MODELLING JOINT DEVELOPMENT OF LAND USE AND LIGHT RAIL TRANSIT STATIONS: THE CASE OF TEL AVIV

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Avigail Ferdman, Faculty of Architecture and town Planning, Technion - Israel Institute of Technology Haifa, Israel
avigaili@tx.technion.ac.il

Dani Shefer, Center for Urban and Regional Studies, Technion - Israel Institute of Technology, Haifa, Israel
shefer@tx.technion.ac.il

Shlomo Bekhor, Transportation Research Institute, Technion - Israel Institute of Technology, Haifa, Israel
sbekhor@tx.technion.ac.il

Abstract

This paper presents findings from a study conducted on LRT surroundings in Tel Aviv, in which land use attributes were explicitly calibrated in travel rates models and forecasts. These land use variables were then tested on several land use development policies, in terms of population density and employment distribution. This simulation of various land use policies on the same site enhances the understanding of the land use–transportation interaction.

The current findings strongly suggest that the zone's density and diversity of land uses can play a major role in determining its trip generation patterns. Factors such as population density, job density, the proximity of one's residence to the workplace and dependency ratio all have the ability to influence daily trip generation trend.

The contributions of the two suggested processes – a combination of model calibration and land use simulations - is a proposed applicable trip generation model, which includes land use variables, and an insight into land patterns and policies which have the greatest influence on daily metropolitan trips.

Keywords: density, transportation modelling, trip generation, land-use mix

Introduction

Growing concerns regarding urban car pollution, congestion and community liveability have been urging planners and decision makers to seek for a sound alternative for the private automobile. Light Rail Transit (LRT) has been gaining popularity as a means of reducing the on going trends of automobile dependency in cities. Currently there are about one hundred LRT systems around the world, mainly in Europe and the USA, and two systems are presently being developed in Israel's major cities – Jerusalem and Tel Aviv.

LRT is also perceived as an important generator of economic growth, mainly in old urban centres. By improving the accessibility to CBDs (Central Business Districts), planners and decision makers expect to revitalize the function of central cities' cores and maintain their importance, especially as CBDs face the increasing competition of growing suburban centres.

Transportation and urban land use are joint up in a complex relationship, each influencing and being influenced by its counterpart. Transportation influences land use by improving accessibility to urban functions, and the built environment affects travel through locations and densities. Thus it is important to explore these dynamics in order to understand the effects that land use has on daily travel, especially around an LRT station.

The main claim of this paper is that land use conditions are accounted for at least some of the daily travel in the metropolis. Current practice in transportation demand modelling puts a lot of weight on socio-economic factors as explanatory variables of daily travel rates. Land use conditions, however, are less employed in such models. Considering that LRT ridership could be influenced by land use conditions, an in-depth investigation into its impacts is warranted.

This paper presents findings from a study conducted on LRT surroundings in Tel Aviv, in which land use attributes were explicitly calibrated in travel rates models and forecasts. These land use variables were then tested on several land use development policies, in terms of population density and employment distribution. This simulation of various land use policies on the same site enhances the understanding of the land use–transportation interaction. First, it enables the evaluation of the marginal influences of density or diversity, which are explicitly modeled in the trip generation models. second, these

effects can be analyzed on a variety of land use policies, which together present a clearer picture of the land use transportation cycle.

The first part of this paper will present current literature dealing with land use influences on urban travel trends. The general dynamics of land use and travel trends are discussed followed by a review of land use factors – such as density and diversity and their impact on travel behaviour. Next follows a brief overview of land use components engaged in transportation modelling, especially trip generation trends. The methodology employed for the study describes the trip generation models calibrated, including the land use variables and their coefficients. The second part of the methodology presents the land use policy scenarios for the LRT surroundings.

Results of the calibration process and comparison of the land use policies is presented next, followed by a discussion of some key findings regarding specific land use factors which seem especially influential in determining trip trends. Finally the implications of these findings on LRT ridership are discussed.

Land use and trip trends – Literature Review

Land Use and Trip Trends

There are numerous theoretical and empirical studies strongly suggesting that certain land use characteristics may promote sustainable growth by reducing the private automobile ridership. The theoretical studies contend that transportation improvements enhance the number of interactions between places, but allow for activities to exploit these improvements by distancing themselves from the centre (Giuliano, 1995). Public transit cannot provide an efficient service in a sprawled environment, since it relies on scale economies. To counter and withhold the uncontrolled sprawl of activities and so promote the use of transit, residential and employment densities, alongside a good public transport infrastructure and large agglomeration size will increase transit's modal share (Wegener & Fürst, 1999). Regarding trip frequencies, however, Wegener & Fürst, based on Zahavi (1974, in Wegener & Fürst, 1999), state that these will not be affected by land use characteristics, since they are submitted to fixed time or budget constraints. People maximize their activities or opportunities in response to their time or budget limit, such

as choosing a location farther away from their employment location, and will not necessarily increase their trip production rates.

