Influence of Land Use on Tour-based Travel

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Inhoud

Samenvatting

De invloed van bereikbaarheid op verplaatsingsketens

Algemeen wordt aangenomen dat in de Amerikaanse new urban designs en de Europese verstedelijking volgens compacte-stadsprincipes, de gemiddelde verplaatsingsafstanden korter zijn en er vaker verplaatsingen in ketens met meerdere locaties voorkomen. Er kan echter ook verwacht worden dat de bespaarde tijd wordt gebruikt voor lager geprioriteerde verplaatsingen, die anders niet mogelijk zouden zijn, zodat uiteindelijk meer verplaatsingen gemaakt worden. Hiertoe is het zinvoller om verplaatsingen in 'tours' – d.w.z. een verplaatsing die thuis begint en eindigt en nul of meer tussenbestemmingen heeft – te bestuderen dan in enkele trips. Er zijn nog niet veel studies die de relatie tussen tours en de gebouwde omgeving bestuderen. In dit paper analyseerden we frequenties van activiteiten en tours, verschillen tussen tours, gemiddelde reistijden per tour en totale reistijd per dag. De conclusies ondersteunen de claims van de stedelijke-inrichtingsconcepten, echter, het werkt wel op een andere manier. Hogere dichtheden doen het aantal bezochte locaties toenemen en daarmee ook het aantal verplaatsingen. Er kan echter niet aangetoond worden dat tours meer locaties bevatten en bijgevolg zijn ook de reistijden niet langer. De analyses op verschillende ruimtelijke schaalniveaus laten zien dat activiteiten- en verplaatsingsgedrag niet op een zeer laag schaalniveau plaatsvindt, maar binnen een gebied met een diameter van circa drie kilometer. Dit kan impliceren dat ruimtelijk beleid zich niet op een zeer laag schaalniveau moet richten.

Summary

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It is assumed that in new urban designs and compact cities that average travel distances tend to be shorter and that more destinations are linked in chains. However, it can be expected that travel time savings are used for lower priority activities that would be impossible otherwise. Thus, higher activity frequencies are expected. In light of this, tours, i.e. chains of trips starting and ending at home, are a better concept for analysis than single trips. To date, few studies have investigated the effect of the built environment on tours. We analyzed activity and tour frequencies, the number of chains, differences in tours between activity types, the average travel time per tour and the total time travelled. The conclusions support the claims of the land use concepts, though the way it works is not as claimed: higher densities increase the number of activity locations visited, and consequently the number of tours, but there is little evidence that tours – and consequently travel times – are longer. Analyses of various spatial scales indicate that activity and travel behavior, at least for maintenance and discretionary activities, do not take place on a very low scale. The best land use indicator appeared to be a combined measure of density and mixed use that takes account of shops and employment within a 3-kilometer radius.

1. INTRODUCTION

While there is a large body of literature that examines the influence of characteristics of the built environment on travel behavior, few studies have investigated the effect on trip chains. A number of studies in the United States, mainly focussed on the neighborhood level, have yielded evidence that supports the hypothesis that spatial features influence travel behavior. In contrast, such effects were not detected in other studies, including some Dutch studies (see Ewing and Cervero, 2001, and Crane, 1996, for overviews of US studies and Van Wee and Maat, 2003, for an overview of Dutch studies). To date, the relationship between chains of trips and the built environment has not received much attention, though there are some exceptions (Golob, 2000; Krizek, 2003; Ma and Goulias, 1999). Hence, there is clearly a need for further investigation of this issue.

Research in this field aims at finding strategies to influence travel behavior by manipulating urban form, and to contribute to policies that reduce the externalities of transport. Examples of such strategies include the new urban designs in the United States and the compact city policy in Europe. What these concepts have in common is that they seek to reduce travel distances (and mode shifting). The rationale behind these policies is that car travel reduction can be achieved by reducing trip frequencies and travel distances. Situating residential, employment, and service locations closer to each other is generally assumed to reduce the distances that need to be covered. It is assumed that when nearby destinations are added to the choice set, average travel distances tend to diminish, as these destinations will be selected over the more distant ones. Moreover, it is expected that shorter travel distances will increase the chances of linking more destinations in a single trip (chain trips). As a result, compact urban designs are assumed to offer the opportunity to travel less.

