	0.32	0.15	0.24	0.36	0.25	0.18	**2.14**

Note: Italic numbers >50%; bold numbers >75%.

have shown that major reasons for the DA concentration in Zones 2, 6, 7, and 8 are mainly due to income and age (over 65). Therefore the simulation is run with a proposed new discounted paratransit service for the elderly, retired, and disabled.

The results of this simulation are illustrated in Fig. 3. First, the lines of the paratransit services are demarcated [Figs. 3(a and b)]. Second, existing passenger demands for PT are checked [Fig. 3(c)]. Finally, the passenger demand volumes of proposed service lines are a result of the new policy/scenario aimed at improving conditions for the DA [Fig. 3(d)].

Table 12. Intraurban Average Performance Indicators per Person

	Distance	Cost	Travel time	Waiting time	Disutility	Private trips
Disadvantaged	1.3	31.2	0.12	0.3	50.08	0.22
Nondisadvantaged	1.03	28.1	0.09	0.18	52.20	0.66
Ratio (%)	−26	−11	−33	−66	4	66
Sample simulation results	1.27	30.3	0.14	0.24	50.03	0.26

The simulation results are also double checked with basic performance measure indicators (i.e., cost, travel time, modal shift) by TRANUS' Reporting Program. These findings were then compared with the model findings as well as other simulation results. Furthermore, congestion levels of roads are also considered by using the Pareto principle in the simulations.

It is clear that the proposed lines would attract voluminous passenger demand, which probably involves greater portions of the DA. Consequently, the simulation results are found to be promising for improving the DA population's conditions.

Conclusions

This paper introduces a methodology based on statistical and GIS-based spatial analyses to evaluate the travel patterns and behaviors of the DA. The study seeks to integrate DA into a TPM. Thus, soundness of the approach rather than the precision of the demand estimations became the prime concern of the study. The model performs practically without any failure and the usefulness of the approach is tested in a pilot study. Contrary to the arguments in some of the literature, this research has demonstrated

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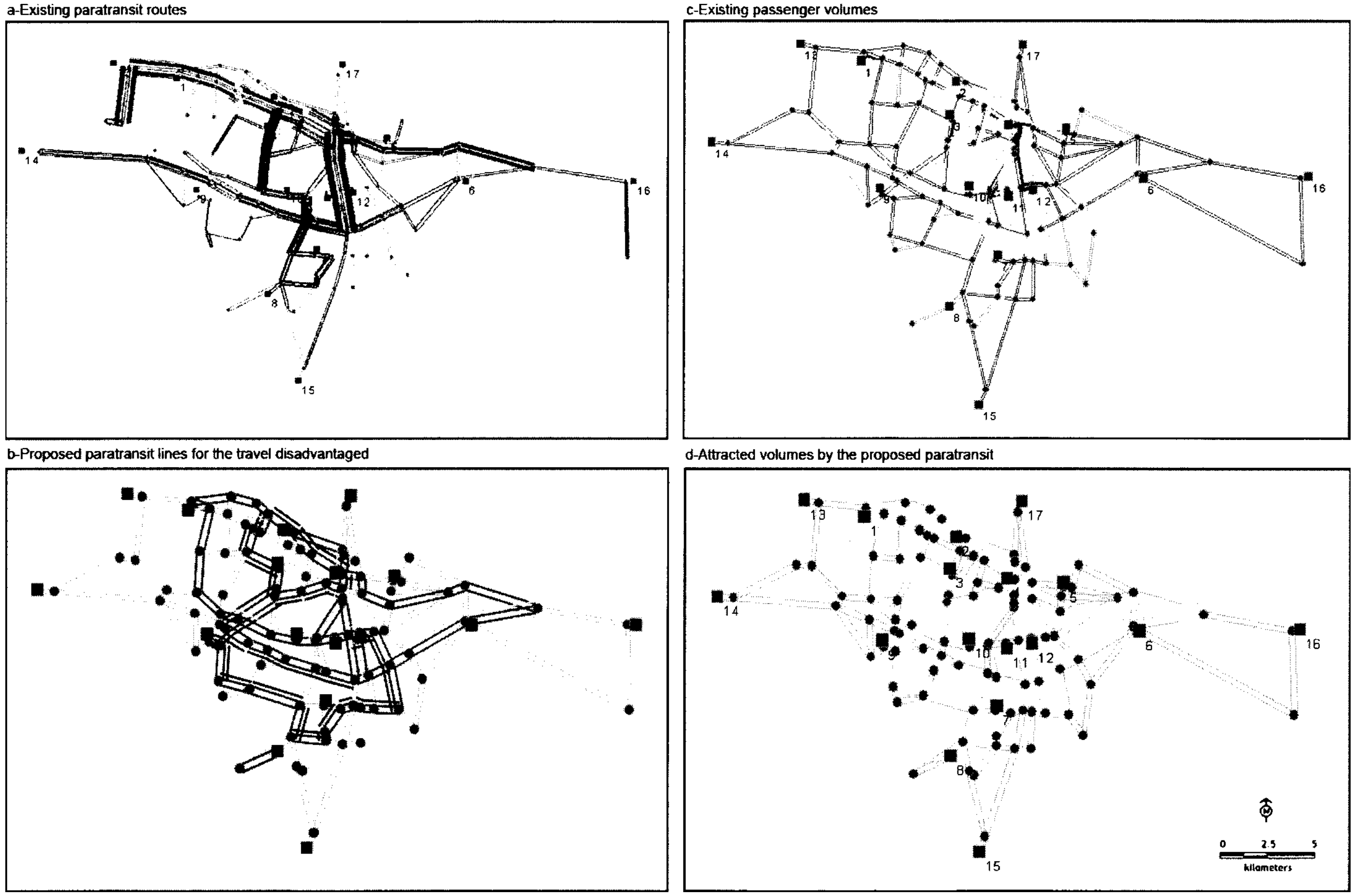

