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Trip generation rates and land use – transport planning in urban environment

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Abstract

In order to assess the land use policy implications, trip generation rates is essential knowledge for both planners and engineers working in the field of town planning and transportation. Within the framework of this paper trip generation rates are presented for the Thessaloniki Metropolitan Area (T.M.A). The structure of the land use system in T.M.A evidently produces many problems in the transportation system. The results of research activities of the Laboratory of Transportation Engineering of A.U.Th concerning the trip generation rates regarding different land uses (education, administration, banks, cultural, hotels industry, hospitals) in T.M.A are presented and discussed. These results are in the form of mathematical equations that have been derived with regression analysis and take into account data resulting from properly designed questionnaire surveys.

1 Introduction

The land use changes in urban and interurban areas affect, in most of the cases, the demand for trips. At a second stage, the new trips affect the transportation system and lead to the redesign of the transport infrastructure in order to satisfy the new demand. The improvement of the transport infrastructure positively affects the economic development of an area and thus, new land uses are attracted, which in turn increase the demand for new trips. Therefore, the integrated consideration of the two systems, land use and transport, and their interaction is essential for planners and engineers when studying the development of an area. The study of the interaction of these two systems includes [1] the use of the integrated land use-transport interaction models and the implementation of the historical-comparative analysis (before and after studies) for the examined areas. The need for such an integrated approach was pointed out in Greece in the framework of various research activities [2,3]. It must be mentioned at this point that "Trip generation models are often used to forecast future travel demands in specific regions, given population characteristics such as household size and composition, income, car ownership and some times residential descriptors, such as density and network connectivity of the zones where the household is situated" [4]. The effects on changes on travel behavior in individual and household characteristics are "assessed using the coefficients of regression models, or by cross-classification of households and individuals on a few variables like income, household size, number of workers, car ownership and license holding" [5].

Within the framework of this paper trip generation rates are presented for the Thessaloniki Metropolitan Area (T.M.A). T.M.A has reached a total population of about 1.000.000 inhabitants presenting a small increase during the last decade (1981-91). TMA has a size of almost 1,100 Km^2 and includes more than 30 municipalities and communities. The structure of the land use system in T.M.A evidently produces many problems in the transportation system. The results of research activities of the Laboratory of Transportation Engineering of A.U.Th concerning the trip generation rates regarding different land uses (education, administration, banks, cultural, hotels industry, hospitals) in T.M.A are presented and discussed. These results are in the form of mathematical equations which have derived with regression analysis and are taking into account data coming out from properly designed questionnaire surveys.

2 Examples of trip generation studies abroad

A study concerning the trip generation for mixed-use developments was conducted by the Colorado/Wyoming Section of ITE [6]. The study results showed that total daily trips generated by a mixed-use site can be accurately estimated using ITE rates as reported in Trip Generation Report [7] applied to individual uses within a mixed-use development. Mixed-use developments could reduce trip generation of individual uses within the development by 25%. In a study concerning fast food restaurants [8] in the city of Newark, Delaware, it was found that, on average, these facilities generate 769 trips daily per 1.000 square feet of gross floor area, including 110 trips per 1.000 square feet during peak hour operation. Based upon the available hotel-casino vehicle trip data of Las Vegas [9] it was found that the single-variant relationships of the form $T=C_1*X+C_2$ had the best correlations and the variable incorporating the average number of employees had the strongest correlation between the three independent variables evaluated (number of hotel rooms in the property, casino floor square footage, average number of employees). A study of six drive-in banks in the Phoenix, Arizona, Metropolitan Area [10], was conducted in order to identify trip-making characteristics of drive-in facilities. Considering the independent variable ATM, the average trip rate for weekdays was found equal to 1682 (range of rates: 652-2.775). Considering the independent variable lobby teller window the average trip rate for weekdays was found equal to 297 (range of rates: 241-347). From a study concerning the investigation into the number of spaces needed for a hotel taxi stand at a random cross section of 22 hotels in the Dallas and Houston areas [11], it was found that the average size of a taxicub stand for the hotels surveyed in Dallas was 1,17 spaces/100 rooms while the respective number in Houston was 0,88. The average for all hotels surveyed was about 1 space/100 rooms. From the results presented the importance of trip generation rates is emphasized.