Pushkarev & Zupan (1977) were the first to report on urban level residential densities and their power to reduce auto ownership and use and positively influence transit demand. Other researchers have demonstrated similar trends (Kenworthy & Laube 1999,a,b; Cervero, 2001; Parsons Brinckerhoff Quade and Douglas 1996). At the micro level, mostly the neighbourhood level, results are somewhat more varied. Cervero and Kockelman (1997) concluded that density and diversity play a significant albeit marginal role in determining trip rates. Other studies had found that residential proximity to a transit station will attract more riders to the station (JHK and Associates, 1987; Cervero et al, 1993, Stringham, 1982 in Parsons Brinckerhoff Quade & Douglas et al, 1995).

Critics of land use attributes ability to affect travel and travel in particular state that and use does not generate significant results in demand forecasts, and that the most influential factors, still, are the socio-demographic ones (Asensio, 2002), or policy factors, such as parking pricing (Hess, 2001; Parsons Brinckerhoff Quade and Douglas, 1996). High residential density, for example, will have very little effect on auto travel lengths if cost measures are not included (Wegener & Fürst, 1999). Others state that even though the connection is existent, it is vague and not clear enough (Gordon & Richardson, 1997; Breheny, 1992; Schimek, 1996 in Rodier *et al*, 2002).

Density

One of the main aims of this study is to investigate the effect land use densities have on daily trip production. Since employment and residential densities seem to affect travel patterns differently, it is useful to distinguish between them.

Employment densities

Cervero and Ewing (2001) argue that employment densities at the work site should be paid more attention than they currently are, both in the literature and in actual planning process. Although the spatial distribution of employment and other out-of-home activities may be the main determinant of travel trends, the focus is mostly cast on residential densities. Practically speaking, employment densities could be much easier to pursue

(Badoe and Miller, 2000), mainly since non-residential developments may face less resentment when developed in high densities (Chatman, 2003). Other opinions state that density's influence on trips to the CBD might be a cause of its central location and public transport service quality (Handy, 1996 in Ewing & Cervero, 2001), or even the disutilities of the private automobile in dense areas, such as congestion and limited parking supply (Steiner, 1994; Miller & Ibrahim, 1998 in Ewing & Cervero, 2001). In any case, CBDs have the highest transits modal split among all metropolitan sub-areas, and the propensity to walk to/from a CBD station is 5 times higher than in other places (Parsons Brinckerhoff Quade and Douglas, 1996). Job concentrations around commuter rail stations in the suburbs also enhance transit use, walking and ridesharing (Cervero, 1989, Frank & Pivo, 1994, Parsons Brinkerhoff Quade and Douglas 1996a, Schimek, 1995 in Badoe & Miller, 2000).

Residential densities

Proponents of TOD (Transit Oriented Development) often argue for higher residential densities adjacent transit stations. Empirical evidence shows that people living in denser areas use transit more frequently, sometimes up to 5-7 times more (Cervero, 1993a in Parsons Brinckerhoff Quade and Douglas, 1996). People are more inclined to walk in denser neighbourhoods (Pushkarev & Zupan, 1977; Newman & Kenworthy, 1989 in Steiner, 1994), and generate shorter trips all in all (Goodwin, 1975; Holtzclaw, 1990; Holtzclaw, 1994 in Steiner, 1994). These studies also found that in more dispersed areas the auto ownership is higher, thus increasing the probability of auto ridership. Light rail is considered to be particularly affected by residential densities near its stations, more so than commuter rail transit. Residential density's biggest impact on LRT boardings occurs when low densities, such as 1 dwelling unit per dunam[1], are increased to medium densities – 2.5-4 dwelling units per dunam. Higher densities than 30 persons per ha will be capable of attracting more riders, but at a diminishing returns (Bernick & Cervero, 1997).

[1] 1 dunam = 0.2471054 acre

None the less, the ability to actually divert automobile riders to transit will depend upon other complementary factors, such as the metropolitan size, station spacing, CBD job densities, parking supply and the physical and functional surroundings of the station, encompassed in land uses diversity and design.

Diversity

The main advantage of a mixed use area, in transportation terms, lies in the proximity of the activities, which shortens traveling distances between them. Especially in suburban commercial areas, the proximity to restaurants, shops and other services may encourage ride-sharing, since the need for an available car during the day lessens (Cervero, 1996).

Many studies report the effects density measures have on urban travel demand. The effects of diversity and design, however, have not been receiving the same attention as density studies (Cervero & Kockelman, 1997). Empirical studies suggest that mixed uses decrease single occupant vehicle utilization, but results are far from uniform. Moreover, it is not clear whether land use mix has the same effect on shopping trips, work trips and other trips (education, errands, etc.) (Cervero, 1996).

Mixed uses' low estimated effects on travel may be due to difficulties in quantifying these effects. Since dense areas tend to some degree of mix, separating mixed uses' impacts form those of the density's are quite difficult. Furthermore, these two land use attributes are not measured on the same scale – density is metric, while mixed uses are often based on nominal or ordinal scales. Up do date there is still insufficient knowledge as to how to quantify and measure multifunctional mixed uses (Shefer, 2002).