Fig. 3. Impact of paratransit service on ridership choices for disadvantaged

that it is possible to develop an integrated modeling approach sensitive to the DA.

The model developed in this study is capable of precisely determining the trips of the DA by multivariate modeling based on the knowledge derived from the differences between the DA and NDA. The pilot study revealed that travel patterns can be accurately determined through the steps of this model, the DA concentrations can be geographically determined, and the degrees and the types of disadvantages can be defined straightforwardly.

The model is particularly of use in the identification of: concentration and location of DA people; their travel patterns and characteristics; paths and links they choose; severity of their disadvantages; and their socioeconomic profiles. In this study, almost all these issues are addressed apart from the concerns of paths and links the DA chose, and the time dimension is out of the scope of the paper. Due to data limitations, measurability, and calibration of paths, links and the time dimension are the only significant problems of the model. Although defining policy variables through the cluster centers is one of the byproducts of the study, it is not in the scope of this paper.

The model is capable of determining the DA by using disadvantage categories. The pilot study has shown that the model is useful in determining spatial concentration of the DA and their travel patterns. The model also provides policy makers/planners with a metric gauge obtained from the differences between the model outputs of the DA and NDA to determine the travel disadvantage of people in various dimensions (i.e., spatial, temporal, magnitude). It also provides a yardstick to: measure the degree of disadvantage for various subcategories of disadvantage; integrate disadvantage-related parameters into the TPMs; and provide a knowledge base for social and spatial disadvantages. Therefore, the model can be utilized as a continuous monitoring medium of performance measures in policy making, which is the main distinction from other models in a sense that other approaches do not focus on the improvement of the conditions of the DA.

The study also produced captured policy variables and DA ratios for the concerned modeling stages that can be transferable to other similar ones. The same variables that are used for Aydin, or the calibration parameters such as beta value differences, can be used as proxies. But, it is best if the unique disadvantage characteristics of every case are examined and then selected as an input to the model, since no place has exactly the same nature. The case findings could also be affected by the availability and reliability of the data posed here, considering that data sample size is quite limited and the model R^2 values are between 0.5 and 0.8. More reliable and more accurate data would bring more significant and robust results, as the method is strictly bounded by higher data requirements. It also requires a more detailed HTS related to the DA and collecting such data is relatively hard. However in further studies a sensitivity analysis will be run in order to test if it is possible to minimize the number of HTS questions.

The pilot findings have shown that the DA produced fewer trips compared to the NDA, traveled a greater distance, and inclined heavily to use PT. However, the most important outcome of this study is being able to determine of the degrees of disadvantages for each zone (Duvarci and Gur 2003). It is also found that socioeconomic variables such as income and car ownership are the most significant ones in defining the pattern of transportation disadvantage. Therefore, for Aydin these variables needed to be considered for effective policy making in addressing the problems and improving the conditions of the DA.

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