3 Trip generation models developed for the Thessaloniki Metropolitan Area

In order to develop trip generation models for the land use system in the Thessaloniki Metropolitan Area, an extensive research has been made during the last two decades from the Laboratory of Transportation Engineering of Aristotle University of Thessaloniki. The data collection concerning the trip characteristics in each land use of the study area, was based on specially designed questionnaires. In the following paragraphs the models developed for each land use were presented.

3.1 Models concerning Education

The research [12] consisted of a questionnaire survey including a sample of 10% of the total number of employees in primary and secondary schools in T.M.A. Regarding the University, the survey included the 1% of the students, the 8% of the academic staff and the 10% of the administration staff. In the following Table 1 the trip distribution per mode to and from education land uses is presented.

Table 1: Trip distribution per mode to and from educational land uses (including employees and visitors)

Mode	Possession of p.c	p.c[1]	P.T[2]	Taxi	2 wheel cycles	On foot trips
Primary schools trips	58,5%	28,2%	12,4%	0,9%	1%	57,5%
Secondary schools trips	52,9%	30,7%	27,2%	1,8%	0,9%	39,4%
University students	12,4%	9,3%	58,2%	1,1%	2,9%	28,5%
University admin. staff	39,8%	53,2%	28,1%	4,6%	1,8%	12,3%
Acad. staff	77,7%	51%	19,2%	6%	2,2%	21,6%

[1]p.c: passenger car, [2]P.T : Public Transport

The number of trips to and from schools is constant and equal to two (2), thus there was no need to develop models. For the trips concerning the University, the

independent variable (X) which was finally taken into account was the number of the people making these trips, and the model derived using regression analysis is the following (9 University faculties were examined, including 615 students, 83 people from the administration staff and 201 from the academic staff):
$Y = -10{,}148 + 2{,}306*X$ (where $R^2 = 0{,}976$, $t=19{,}133>4{,}781$)
Y = number of daily trips to/from the University (all categories of people)
X = number of people (students, administration staff, academic staff)

3.2 Models concerning Administration

The research [13] consisted of a questionnaire survey including employees and visitors in the Administration in T.M.A using the following categorization: 11 Municipalities, 16 Tax offices, 7 Public Organizations and 8 Departments of Ministries. In the following Table 2 the trip distribution per mode to and from the Administration concerning employees and visitors is presented.

Table 2: Trip distribution per mode to and from Administration (including employees and visitors)

Mode	p.c[1]	P.T[2]	Taxi	Official vehicle	2 wheel cycles	On foot trips
Municipalities	55,3%	9,8%	0,9%	0,9%	6%	27,1%
Tax offices	24,4%	48,3%	3,8%	-	1,7%	21,8%
Public Organ.	39,1%	42,6%	0,4%	-	1,7%	16,2%
Ministries	55,6%	23%	1,2%	1,6%	1,1%	17,5%

[1]p.c: passenger car, [2]P.T : Public Transport

The models derived for the Municipalities are the following (1.225 employees and 1.495 visitors took part in the survey):
$Y = 3{,}568*X - 32{,}721$ (where $R^2 = 0{,}986$)
Y = number of daily trips of employees to/from Municipalities
X = number of employees in the Municipalities

$Y = 0{,}892*X + 33{,}512$ (where $R^2 = 0{,}92$)
Y = number of daily trips of visitors to and from the Municipalities
X = number of employees in the Municipalities

$Y = 4{,}46*X + 0{,}791$ (where $R^2 = 0{,}989$)
Y = number of daily trips of employees and visitors to/from the Municipalities
X = number of employees in the Municipalities