In the present paper, we investigate the simultaneous use of population and job density variables alongside mixed-use variables around proposed LRT stations in Tel Aviv

Land Use Variables and Trip Generation Modelling

One of the most prevalent methods for evaluating land-use's impact on travel trends is employing a transportation forecasting model. The supply side is generally represented by the highway and transit networks. The demand side is a series of mathematical models, from which the most common is the "four-step" model, designed to estimate trip generation; trip distribution; mode choice and trip assignment. In most models, trip

generation is treated as inelastic (is not influenced by the results of the modal split or assignment stages). Essentially, this means that they are not affected by the level of service provided by the transportation system, which is determined by the trip assignment output – trip lengths and time. Taking into account that essentially demand for travel is derived, i.e. it is subject to peoples' needs and preferences (Ortuzar & Willumsen, 1990), which, this study contends, might be strongly influenced by the land use patterns. Therefore, it is vital that land use influence will be modeled.

The land use-transportation interaction is very often investigated in the context of the four step model, especially on the modal split stage, since the majority of empirical studies are concerned with this process. Less frequent are studies which focus on the first stage of the four step model – the trip production/attraction estimation. The reason that most of the literature in the field focuses on modal split is that trip frequencies are thought to be influenced primarily by socio-demographics, and only secondarily on the built environment.

Most of the studies that do investigate trip frequencies do so in neighbourhood type comparisons (i.e. traditional vs. contemporary, auto vs. pedestrian oriented, urban vs. suburban). According to Ewing & Cervero (2001), out of 28 studies on land use patterns and their influence on travel patterns, only 3 have used trip frequencies as explained variables. Ewing *et al* (1996 in Ewing & Cervero, 2001) had found no significant relationship between total trip frequencies and land use, Dunphy and Fisher (1996 in Ewing & Cervero, 2001) had found that vehicle trips are less frequent at higher densities, and Kasturi *et al* (1998 in Ewing & Cervero, 2001) had found that total trip frequency is higher in areas of high job accessibility. Ewing & Cervero therefore conclude that travel demand is inelastic in respect to accessibility, and overall trip frequencies differ little, if at all, between built environments. Wegener & Fürst (1999) also maintain that trip frequencies are subject to fixed time and budget constraints. Trip lengths and mode choice, however, are expected to be influenced by land use patterns.

Trip production rates, measured at the household level, according to Wegener & Fürst, are not expected to be affected by land use changes. Aviram (2001), for example, had found that the income elasticity in respect to transport in 1995 in Israel is higher than 1, meaning that the expenditure on transport increases in a rate higher than that of an

increase in income. A transportation improvement, which reduces transport costs, simultaneously increases the household's disposable income, therefore raising the expenditure on transportation. Some of this expenditure could be manifested in a raise of the total number of trips produced. A major land use change could bring about, via improved accessibility, a reduction of the transportation cost, thus potentially altering the total trip rates generated.

Based on the theoretical and empirical literature regarding land use influence on travel demand, three hypotheses were investigated: Mixed land use reduces motorized trips production and attraction; Dense land use attracts less motorized trips; Dense land use produces less motorized trips.

The first hypothesis follows other studies by assuming that the proximity of activities in a mixed land uses shortens distances between them, thus reducing the need for motorized trips while enhancing non motorized modes, mainly walking and cycling.

The second hypothesis regards to agglomeration effects: the denser the environment, the better it can be served by transit and non-motorized modes. The total trips in question are exclusively motorized, with no regard to the internal modal split (no distinction has been made between auto or transit travel).

The third hypothesis contradicts Wegener & Fürst's (1999) claim regarding trip frequencies – namely, that trip production rates will not be affected by the land use conditions, since they are most exclusively influenced by the household characteristics – budget and time limits. Another way to put this hypothesis is that an intensification of land uses entails new prospects (or disadvantages) that would change a household's preferences, and consequently its budget and time limits.

Methodology

Transportation Models Calibration

The first part of the research methodology includes an analysis of land use attributes in trip generation models in Metropolitan Tel Aviv. A previous transportation study was conducted in the Tel Aviv Metro Area to forecast LRT ridership (NTA, 2001). The trip generation models in that study were calibrated based on socio-economic characteristics only. In order to investigate whether land use attributes indeed influence trip rates, land

use variables were added to these transportation models. The additional land use attributes include job density, population density, job-population balance, service employment density, intra-zonal workforce ratio and a dummy variable for mixed land use. The trip rates are measured as daily trips created by a household or induced by workplaces. In total, 9 sub-models were estimated, 4 for the trip production process – for estimating trips based at home with commuting, education and other trip purposes, and non-home-base trips, and 5 sub-models for the trip attraction process, for estimating the purposes mentioned above and also shopping trips.

The data which both the original and the recalibrated models use, was taken from the 1996 national travel habit survey (for travel data), and the 1995 census (for zonal characteristics) (CBS, 1998; 1999). 702 statistical zones were analyzed, containing all in all a population of 2,282,465, a workforce of 1,007,570 (employees who reside in metropolitan Tel Aviv), and 1,107,567 jobs. Of the travel habit survey 18,823 records of household daily trip rates were used. The technique used for parameter calibration is based on MCA – multiple classification analysis (Andrews *et al*, 1973). The land use variables coefficients of the trip production stage are presented in table 3.1.