In investigating that relationship, we subscribe to the view that travel often results from activities in which people wish to participate. Individual and household characteristics influence people's basic needs and preferences, and consequently, their desired activity patterns. For example, men are assumed to spend more time than women on subsistence activities. Likewise, parents of young children tend to engage in more activities, such as extra shopping and the trips made to get and bring children to and from school, sport clubs, etc. As activities are separated in space, travel is needed to connect them. Hence, shorter travel times between home and activity locations, due to higher densities and mixed uses, may result in shorter trips and more linked trips.

However, shorter trips and chain trips serve to save travel time, time that can be used for lower priority activities that would be impossible otherwise (Golob, 2000). Thus, ceteris paribus, higher activity frequencies can be expected. Another reason that people might make more trips could be that they travel less efficiently when distances are short. Consequently, compact urban forms may induce higher activity frequencies, thereby actually increasing the number of kilometers traveled (Maat et al., 2005).

This study seeks to gain a better understanding of the relationship between travel behavior and the built environment in order to test the hypotheses that compact urban forms reduce travel. When analyzing, this study focuses on tours rather than trips. A trip makes the connection between two locations. By contrast, a tour is defined as a chain of trips, starting and ending at home. In real life, we often make chains of multiple destinations, or even zero destinations, as we do, for instance, in walking the dog. Moreover, it is assumed that land use affects the complexity of chains. In light of this, tours are a better concept for the purposes of analysis than single trips. We analyzed activity frequencies, tour frequencies, the number of chains, differences in tours between activity types, the average travel time per tour and the total time travelled. To reflect the characteristics of the built environment, we followed the assumptions of land use concepts that assign an important role to density and mixed use. As an alternative, we also tested various accessibility measures, which define the ease with which locations can be reached, and thus conceptually connect the built environment and travel behavior. The assumptions about the effects of various land use characteristics involve different scales, ranging from the regional to the local and neighborhood levels. Hence, we examined the hypothesis that some activities or individuals are more oriented towards a lower spatial level (small action space), while others are more oriented towards higher levels, by introducing more spatial levels in the analyses reported in this paper.

We explored these relationships, using data derived from a data set collected in the Amsterdam-Utrecht corridor in the Netherlands. The data was analyzed with various types of regression models. Due to the count nature of the data, activity and tour frequencies were analyzed, using Poisson and negative binomial regressions. At the same time, the occurrence of zeros were into account, by using zero-inflated models. Continuous data, such as travel times, were analyzed with OLS regressions.

The remainder of this paper is structured as follows. The next section provides an overview of the research methodology and the travel and land use data. Then, the model results are presented, and finally the results are discussed and the conclusions are drawn.

2. RESEARCH DESIGN AND DATA

2.1 Sample

The need for data about activities, travel, socio-demographics and the characteristics of the spatial context makes the task of collecting data a very demanding one. Existing data sources, such as the Dutch Travel Behavior Survey, neither provide activity data nor a more detailed identification of the residential location beyond the municipality. In order to obtain the required data, a new, comprehensive data set was collected based on a recently developed activity diary (Arentze et al., 2001). In the meantime, a range of land use and accessibility indicators was developed from a variety of spatial data sources.

This research project covered 57 neighborhoods in a central and highly urbanized region of the Netherlands, which encompasses the cities of Amsterdam and Utrecht as well as a number of smaller towns, suburbs and villages. The neighborhoods were selected carefully to ensure the inclusion of a wide variety of urban forms. The survey was conducted in the spring and autumn of 2000. It was preceded by a random sample mailing of 50,000 questionnaires to select households requesting participants. In total, 3,300 households were willing to participate in the study. To prevent over- and under-representation, the proportion of respondents over the age of 50 was reduced, and the proportion of public transport users was increased. A total of 3,412 individual questionnaires and diaries, covering 1,960 households, were returned. However, the actual sample used for analysis was further reduced because of missing values and the need for diary entries relating to two full weekdays (weekend days are not comparable with working days). In addition, the study population was limited to individuals over 18. This resulted in a sample of 1,852 individuals. The main survey involved a questionnaire with a list of questions related to the household and residential context, a personal questionnaire focusing on demographic and socio-economic characteristics, and an activity travel diary. All the respondents were asked to record their activities and trips in the diary for two consecutive days, with the pairs of days staggered across the seven days of the week.