The model derived for tax offices is the following (838 employees took part in the survey):
$Y = 2{,}412*X - 3{,}24$ (where $R^2 = 0{,}79$)
Y = number of daily trips of employees to and from the tax offices
X = number of employees in the tax offices

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The model derived for Public Organizations is the following (676 employees took part in the survey):
$Y = 2{,}13*X + 26{,}167$ (where $R^2 = 0{,}911$)
Y = number of daily trips of employees to and from the Public Organizations
X = number of employees in the Public Organizations

The model derived for the Departments of Ministries is the following (1235 employees took part in the survey):
$Y = 2{,}239*X + 18{,}601$ (where $R^2 = 0{,}966$)
Y = number of daily trips of employees to and from the Public Organizations
X = number of employees in the Public Organizations

The model derived for all Administration land uses is the following (3974 employees took part in the survey):
$Y = 2{,}739*X - 7{,}68$ (where $R^2 = 0{,}916$)
Y = number of daily trips of employees to and from the Administration
X = number of employees in the Administration

3.3 Models concerning Banks

The research [14] consisted of a questionnaire survey including employees and visitors in the Banks of T.M.A using the following categorization: 20 Banks in the city center and 47 outside of it. In Table 3 the trip distribution per mode to/from the Banks concerning employees and visitors is presented.

Table 3: Trip distribution per mode to/from Banks (employees and visitors)

Mode	p.c[1]	P.T[2]	Taxi	2 wheel cycles	On foot trips
Banks in the city center					
Employees	26%	41%	9%	7%	17%
Visitors	26%	13%	1%	17%	43%
Banks outside the city center					
Employees	59%	22%	2%	2%	15%
Visitors	33%	11%	0%	12%	44%

[1]p.c: passenger car, [2]P.T : Public Transport

For the trips concerning Banks, two independent variables were examined: the floor space and the number of employees. The models derived are the following :
$Y = 10{,}447 + 0{,}0878*X$ (where $R^2 = 0{,}7098$)
Y = number of daily trips of employees to/from the Banks in the city center
X = Floor space of Banks, (620 employees took part in the survey)

$Y = 18{,}4774 + 0{,}04319*X$ (where $R^2 = 0{,}4194$)
Y = number of daily trips of employees to/from the Banks outside the city center
X = Floor space of Banks, (1410 employees took part in the survey)

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$Y = 10{,}139 + 0{,}0817*X$ (where $R^2 = 0{,}6218$)
Y = number of daily trips of employees to and from the Banks (all Banks)
X = Floor space of Banks, (2030 employees took part in the survey),

$Y = 4{,}0183 + 2{,}0696*X$ (where $R^2 = 0{,}9987$)
Y = number of daily trips of employees to/from the Banks in the city center
X = Number of employees in the Banks, (620 employees took part in the survey)

$Y = 0{,}2001 + 2{,}3588*X$ (where $R^2 = 0{,}9782$)
Y = number of daily trips of employees to/from the Banks outside the city center
X = Number of employees in the Banks, (1410 took part in the survey)

$Y = 3{,}2892 + 2{,}1062*X$ (where $R^2 = 0{,}9937$)
Y = number of daily trips of employees to and from the Banks (all Banks)
X = Number of employees in the Banks, (2030 took part in the survey)

3.4 Models concerning cultural land uses

The research [15] consisted of a questionnaire survey including employees and visitors in the cultural land uses found in T.M.A. The following categorization was used: 4 museums, 3 theaters, 3 exposition centers, 3 conference centers, 7 cultural centers. In the following Table 4 the trip distribution per mode to and from the cultural land uses concerning employees and visitors is presented.