The technique employed for trip attraction estimation was multiple regression equations. Table 3.2 presents all two types of models investigated – models with no explicit land use variables and models with land use variables.

Land Use Scenarios – Density and Diversity

The second step was to compare various land use policies applied on the same area or site. Four different land use scenarios, in terms of density and diversity were constructed, and compared to previous land use forecasts. The scenarios modified population, households, jobs and workforce density features. With the intention of examining solely the influence land uses have on LRT station areas, only the TAZs (traffic analysis zones) surrounding a proposed LRT line were chosen[2]. This LRT line will pass through the metropolitan CBD of Tel Aviv and will consist of 33 stations. The zones around the line were divided into three groups: CBD stations, inner stations and outer stations.

[2] These TAZs are included in a 500m radius buffer, a distance recommended in the literature as an average walking distance to a station (Untermann, 1984; O'Sullivan & Morrall, 1996).

Table 3.1 - Trip production added land use coefficients model results[3][4][5]

land use variable	home-base-work		home-base-education		home-base-other		non-home-base	
Intra-zonal workforce	1.5	F - 117922	0.52	F - 28597	0.6	F - 8571	0.6	F - 14036
Job density	-0.01	F - 5288						
Workforce density	-0.004	F - 688						
Total household density	-0.2	F - 126114						
Job-population balance							0.04	F - 1421
Dependency ratio					1.5	F - 10063		
No. Of observations	16302		18486		18114		18111	
R square	0.47		0.2		0.15		0.13	

Table 3.2 – trip attraction land use coefficients

trip purpose	coefficient				R^2
	land use		other		
	service employees density	19.61			
	t value	*2.27*			
			employees in education	4.05	
home-base-education			*t value*	*28.04*	0.85
	log of job density per km²	332.97			
	t value	*4.97*			
			commerce employees	0.94	
home-base-shopping			*t value*	*5.92*	0.55
	mixed use (dummy)	2558.3			
	t value	*2.72*			
	dependency ratio	3985.9			
	t value	*2.44*			
			service employees	0.92	
			t value	*9.27*	
			total households	0.67	
home-base-other			*t value*	*5.25*	0.85
	mixed use (dummy)	4329.8			
	t value	*7.48*			
	dependency ratio	1222.6			
	t value	*2.20*			
			service employees	0.55	
			t value	*7.33*	
			commerce employees	1.27	
non-home-base			*t value*	*5.06*	0.87
			total employees	1.46	
home-base-work			*t value*	*37.39*	0.9

[3] The variables presented here represent the additional land use variables. Socio-economic variables are not presented. These variables coefficients yielded very similar results to models containing only socio-economic characteristics.

[4] The F statistic is more suitable for an MCA technique, since the coefficients are an average of the sub-group.

5 Note that the R^2 value of the trip production models is low. This outcome was somewhat expected, given that the recalibrated sub-models were not expected to alter the MCA original results significantly due to the high level of disaggregation. The categorical disaggregated method, however, provides a household level analysis, better suited for a trip production investigation.

Two types of scenarios were created, varied in their population and job densities and in their degree of mix. Three scenarios represent different rates of population and job densities, varied in the location of the dense TAZs, and one mixed use scenario, to simulate a diverse space around the LRT stations. The dense scenarios all increase the commercial densities in the CBD (the areas surrounding the most central stations of the proposed line) to 20 jobs/dunam, and the service and commercial employment ratio to 0.25 and 0.2 (accordingly) of the CBD employees. As for the non-CBD stations, the population densities were increased in the inner and outer stations of the line: scenario 1 increases population densities to medium (15 people/dunam) in the inner stations, and high (25 people/dunam) in the outer stations, scenario 2 increases population densities to high in the inner stations and medium in the outer stations, and scenario 3 increases both the inner and outer station areas' to high density. The high density values represent the high category values of the entire metropolitan Tel Aviv area, so as to stick to regional characteristics as much as possible.

Since household characteristics are thought to be the most influential attributes of trip production, the dependency ratio (the ratio between employed and total population in a zone) in these scenarios was increased to 0.55 in the CBD and 0.5 in the non CBD areas (compared to a regional 0.46 in the original forecast), in anticipation of these areas hosting such households or individuals whose participation in the workforce will be high, especially in the CBD.

In the mixed use scenario approximately half of the TAZs were designated as having mixed land uses, and they were chosen as alternating areas around the line. Four measures were used as attributes of mixed land uses: a high rate of intra-zonal workforce, a high rate of dependency ratio, high ratios of service and commercial employment as in the dense scenarios, and a balanced job-population value, as much as possible. In addition, each mixed land use was assigned a dummy value representing the degree of mixed land use, later to be assigned the dummy variable coefficient of the model calibration stage.

Results

Model Calibration –Trip Production

According to the hypothesis regarding trip production rates, dense land use settings will produces less motorized trips, due to the proximity of functions which reduce the need for motorized modes. The results of the models estimations, however, contradict this hypothesis, since all the land use variables added little, if anything to the models' explanatory power. Generally, the trip production models results fits the assertions made by authors such as Wegener & Fürst (1999) and Ewing & Cervero (2001), that household trip production is mainly influenced by its characteristics: size, income (proxied here by the number of cars per household), and number of employees. A household facing the need to reach its various daily activities will generate its trips according to its makeup and income, rather than the built environment it is located in. Still, the trip production models measured only the total number of trips made by a household. A test measuring the VMT (vehicle miles traveled) or trip mode choice might indicate differently – denser and mixed land uses indeed might shorten trip lengths or influence the use of transit and non-motorized trips as stipulated in the literature review.