The spatial data were derived from a variety of sources and pre-processed with the aid of a GIS. Dwellings were obtained from the LBV National Database of Real Estate, and the number of employed persons from the LISA Register of Businesses. The Basic Register of Points-of-Sale contains detailed information on shops, including the amount of floor space devoted to sales, broken down for daily shopping and non-daily shopping. The data were assigned to their locational position, using postal codes, yielding highly detailed spatial information. Distances and travel times between origins and destinations were calculated, using the Basis Network (see also Maat et al., 2004).

Table 1. Descriptive statistics of the activity participation and travel variables over two days.

	All cases		Cases > 0		
	Mean	StdDev	Share	Mean	StdDev
# subsistence activities	1.99	1.66	80	2.49	1.48
# maintenance activities	2.68	2.72	79	3.38	2.64
# discretionary activities	1.61	1.96	68	2.38	1.97
# tours	3.65	1.90	100	3.67	1.88
# complex tours with work	0.53	0.72	39	1.33	0.49
# complex tours without work	0.30	0.57	25	1.20	0.45
average chain lenght	2.67	1.09	100	2.68	1.08
total travel time [minutes]	191	105	100	191	105
average travel time per tour [minutes]	65	57	100	65	57

2.2 Activity and travel variables

All the behavioral variables were measured and applied for two days. The activities were classified into three categories: subsistence (work, education); maintenance (e.g. shopping, visits to businesses/ services such as the doctor, bank, post office, library); and discretionary (e.g. leisure, social visits, sports). This typology has been employed before by such authors as Reichman (1976), Golob (2000) and Krizek (2003). Travel behavior was split into the following variables: number of tours (starting and ending at home); chain length (the number of trips per tour); complex tours, including subsistence and other destinations; complex tours without subsistence; average travel times per tour; and total travel time. Travel times were measured across the road network, using a geographical information system. Table 1 presents some descriptive statistics.

2.3 Personal and household variables

The socio-demographic variables correspond to those used in similar studies. Obviously, age, gender and household size were among the variables. Personal income was measured on a 9-point scale. Two dummies indicate the presence of children in the household, specifically children under the age of 6 and those aged 6 to 12. Individual access to a car was the measure used for car ownership. In the Netherlands, this is a better indicator of car use than actual car ownership or the possession of a driver's license. Finally, a dummy indicates whether the house is a single family dwelling or a multi-story apartment.

2.4 Land use variables

To reflect the characteristics of the built environment, we worked with the assumptions of land use concepts that assign an important role to density and mixed use. As such measurements are sensitive to differences in shape and size, administrative and statistical divisions (e.g. neighborhoods or postal code areas) proved inadequate. This problem was addressed by converting the data into grid cells, measuring 250 by 250 meters.

Three composite density measures were developed, at various spatial scales. All measures used one figure for each cell to express the total density of housing, employment, and shopping. Since these categories were measured in non-comparable units, the variables were standardized using the national totals (Maat and Harts, 2001). Then, each measure was aggregated by calculating the spatially moving average for each cell. i.e. the average value of the cell itself and the values of the adjoining cells, using various radiuses: 750 metres, 3 kilometres and 10 kilometres. One indicator, DENSMIX, was used to measure the mix of employment and shopping, weighted by the combined density of employment and shopping within a 3-kilometer radius. As a result, a measure was developed, that increases when the mix of uses and the density increases. All measures were normalized in order to obtain a value between 0 and 1.

Finally, accessibility measures were developed, using potential measures. Such measures are defined as the potential for interaction. For example, a potential measure for employment summarizes all employment, weighted by travel time or distance, using a distance decay function. We used a loglogistic decay function (Geurs and Ritseman van Eck, 2001). Four accessibility measures were generated for employment, daily shopping, non-daily shopping and services, respectively.