Table 4: Trip distribution/mode to/from cultural land uses (employees & visitors)

Mode	p.c[1]	P.T[2]	Tourist bus	Taxi	2 wheel cycles	On foot trips
Employees	62%	23%	-	4%	4%	7%
Visitors	52%	14%	21%	5%	4%	4%
All	59%	18%	13%	4%	2%	4%

[1]p.c: passenger car, [2]P.T : Public Transport

The independent variable examined is the number of employees. No relation was found for conference centers. The models derived per land use category are:
$Y = 1{,}3419*X + 70{,}143$ (where $R^2 = 0{,}9171$)
Y = number of daily trips of employees and visitors to and from the museums
X = number of employees in the museums, (133 employees, 98 visitors)

$Y = 2{,}0425*X + 38{,}626$ (where $R^2 = 0{,}99$)
Y = number of daily trips of employees and visitors to and from the theaters
X = number of employees in the theaters, (144 employees, 59 visitors)

$Y = -8{,}7308*X + 135{,}54$ (where $R^2 = 0{,}9999$)
Y = number of daily trips of employees and visitors to/from exposition centers
X = number of employees in the exposition centers, (20 employees, 92 visitors)

$Y = 3,4879*X + 41,392$ (where $R^2 = 0,6811$)
Y = number of daily trips of employees and visitors to/from the cultural centers
X = number of employees in the cultural centers, (226 employees, 198 visitors)

$Y = 1,9903*X + 62,458$ (where $R^2 = 0,762$)
Y = number of daily trips of employees and visitors to/from all cultural land uses
X = number of employees in all cultural land uses, (533 employees, 544 visitors)

3.5 Models concerning Hotels

The research [16] consisted of a questionnaire survey including employees and visitors in 15 out of 17 hotels of T.M.A. The following categorization was used: luxury, first class, second class, third class hotels. The trip distribution per mode to and from the hotels is in the area of 40% for passenger cars, in the area of 29% for taxis and in the area of 31% for public transport. The independent variables which were examined are: number of beds, number of employees, number of visitors, floor space. The models derived are (687 employees and 1032 visitors took part in the survey, the occupied beds were 2235):
$Y = 155,77693 + 7,30503*X$ (where $R^2 = 0,92556$, $t = 8,46862$)
Y = number of daily trips of the employees and visitors to and from the hotels
X = Number of occupied beds in the hotels

$Y=215,658+3,6531*X_1 + 6,6907*X_2$ (where $R^2=0,9915$, $t_1=0,98789$, $t_2=4,21842$)
Y = number of daily trips of the employees to and from the hotels
X_1 = Number of occupied beds in the hotels
X_2 = Number of visitors per days

The model derived using multiple regression analysis [17] is the following:
$Y = 292,178 + 4,4636*X_e + 3,0702*X_b$ ($R^2 = 0,9989$)
Y = number of daily trips of the employees to and from the hotels
X_e = number of employees, X_b = number of occupied beds in the hotels
Max. and min. values of independent variable: $80<X_b<823$, $7<X_e<150$

3.6 Models concerning Industry

The research [18] consisted of a questionnaire survey including employees and visitors of 33 industries in the area of Thermi, T.M.A. The following categorization was used for the needs of the survey: 14 textile industries, 6 chemical industries, 3 mechanical industries, 4 furniture industries, 6 other. The trip distribution per mode to and from the various industries is in the area of 19% for passenger cars, in the area of 21% for public transport and in the area of 60% for company buses. The independent variables examined are the floor space and the number of employees. The models derived are per industry category:
$Y = 0,061*X - 100,467$ (where $R^2 = 0,94$)
Y = number of daily trips of the employees to and from the textile industry
X = Floor space of textile industry, (1117 employees took part in the survey)

$Y = 0{,}026{*}X + 18$ (where $R^2 = 0{,}96$)
Y = number of daily trips of the employees to and from the chemical industry
X = Floor space of chemical industry, (376 employees took part in the survey)

$Y = 0{,}006{*}X + 36$ (where $R^2 = 0{,}65$)
Y = number of daily trips of the employees to and from the mechanical industry
X = Floor space of mechanical industry, (61 employees took part in the survey)