Model Calibration –Trip Attraction

Trip attraction models measure the power of a zone to draw trips to it, according to its land use features – function, makeup and attractiveness. This stage of the transportation modelling maps a daily pattern of trip destinations, which coupled with the trip production models create a complete daily origin-destination matrix.

Contrary to the case of the trip production sub-models, the land use variables included in the attraction models indeed have a significant impact on travel forecasts. In addition, all the models tested applied a Durbin-Watson test, and ranged between 1.93-2.2, suggesting that there is no auto correlation between the variables, especially the land use variables and the other zonal characteristics.

Home-base-education trips, for instance, are influenced by the additional land use variable, *service employment density*, suggesting that the commercial make-up of a zone might co-affect its education trips attraction power, considering that education trips are consisted of trips to higher education facilities, informal education activities, grownup

education and so on. This result may be interpreted in two ways: first, the linkage between education trips and locations catering for high levels of service activities might point at a mixed use environment. Second, the motivation of a trip maker to link an education trip with service facilities might indicate towards a tendency to chain activities and thereby chain trips, which form a more efficient travel pattern, mainly due to the short travel distances and the possibility to utilize transit and other non motorized modes.

The home-base-shopping model also benefits from the inclusion of the land use variable. The log of the job density coefficient demonstrates that the higher the job density, a zone's attraction power increases[6]. This model's results clearly indicate that higher job densities attract more home-base-shopping trips. This finding, coupled with Cervero's (1996b) suggestion that employment centers should include more retail activities, strengthens the claim that a mixture of land uses in employment concentrations could boost trip chaining and decrease the use of auto mode for shopping purposes.

Home-base-other and non-home-base trip attraction models both used a mixed use dummy variable and the dependency ratio variable. In both cases the land use coefficients are very high[7]. A possible interpretation is that diverse areas attract a variety of trip purposes, which benefit from the proximity of uses. Some of these trips might be part of a trip chain (the non-home-base trips). This finding may contradict Kumar & Levinson's (1995) claim that areas accessible to a multitude of activities do not encourage trip chaining. In this case, from the planning perspective, there is a strong point for intensifying and diversifying transit hubs for enhancing the transit/non motorized modes among these motorized non-home-base trips.

The interpretation of the model calibration stage allows us to attain an estimate of the direction of the land use variables influence. An application of these models to the

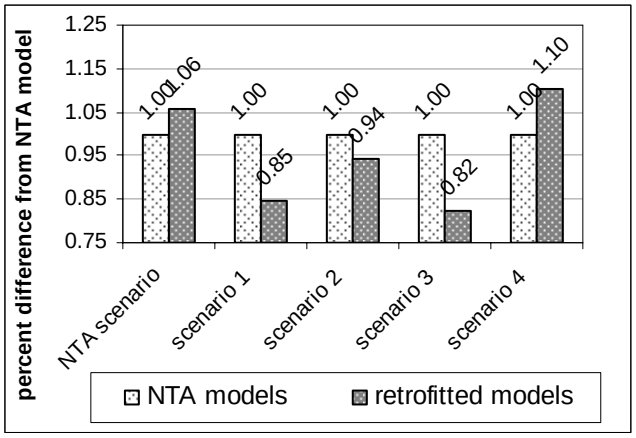
[6] The additional variable - log of job density per km² - was chosen over the job density itself, since the job density values distribution is non-normal.

[7] The mixed land use dummy variable, a category attributed to only 12 zones out of the 158, indicates that areas with diverse activities draw a large amount of trips other than work, shopping or education, which originate or end at home. Zones with a high dependency ratio also attract home-base-other trips, indicating the existence of other activities (apart for the residential activities) which attract these home-base-other trips. However, the high coefficient could be misleading for a high dependency ratio could exist in zones which are strictly residential, and do not include any other uses that would draw home-base-other trips, other than social visits.

proposed land use scenarios extends the scope of the recalibration analysis, by allowing us to ponder on the magnitude of the phenomenon. The use of the land use scenarios described previously assists in comparing the two types of models. When comparing the application of the "non-land use" model and the "land use" model on each scenario, it seems that trip attraction rates in models with land use variables, in contrast to trip production, are significantly different than models with no land use variables. The forecasts are as far as 18% different from the original model estimates, implying that land use variables, when explicitly used in an attraction forecasting model, could have a substantial effect on the models' output.

Of particular interest is the direction of the change: among the denser scenarios the recalibrated model reduces the total estimation of trips attracted, while in the case of the base scenario and mixed use scenario, the recalibrated models actually raise these estimates (figure 4.1).

Figure 4.1: Total trip attraction per workplace



For example, the results of the comparison between the two types of models in the case of home-base-shopping trips, show that job density increases the forecasts by 42-51% compared to the original model. These results once again enhance the point made earlier, that dense job concentrations will draw more shopping trips, an outcome which couldn't have been illuminated by the original model, containing no density measures.