2.5 Methodology

The activity and tour models developed in this research project used both the Poisson and negative binomial models and explored the use of zero-inflated models. Poisson regression models represent the relationship between the observed count data that follow a Poisson distribution and a set of explanatory variables. Let us suppose that we have a sample of n observations $y_1, y_2, \ldots, y_n$, which can be treated as realizations of independent Poisson random variables, with $Y_i \sim P(\mu_i)$, and that we want to let the mean μ_i depend on a vector of explanatory variables x_i. We could entertain a simple linear model of the form

$$\mu_i = x_i\beta$$

However, this model poses a disadvantage: the linear predictor on the right side can assume any real value, whereas the Poisson mean on the left side, which represents an expected count, must be non-negative. A straightforward solution to this problem is to model instead the logarithm of the mean using a linear model, formulating a log-linear model as

$$log(\mu_i) = x_i\beta$$

In this model, the regression coefficient β_j represents the expected change in the log of the mean per unit change in the predictor x_j. In other words increasing x_j by one unit is associated with an increase of β_j in the log of the mean. Exponentiating the equation, we obtain a multiplicative model for the mean itself:

$$\mu_i = exp(x_i\beta)$$

In this model, an exponentiated regression coefficient $exp(\beta_j)$ represents a multiplicative effect of the j-th predictor on the mean. Increasing x_j by one unit multiplies the mean by a factor $exp(\beta_j)$. The use of this coefficient is derived from empirical observations that with count data the effects are often multiplicative rather than additive, because one typically observes small effect for small counts and large effects for large counts (Rodríguez, 2004). The model parameters are estimated by maximizing the log likelihood function.

One limitation to the Poisson regression model is that the variance must equal the mean. If this condition is not met, the data is overdispersed and the Poisson model is not appropriate. In that case, the negative binomial model may offer a better modeling approach. Overdispersion is shown by the so-called α parameter. As alpha goes to zero, the negative binomial regression yields the Poisson regression.

In taking account of the possibility that the Poisson model may not accurately assign the probability that $Y = 0$, we also considered the zero-inflated Poisson (ZIP) and the zero-inflated negative binomial (ZINB) models in this research project. These models account for the presence of two regimes, where the outcome is always zero in one regime, and the Poisson or negative binomial process is at work in the other regime (Green, 1994). The Vuong (1989) statistic was used to first test whether two regimes were at work and whether a ZIP or ZINB model was appropriate. Large values favor a ZIP model, and values less than -1.96 reject the ZIP model.

The overall model fit can be assessed by various goodness-of-fit statistics. It is not possible to calculate the percentage of explained variance like the R-square in linear regression. An acceptable approach is Cragg & Uhler’s maximum likelihood R^2, which is refered to as R^2_{ML}. This measure compares a model with just the intercept to a full model with all parameters [13].

3. RESULTS

3.1 Activities

Models of activity frequencies were estimated for subsitence, maintenance and discretionary activities. The mean and variance of the number of subsistence activities were fairly close, which suggests the adequacy of the Poisson model. A zero-inflated Poisson model was applied, because 25 percent of the dependent consisted of zeros, mainly from individuals who could not engage in subsistence activities because they were not employed or studying. The appropriateness of the zero-inflated Poisson regression was confirmed by a significant Vuong value. The model fit was good with a $R^2_{ML} = .51$. As expected, subsistence frequencies were significantly influenced by personal and household characteristics. Negative effects were found for women, age, and households with children below the age of six. An obvious positive effect was observed for income. Contrary to expectations, areas with high employment accessibility showed no evidence of self-selection in terms of the concentration of working or studying individuals.

Table 2. Regression results for subsistence, maintenance and discretionary activity frequencies

	Zero-inflated Poisson		Negative Binomiaal		Negative Binomiaal	
	Subsistence		Maintenance		Discretionary	
	exp(β)	p-value	exp(β)	p-value	exp(β)	p-value
Gender (male)	1.162	0.000	0.739	0.000		
Age	0.993	0.000	1.009	0.000	0.991	0.001
Household size					0.947	0.060
Children < 6 years	0.805	0.000	2.006	0.000	0.824	0.024
Children 6 -12 years			1.683	0.000		
No. of workers					0.838	0.001
Income	1.059	0.000	0.929	0.000	0.976	0.055
Car availability			1.172	0.008	1.239	0.004
DensMix			2.654	0.000	2.729	0.004
Worker			0.807	0.003	0.839	0.066
Utrecht region					1.130	0.056
Almere region					1.208	0.089
	Vuong = 16.46; p-value = 0.000		Likelihood-ratio test alpha = 0: 0.000		Likelihood-ratio test alpha = 0: 0.000	
	R^2_{ML} = 0.508		R^2_{ML} = 0.192		R^2_{ML} = 0.044	
	N = 1852		N = 1852		N = 1852	