$Y = 0{,}025{*}X + 20$ (where $R^2 = 0{,}95$)
Y = number of daily trips of the employees to and from the furniture industry
X = Floor space of furniture industry, (201 employees took part in the survey)

$Y = 0{,}027{*}X - 0{,}653$ (where $R^2 = 0{,}85$)
Y = number of daily trips of the employees to and from other industry categories
X = Floor space of other categories (202 employees took part in the survey)

$Y = 0{,}039{*}X - 24{,}768$ (where $R^2 = 0{,}86$)
Y = number of daily trips of the employees to/from industry (all categories)
X = floor space of all industries (1957 employees took part in the survey)

The model derived using multiple regression analysis [17] is the following:
$Y = 3{,}0447 + 1{,}9451{*}X_e + 0{,}0046{*}X_f$ ($R^2 = 0{,}9989$)
Y = number of daily trips of the employees to/from industry (all categories)
Xe = number of employees, Xf = floor space
Maximum-minimum values of independent variable: $500\ m^2 < Xf < 16.000\ m^2$

3.7 Models concerning Hospitals

The research [17] includes a representative sample of hospitals in the Metropolitan Areas of Athens and Thessaloniki. For the trips concerning hospitals, the independent variables which were examined are: number of beds, number of employees, floorspace. The models derived are the following :
$Y = -379{,}897 + 4{,}2747\ X_e - 0{,}008\ X_f + 4{,}3915\ X_b$ ($R^2 = 0.9947$)
Y = number of trips of the employees to and from the hospitals
X_e = number of employees, X_f = floor space, X_b = number of beds
Maximum and minimum values of independent variables:
$75 < X_b < 500$
$2050\ m^2 < X_a < 41150\ m^2$

$Y = -576{,}28 + 10{,}73{*}X_b$
Y = number of trips of the employees to and from the hospitals
X_b = number of beds

The comparison of trip generation rates in Greece with those in the U.S.A is presented in the following Table 5.

Table 5: Comparison of trip generation rates between Greece and U.S.A.

Independent variable	Trip generation rates							
	Average trip rate*		Maximum rate		Minimum rate		Average size of independent variable	
	GR	USA	GR	USA	GR	USA	GR	USA
Hospitals								
Employee	6,34	5,50	7,87	11,10	5,3	2,17	505	829
1000 sq.feet	21,37	16,91	37,0	-	9,9	-	150	322
Bed	9,11	12,16	10,65	32,83	4,5	3,00	351	375
Industries								
Employee	2,30	3,00	4,00	15,7	2,09	1,4	60	96
1000 sq.feet	3,27	5,43	5,85	52,0	0,80	0,5	42	98
Hotels								
Employee	26,87	11,3	76,20	17,2	16,0	7,2	45	181
Bed	4,80	-	9,15	-	3,18	-	260	-
Administration								
Employee	5,51	-	9,80	-	2,20	-	203	-

*daily person trips for Greece and daily vehicle trips for U.S.A.
Source: [17]

4 Conclusions

Concerning Education, the number of trips to and from primary and secondary schools is inelastic (equal to two). For trips to/from the University, two independent variables were examined (number of trip makers, floor space) but only the first one was finally proved important. For trips concerning the Administration activities, no relation was found with the floor space. For the trips concerning Banks, two independent variables were examined: the floor space and the number of employees. The separate examination of banks within the city center and outside of it help to obtain a more clear image of these trips. Considering cultural activities, no relation was found for conference centers as it was expected. It is important here to mention the high percentage of tourist buses (21%) for trips made by the visitors.

For hotels the independent variables examined included the number of beds, number of employees, number of visitors and floor space. It must be noted here that the high percentage of the use of taxis (29%). Concerning industry, the independent variables which were examined are the floor space and the number of employees. Finally, the independent variables which were examined for hospitals are the number of beds, number of employees and the floor space. The production of such models for more land uses will provide planners and engineers in the country with a useful tool to assess the traffic impact from land use changes in an urban area.

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