Land Use Scenarios – Density and Diversity

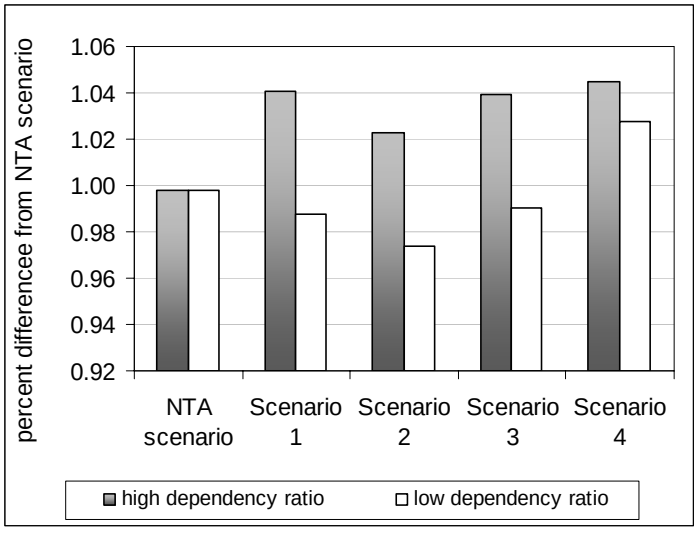
Household employment rates and trip production frequencies – dependency ratio sensitivity tests

Comparison of the various land use policy scenarios allows us to estimate policy impacts on trip rates. Contrary to Wegener & Fürst's (1999) claims that trip rates would not be influenced by land use features, households seem to respond differently when residing in different land use settings.

The apparent distinction between the land use scenarios in terms of trip production per household, as shown in figure 4.2, is the result of the raised workforce population balance. It is evident that prior to the raise of dependency ratio the variation between the scenarios was smaller. The scenarios most sensitive to the raise are the dense scenarios. The difference in total trips produced is a cause of the home-base-work trips sensitivity to dependency ratio. The dynamics are obvious: households having more workers produce more trips to work than households with fewer employees. The home-base-work trips produced is the trip purpose with the most influence on the total trip production rates made by households; therefore the total trip production rates are also higher in the high dependency ratio scenarios.

There seems to be a substitution between home-base-work trips and home-base-other trips when the dependency ratio is higher – households with more workers will produce

Figure 4.2: Total trip production per household



more home-base-work daily trips, and less home-base-other trips, which might be replaced by non-home-base trips which are made on the way back home.

Out of the four hypothetical scenarios simulated in this study, the most affected by changes in zonal dependency ratio are the dense scenarios, perhaps since their high dependency balance is coupled with a densification of the population which in itself contains more employed people. Out of the dense scenarios, the least dense scenario (scenario 2) produces fewer trips than its dense peers.

Population density and trip production

Differences between the scenarios are also apparent when changes in population densities are introduced. Even when the dependency ratio is low for all the scenarios, population densities still affect trip rates differently (figure 4.2). There is a visible trend towards a reduction in trip production when accompanied by a rise in population density (scenarios 1-2-3). Scenario 2, having the lowest average density (17 people/dunam) within the high density group scenarios, produces the least daily trips, compared with all the other scenarios, including the base scenario. The denser scenarios, scenarios 1 and 3 (19 and 20 accordingly), produce more motorized trips per household than scenario 2, a finding indicating that above a certain density threshold, trip production rates will rise and the density effects will diminish. This might be due to fact that the denser an area is, the larger the number of activities it contains. These activities might be creating more trip production in addition to the delta of trips produced by the population residing there.

The hypothesis that land use variables affect the trip production choices made by households is again reinforced. The enhanced opportunities (or obstacles) brought about in the process of population densification, could change the household preferences and so influence its trip production choice. It seems that the dense areas, as demonstrated by the dense scenarios, indeed influenced regional opportunities, which in turn reduced the original trip production rates.

Intra-Zonal Workforce Ratio

The intra-zonal variable's coefficient sign is positive in the home-base-work trip production model, while its counterparts are negative (meaning that increasing their value

is expected to reduce trip production). A possible explanation is that people who work in proximity to their residence are likely to generate more trips[8]. This variable is significant in all 4 trip purpose production models (see table 3.1).

Also, a comparison of the model containing this variable to a model with no land use variables applied on the mixed use scenario shows that the intra-zonal workforce ratio has caused a rise in commuting trip production rates, and has raised the production estimates by 8%. Again, this might be evidence that workers living close to their residence might not be deterred by the distance to their workplace, thus inclined to produce more (possibly shorter) daily trips to work.

Some authors are in favour of a balance between jobs and housing (Cervero, 1996; Shefer & Degani, 1998) which enhances walking, and is supposed to reduce overall motorized trips. The intra-zonal coefficient used in this study might imply the contrary, i.e. the short distance actually motivates individual to generate more (maybe shorter) motorized daily trips. However, since the data used in this study involved only motorized trips, there is no knowledge as to whether these trips substitute walking and cycling or whether they add to the total production rates.