Overdispersion tests produced significant alphas for maintenance and discretionary activities. This suggests that negative binomial models are most appropriate, producing model fits of R^2_{ML} = .19 and .04, respectively. Coefficients indicate that men and individuals without subsistence activities are less likely to engage in non-subsistence types of activity. The presence of more household members and children increases the number of maintenance activities, but decreases the number of discretionary activities. Access to a car shows a positive effect. Three sets of spatial indicators were tested. A model that included all these spatial indicators unexpectedly produced signs of some of the estimated parameters. On closer inspection, it appeared that these unexpected signs were caused by strong correlations between these variables. Consequently, we compared various model specifications and report on the model that produced interpretable and consistent results.

For both activity types, it was found that the local-level indicators did not perform well. The indicator with the highest positive coefficient was DENSMIX, a combined indicator of density and mixed use that takes account of shops and employment within a 3-kilometer radius.

3.2 Tour frequency

To identify relationships between tour generation and the built environment, models were tested with various built environment indicators. With a mean that equals the variance and an insignificant alpha, a Poisson model appeared to be appropriate with R^2_{ML} of 0.13. As expected, women, older individuals, households with children and access to a car showed positive signs, while individuals living in double-income families and income showed a negative sign. The latter finding indicates that having a job reduces the number of tours. On testing various built environment variables, it was observed that DENSMIX showed a clear positive sign (Table 3). Other models were tested, including densities for three spatial levels and accessibilities. Just density within 3 kilometers and accessibility to services showed significant effects, both small and positive.

To test whether the built environment influences tour frequency primarily through the frequency of activities, or whether there is an additional land use effect, a model was estimated that included the frequencies of the three activity types. It stands to reason that higher densities not only encourage trip making, but also encourage trip chaining, thus reducing the number of tours. As expected, activity frequencies showed positive signs, but the DENSMIX variable disappeared, suggesting that there is no additional land use effect. To gain more insight into this, specific models on the complexity of tours were estimated.

Table 3. Regression results for number of tours and chain length

	Number of tours (Poisson)		Chain length (OLS)	
	exp(β)	p-value	coefficient	p-value
Gender (male)	0.949	0.093		
Age	1.004	0.002	-0.009	0.000
Household size	1.063	0.000	-0.122	0.000
Children < 6 years	1.170	0.000	0.182	0.048
Children 6 -12 years	1.192	0.000	0.173	0.093
No. of workers	0.958	0.060	0.092	0.048
Income	0.954	0.000	0.056	0.000
DensMix	1.495	0.007		
Car availability	1.089	0.013	0.225	0.001
Constant			2.723	0.000
	R^2_{ML} = 0.128 N = 1852		adj. R^2 = 0.046 N = 1852	

3.3 Tour complexity

Three models for tour complexity were estimated. Given the continuous nature of the data, the mean chain length, which is the ratio of trip and tour frequencies, was estimated using OLS regression (Table 3). Unfortunately, with an adjusted R^2 of 0.046, the model is somewhat poor. Coefficients show that families with children, double-income workers and car drivers are more inclined to make complex tours. However, the land use indicators were not significant.

Subsequently, models were estimated for the number of complex tours that included a subsistence activity and at least one other activity, and for the number of tours with at least two activities, but no subsistence activity (Table 4). The mean and variance were close for both variables, but the dispersion tests show insignificant alphas, suggesting Poisson regression. The appropriateness of using zero-inflated models was also obvious, as most cases had zeros for both variables. This was confirmed by significant Vuong statistics.

The goodness-of-fit for complex tours with subsistence was fairly good with R^2ML = 0.179. Using ZIP regression, separate models were generated to determine whether individuals made complex tours and to establish the frequency of those tours. The binary model yielded positive signs for families with children, and negative signs for age, income and the number of workers. By contrast, DENSMIX was not significant. The frequency model yielded positive signs for households with children, number of workers, income and access to a car. However, once again, no effects were observed for land use, except in one remarkable, but obvious case: residents of the isolated city of Almere were less inclined to make complex tours.

The goodness-of-fit for non-subsistence complex tours was weaker with a R^2_{ML} of 0.043. Two effects influence whether individuals make such tours. The negative sign for individuals with access to a car and the strong negative coefficient for DENSMIX indicate that higher values reduce the chances of zero complex tours, which means that they make more often a complex non-subsistence tour. The frequency model presents only personal and household effects.