Trip attraction in dense and diverse settings

it is interesting to note that although the trip attraction rates per workplace is the same across the scenarios, commuting trips proportion is lower for the dense scenarios, and especially for the mixed use scenario, while the other trip purposes attraction proportion rises.

Summary and Conclusions

The methodology employed in this study was two-fold: In order to verify whether the inclusion of land use variables affects the trip frequency demand in Tel Aviv metropolitan area, a trip production/attraction demand model was recalibrated. In order to explore whether different land use scenarios also impact the trip frequency rates, the results of the demand models were applied to 5 different land use scenarios representing the surroundings of a planned LRT line.

[8] Since the models only test for total number of trips, we can say nothing about whether these trips are actually shorter, or what mode they utilize.

The first process offers an empirical answer to the debate regarding the need to include land use variables in trip generation models. The second paints a clearer picture of dense and diverse land-use impacts on daily travel rates. It was important to combine these two processes, first to gain a clearer picture of the magnitude of difference between NTA forecasts and land use enhanced forecasts. Second, to attain a refined analysis of travel rates in different land use scenarios using models which incorporate their distinct land-use attributes.

The contributions of these two processes is a proposed applicable trip generation model, which includes land use variables, and an insight into land patterns and policies which have the greatest influence on daily metropolitan trips, among them transit trips.

Land Use Variables in Trip Generation Models

Incorporating land use variables in trip demand forecasting models can shed more light on metropolitan travel trends, compared to models using solely household attributes or general zonal employment characteristics. Outputs of the recalibrated models, especially in the attraction stage, had altered trip rates forecasts significantly. As expected, Trip rates forecasts were influenced by the land use settings in their zones, in accordance with the assumption that land use variables will affect daily trip rates forecasts.

The trip production results, however, do align with Wegener & Fürst's (1999) claim that households do not match their trip production rates to the land use surroundings. The only exception in the results to this assertion is the intra-zonal workforce ratio variable, which was used in all of the trip production models. The coefficient's positive sign indicates that residing in proximity to the workplace could raise the motivation for making more daily commuting trips, and reduce the motivation for chaining trips. This conclusion is enhanced by the non-home-base production result, which finds that the intra-zonal coefficient, while being positive and significant, does not raise the chained trips produced. Furthermore, it is consistent with Kumar and Levinson's (1995) assertion that living in settings which provide good accessibility reduces the will to combine trips.

The current findings strongly suggest that the zone's density and diversity of land uses can play a major role in determining its attraction power. The first conclusion to be drawn from the modeling process is that excluding land use variables from the set of

explanatory variables in a forecasting model could have major implications on its outcomes. Feeding partial or biased trip production and attraction levels for the sequential model steps could result in miscalculation of the demand for auto travel, transit and the non motorized modes, and consequentially of the network assignment. These miscalculations could result in grave costs – enormous investments could be misplaced, making each metropolitan resident and visitor endure the consequences. Not only would congestion not be relieved, air quality would not be improved either, and the expectation for economic growth and urban rejuvenation would not be met.

Density, Diversity in various land use policies

People living in different land use settings appear to generate different travel patterns. Urban functions set in different densities and degrees of mix also attract trips differently. The second stage of this study was aimed at exploring whether density and diversity of uses, could actually reduce motorized travel demand.

A few important findings emerge from analyzing the various scenarios. The first – trip rates are indeed influenced by density and diversity. In spite of the preliminary calibration results that showed that land use variables can have little or no effect on trip production trends, there are actually some differences between the scenarios. High population densities, high intra-zonal workforce ratio and high dependency ratio (the ratio between employed and total population in a zone) can influence the number of trips made by the household. The biggest differences in trip frequency rates occur between the base scenario, the dense scenarios and the mixed land use scenario. The mixed land use scenario, surprisingly, predicts higher trip rates (especially for attraction forecasts) than the more homogenous scenario represented by the base scenario. It was expected, as elaborated in the literature review, to enhance non motorized modes use, thus reducing motorized demand. The current results indicate that contrary to assumption, mixed land uses encourage motorized trips. This evaluation, however, could be biased, as a result of possibly overestimated coefficients, that measured trip production and attraction in mixed land uses. In addition, there is no information as to what modes these trips utilize, or what their length is, therefore one cannot conclude whether mixed land use, in the case of metropolitan Tel Aviv, decreases or increases everyday travel.

The mixed use scenario has also shown that high intra-zonal workforce ratio increases average home-base-work trip production quite substantially. Still, the high rate of intra-zonal workforce ratio in this scenario is hardly expected in every mixed use area. Secondly, it is quite difficult to target and plan for this particular population. In the free market environment, people cannot be forced to reside close to their workplace, and vice-versa.

Having said that, if this market segment would be inclined towards transit, or could potentially be diverted to transit, it is worth investing into. The challenge, according to Cervero (1996b) and Shefer & Degani (1998) is to supply areas with appropriate jobs, otherwise these jobs would not apply to close by residents. Still, in CBDs, where there is a large and diverse concentration of jobs, adding an assortment of housing types, for example, could be a possible solution.

In any case, the intra-zonal workforce ratio could serve as a valuable factor for measuring mixed land use influence on trip frequency, among other more popular variables, such as activity intensity and spatial heterogeneity.

The dense scenarios also play a considerable and maybe clearer role in determining travel demand. High density zones, for example, attract less home-base-work daily trips per worker, relative to the other trip purposes. Agglomeration effects may be in play in this case too – dense and diverse settings include a variety of uses which draw more trips and different types of trips. This finding is consistent with previous studies, maintaining that dense job concentrations reduce the need for auto travel, either due to transit's increased efficiency, or due to negative externalities that density causes (insufficient or costly parking and congestion).

According to the trip attraction allocation by purpose, the dense and especially the mixed land use scenario, according to the recalibrated sub-models, reduce the home-base-work trips and raise the home-base-other and non-home-base trips attracted. According to previous studies, raising employment densities and mixed land uses enhance the use of transit and walking (Cervero, 1988, 1991 in Cervero, 1996; Ewing & Cervero, 2001; Frank & Pivo, 1994). Since the attraction rates discussed here represent only motorized trips, without modal split, it is difficult to either confirm or contradict the findings of these studies. On one hand, both the dense and mixed scenarios yielded higher trip

attraction results than the base scenario, meaning that they actually do not reduce the demand, but rather enhance it. On the other hand, since only the motorized demand is accounted for, there is no information regarding the actual share of non motorized modes, and especially about the demand for transit modes.

Previous studies show that that trip frequencies will be subject to household characteristics (Ewing & Cervero, 2001) and fixed budget restraints (Wegener & Fürst, 1999). The comparison of the scenarios shows that trip frequencies can indeed be influenced by land use features. Households in denser areas probably respond to enhanced opportunities (or disadvantages) in the metropolitan area, and reduce their trip production rates. In Wegener & Fürst's terms – the land use settings might affect the household disposable income, and hence affect its trip making pattern. In urban agglomeration terms, densely populated areas require more and possibly different services than dispersed population areas, therefore giving rise to the daily trip rates produced.

Dependency ratio and daily travel

The dependency ratio has proved as a valuable variable in explaining trip rates. This ratio (the ratio between employed and total population in a zone) is a socio-demographic feature, more so than a land use feature. It is an aggregation of the household employment to the zonal level. However, although the dependency ratio is not strictly a land use attribute, it could well be affected by land use regulations. For example, a supply of residential units fit for small households or individuals may attract precisely the populations which produce the high rates of home-base-work trips. Furthermore, high dependency ratio zones demonstrated a greater tendency towards chaining trips (at the expense of home-base-other trips). Were this market segment found to be inclined towards transit and non motorized trips (this assumption would have to be established by a mode choice analysis), station surroundings could include such residential use and improve their transit ridership share, by diverting a substantial share of the home-base-work trips generated to transit.

Yet home-base-work trips are not the only trips produced by households. Rather, they make up 40% of households daily trip production. The other 60% of daily trips produced,

when they are located in a transit accessible area, should also be allowed to use of transit. Creating more mixed uses around stations, as elaborated earlier, could influence ridership in a number of ways: first, it may be able to divert the home-base-work auto trips to transit. Second, some of the home-base-work trips could be diverted into chained trips. Third, the other trip purposes could also enjoy the mixed environment, utilize transit or be carried out by non motorized modes.

Another point to be made regards the nature of this variable. The dependency ratio variable, as shown in the analysis above, can be an intermediary between socio-demographic factors and land sue factors for understanding travel demand. It is basically a feature describing an aggregate picture of the zonal household makeup. However, high dependency ratio scenarios have generated trip forecasts which imply that they might incorporate other uses, and so might serve as a proxy for a zone's diversity, in future studies as well. High values of dependency ratio may point at more than just the ratio between the employed and unemployed population of an area – the employed sector may represent diverse demand in terms of services, influencing allocation of land use, which in turn will influence travel demand patterns. This influence may especially manifest itself in CBDs and other mixed use areas where households belong to a variety of employment sectors. Exploring the potential capability of this variable in transportation demand forecasting could shed some more light as to how the household level and the spatial distribution of uses converge to influence travel demand.

Intra-zonal workforce variable - further discussion

Since the data analysis did not include any measure of VMT or distance traveled, we cannot infer anything regarding the overall energy consumption or travel time of zones with high intra-zonal ratio. Their trips could indeed mount to the same VMT or even less (because of the shorter distance to work), compared to other metropolitan travelers. However, even in the case of equal VMT or time traveled, the higher trip rates could suggests more frequent cold ignitions, which result in more harmful emissions and compromise air quality.

However, the main contribution of the intra-zonal workforce variable is that the methodology is universal - it can serve as an explanatory variable in trip generation models, which include a variety of trip modes, motorized and non-motorized.

The modal split of this particular market segment should be investigated too. The short distances between home and work could actually encourage transit use, especially in dense areas, where parking is costly or insufficient and public transportation is highly accessible.

The most apparent conclusion from all of the above is that a joint development of LRT stations and land use could stimulate and promote potential development incentives created around the stations, and assist in realizing the full potential of LRT in alleviating the current transportation trends in cities, for the benefit of its dwellers, commuters and visitors.

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