Table 4. Regression results for the number of complex tours

	No. of complex tours with subsistance		No. of complex tours without subsist.	
	exp(β)	p-value	exp(β)	p-value
Gender (male)			0.718	0.002
Household size	0.846	0.001	0.894	0.077
Children < 6 years	1.486	0.002		
Children 6 -12 years	1.698	0.000		
No. of workers	1.161	0.096	0.853	0.049
Income	1.088	0.000	0.936	0.003
Car availability	1.387	0.002		
_Iregio_3	0.685	0.056		
Inflation				
Age	0.078	0.030		
Children < 6 years	2.804	0.058		
No. of workers	-3.547	0.000		
Income	-0.398	0.013		
Car availability			-2.837	0.007
DensMix			-8.203	0.003
Constant			1.976	0.001
	$R^2_{ML} = 0.179$		$R^2_{ML} = 0.043$	
	N = 1756		N = 1756	
	N (nonzero) = 695		N (nonzero) = 427	
	Vuong = 3.99; p=value = 0.000		Vuong = 2.20; p=value = 0.000	

3.4 Travel time

Finally, two models were estimated in order to analyze the influence of tour frequency and complexity on average travel times per tour and the total time traveled (Table 5). Given the continuous nature of the data, travel time was analyzed, using OLS regression. The models offered fairly good explanations, with an adjusted R^2 of 0.23 and 0.51, respectively. It appeared that chain length has the same positive effect on both the average travel time per tour and total travel time. While this is evident for the travel time per tour, it was expected that trip chaining would save total travel time. Furthermore, it appeared that with higher tour frequencies, less time was spent per tour. Conversely, total travel time appeared to be higher with higher frequencies. Nevertheless, as regarding the question at the focus of this study, the built environment shows a clearly negative effect: as DENSMIX increases, both travel time per tour and total travel time decrease. Alternative models (not displayed here) with densities and accessibilities were also tested, but the model with DENSMIX showed the best fit. Interestingly, however, the density that measured over 10 kilometers was the only significant one. This suggests that the influence of the built environment is not the same for travel time as it is for tour frequencies.

Table 5. Regression results for travel time (OLS)

	Average travel time per tour		Total travel time	
	coefficient	p-value	coefficient	p-value
Gender (male)	6.682	0.005	1.168	0.026
Age	-.179	0.041	-.5980	0.006
Children < 6 years	-7.994	0.004	-2.369	0.000
Children 6 -12 years	-6.265	0.049	-1.483	0.035
Income	2.589	0.000	9.025	0.000
Worker			2.444	0.002
No. of tours	-7.111	0.000	1.461	0.000
Chain length	2.759	0.000	3.490	0.000
DensMix	-4.376	0.000	-5.488	0.035
Constant	1.818	0.005	1.199	0.461
	adj. $R^2 = 0.468$		adj. $R^2 = 0.510$	
	N=1629		N=1629	

4. CONCLUSIONS

This study aimed at obtaining a better understanding of the relationship between characteristics of tour-based behavior and the built environment in order to test the hypotheses that compact urban forms reduce travel. A tour is defined as a chain of trips, starting and ending at home. Since land use is assumed to affect the complexity of chains, tours are a better concept to analyze than single trips. To reflect the characteristics of the built environment, we adhered to the assumptions of land use concepts that assign an important role to density and mixed use on several spatial levels. In addition, we tested various accessibility measures and controlled for personal and household variables. To this end, Poisson and negative binomial regression models were developed for count data, and OLS regressions were used for continuous data. The model was based on data from two-day diaries, which was collected in the Amsterdam and Utrecht region.

All activity and travel variables were significantly influenced by the personal and household variables, and generally showed the expected signs. In particular, people with children engaged in more activities, resulting in more tours, and were more inclined to make complex chains. The same holds true for individuals with access to a car. Employment, on the other hand, had effects in the other direction. There appeared to be no difference between dwellers of single-family houses and apartments.

Models for subsistence frequency did not show any influence of land use, but DENSMIX did significantly encourage maintenance and discretionary activities. Since work and school are mandatory activities, most influence of the built environment can indeed be expected for other activities. This is in line with Handy's (1993) and Krizek's (2003) observations that non-work travel is influenced by land use. The built environment also influences tour frequency, although closer inspection showed that this effect was derived from proximity to activities and was not an additional travel effect. In keeping with this result, the chain length was not influenced by the built environment, nor were the number of complex subsistence tours (tours with at least one subsistence and one other destination). There was merely an effect on other complex tours (without subsistence activities): density reduces the chances of people not making complex tours. Although theoretically was expected that the built environment would affect complex trip making, it was not empirically observed, which is in line with results of Krizek in the US.

Our analyses of travel time revealed that the more trips made per chain and the more tours made in total, the more time spent on travel per day. Thus, higher densities encourage more and longer tours. Nevertheless, there is a significant and strong negative effect of the built environment: as DENSMIX increases, both travel time per tour and total travel time decrease.

This conclusion supports the claims of the land use concepts. However, the way it works is not as claimed: higher densities increase the number of activity locations visited, and consequently the number of tours, but there is little evidence that tours – and consequently travel times – are longer. Resolving this issue is a task that will require further research.

Finally, we should comment on the spatial variables and levels. Generally, densities that are measured on a scale with a radius of three kilometers, are more frequently significant than low-scale measures (radius of 750 meters) and high-scale measures (radius of 10 kilometers). This indicates that activity and travel behavior, at least for maintenance and discretionary activities, do not take place on a very low scale, as proposed by the US urban designs. This is again in line with Krizek. Rather, the scale of these activities falls within a 15-minute bike ride or several-minute car ride. The best indicator appeared to be DENSMIX, which combined not only density, but also the mix of uses.

5. REFERENCES

Arentze, T., M. Dijst, E. Dugundji, J. Chang-Hyeon, L. Kapoen, S. Krygsman, K. Maat and H. Timmermans, 2001, New Activity Diary Format: Design and Limited Empirical Evidence. *Transportation Research Record*, **1768**, 79-88.

Crane R (1996) On form versus function: will the new urbanism reduce traffic, or increase it? *Journal of Planning Education and Research* 15(2): 117–126.

Ewing R and Cervero R (2001) Travel and the built environment: synthesis. *Transportation Research Record* **1780**: 87–112.

Geurs, K.T. and J.R. Ritsema van Eck, 2001, *Accessibility measures: review and applications,* RIVM report, National Institute of Public Health an00d the Environment, Bilthoven.

Golob, T.F., 2000, A simultaneous model of household activity participation and trip chain generation. *Transportation Research B* **34**, 355-376.

Greene, W. H., 1994, Accounting for Excess Zeros and Sample Selection in Poisson and Negative Binomial Regression Models. Working paper, Stern School of Business, NYU EC-94-10.

Handy SL (1993) Regional versus Local Accessibility: Implications for Nonwork Travel. *Transportation Research Record* **1400**: 58–66.

Krizek, K.J., 2003, Neighborhood services, trip purpose, and tour-based travel. *Transportation* **30**: 387–410.

Ma, J. and K.G. Goulias, 1999, Application of Poisson Regression Models to Activity Frequency Analysis and Prediction. *Transportation Research Board*. Washington D.C.

Maat, K. and J.J. Harts, 2001, Implications of Urban Development for Travel Demand in the Netherlands. *Transportation Research Record* **1780**, 9-16.

Maat, K., B. van Wee and D. Stead, 2005, Land use and travel behaviour: expected effects from the perspective of utility theory and activity-based theories. *Environment and Planning* **32** (1): 33 - 46

Maat, K., H. Timmermans and E. Molin, 2004, A Model of Spatial Structure, Activity Participation and Travel Behavior. 10th World Conference on Transport Reserach. Istanbul, 5 – 8 July 2004 (CD-ROM).

Reichman, S., 1976, Travel adjustments and life styles: a behavioral approach. In Stopher PR & Meyburg AH (eds), *Behavioral Travel-Demand Models* (pp 143–152). Lexington, MA: Lexington Books.

Rodríguez, G., 2004, Lecture Notes: http://data.princeton.edu/wws509/notes/c4.pdf

Vuong, Q. H., 1989, Likelihood ratio tests for model selection and non-nested hypotheses. *Econometrica* **57**: 307–333.

Wee, B. van, and K. Maat, 2003, Land Use And Transport: A Review and Discussion of Dutch Research. *European Journal of Transport and Infrastructure Research*. **3** (2): 199-218.