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Car ownership as a mediating variable in travel behavior research

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ABSTRACT

Car ownership is considered as an important variable in research on the influence of the built environment on travel behavior. Car ownership is determined by the built environment, and influences on its turn other aspects of travel behavior. However, empirical studies generally consider car ownership either as a dependent variable or as an independent variable. This paper combines both approaches into one single analysis. A model in which car ownership mediates the relationship between the built environment and car use is estimated using Structural Equation Modeling (SEM). This SEM-model confirms the true mediating nature of car ownership.

1. INTRODUCTION

Living, working, shopping and recreating are spatially separated activities. In order to participate in these activities, people have to travel. Consequently, it seems logical that the travel behavior of individuals and households might be altered by changing the location of these activities and the design characteristics of these locations.

So far, many studies have tried to determine the influence of the built environment on travel behavior. Within this research debate, car ownership is considered as mediating the relationship between the built environment and travel behavior. A theoretical justification for this is given by Ben-Akiva and Atherton (*1*). They embedded the built environment, car ownership and travel behavior in a hierarchy of choices. Car ownership is considered as a medium-term decision, which is influenced by long-term decisions such as employment and residential location choices. Characteristics of these locations, such as the availability of public transport, constrain or facilitate car ownership. Car ownership, on its turn, affects short-term decisions such as daily travel behavior of individuals and households.

However, most empirical studies do not consider car ownership as a mediating variable. Car ownership is mainly used as an exogenous variable, besides spatial and socio-economic variables, to explain travel behavior (e.g., *2, 3, 4, 5*). On the other hand, some studies consider car ownership as an endogenous variable and try to explain it based on various spatial and socio-economic variables (e.g., *6, 7, 8*). Only a limited amount of studies combines both research approaches and considers car ownership as mediating the relationship between the built environment and travel behavior (e.g., *9, 10*). Travel behavior is, then, directly determined by car ownership and the built environment, and car ownership itself is also influenced by the built environment. This results in an indirect effect of the built environment on travel behavior through the mediating variable car ownership. If this indirect effect is ignored, the effect of the built environment on travel behavior is inadequately estimated.

This paper extends the debate on car ownership as a mediating variable. The remainder is structured as follows. First, a brief literature review is presented. Then, the methodological framework of Structural Equation Modeling (SEM) is outlined. A SEM-model is represented by a series of simultaneously estimated equations. Doing so, SEM can handle relationships between several exogenous and endogenous variables which results in one of the main advantages of SEM (e.g., compared to regression analysis): the modeling of mediating variables and, as a consequence, the distinction between total, direct and indirect effects. The analysis is preceded by a discussion of the used dataset and the applied research design. Finally, the conclusion summarizes the most important findings.

2. LITERATURE REVIEW

There are many studies on the relationship between the built environment and travel behavior, which leads to an enormous variety of variables taken into consideration. These variables refer to three important components: (i) a spatial component, (ii) a socio-economic component, and (iii) a personality component. This section briefly summarizes some of the relevant literature on car ownership and travel behavior (for more comprehensive reviews, see, e.g., *11, 12, 13*).

2.1 A Spatial Component

The effects of *density* on travel demand have long been acknowledged (e.g., *14*) and remain well-studied and understood. Higher densities are associated with more public transport use, more walking and cycling, and less car use. After all, public transport is organized more efficiently (more routes, higher frequency of services) in high-density areas and car users may face more congestion. Furthermore, travel distance and time is negatively associated with density (*15, 16, 17, 18, 19*).

Several measures have been developed to estimate *diversity*: among others, a jobs/housing ratio (*20, 21*), an entropy index to quantify the degree of balance across various land use types (*22, 23*) or a dissimilarity index to indicate the degree to which different land uses lie within one another's surrounding (*22*). The effects of more diversity on travel behavior are comparable to the effects of higher densities.

Design can be characterized by a general classification of neighborhoods with a standard suburban neighborhood and a neo-traditional neighborhood as extremes (*24, 25*). Standard suburban neighborhoods are characterized by low densities, limited diversity, and a car-orientated design. As a consequence, these neighborhoods are associated with more trips and more car use. However, design can be characterized more specifically by site design, and dwelling and street characteristics. Findings indicate that neighborhoods characterized by small block sizes, a complete sidewalk system, the absence of cul-de-sacs and limited residential parking encourage walking and cycling (15, 17, 26). Meurs and Haaijer (*27*) noted that, although characteristics of the dwelling, street, and neighborhood may influence modal choice, this is only true for shopping and social or recreational purposes. Working trips can be less influenced by design characteristics.

2.2 A Socio-economic Component

Empirical studies control their results for various socio-economic and demographic characteristics of the individual and the household.

Car ownership, and consequently car use, is lower among older persons (aged above 65 years). Moreover, if older persons travel by car, they travel shorter distances. Note also that older persons not only travel because they want to participate in activities, the traveling itself has socializing opportunities. Ride-sharing for non-work trips is, therefore, found to increase by *age* (*17, 18, 19, 21*).

Women travel more often by public transport, by bike or on foot, whereas car use is higher among men. Because women are more relied to slow modes, they cannot travel long distances (*5, 17, 19*). This *gender* difference may be explained by, among other, the fact that women earn lower wages and obtain different types of jobs than men (*28, 29*). However, women remain responsible for most household maintenance tasks. As a result, car use is higher and longer travel distances are made for non-work trips by women (*21*).

Educational level, *employment* status, and *income* are related, resulting in comparable findings. For example, highly educated persons often obtain specialized jobs which are concentrated in high-density office parks. As a result, they are more involved in long-distance commuting and car use is higher (*2, 5, 17, 18, 21, 23*). However, the use of public transport, especially train use, is higher if these office parks are located nearby a train station.

Household size is positively associated with car ownership. Because of intra-household decisions related to the activities of several household members, it may be appropriate to own more cars. Households that own a car will use it more often. Furthermore, because these households are more car dependent, they can travel longer distances as well (*18, 23*). Comparable results are found with respect to the number of employed persons in the household (2, 15) and the presence of children. However, travel distances and times are longer for singles and couples, because they do not have child care responsibilities (4, 5, 17, 18, 21)

As mentioned previously, *car ownership* influences car use: households owning a car will use it. However, car ownership in itself is influenced by other socio-economic variables, especially income. Car ownership is higher among high-income groups (4, 5, 19, 21, 23, 24).

2.3 A Personality Component

In the 1970s, various studies focused on *perceptions* and *attitudes* in travel behavior (e.g., towards travel modes) (e.g., *30, 31, 32*). However, these studies did not include a spatial component. Recent studies rediscovered the importance of perceptions and attitudes, and measure the relative influence of the spatial, socio-economic and personality dimension. Attitudes towards urban form (*33*) and towards travel (*3, 34*) add explanatory power to models of travel behavior that already include spatial and socio-economic variables. Moreover, perceptions and attitudes are considered as the result of *lifestyles*. The study of lifestyles in travel behavior research is, therefore, important (*3, 16*).

3. STRUCTURAL EQUATION MODELING

Structural equation modeling (SEM) is a research technique dating from the 1970s. Most applications have been in psychology, sociology, the biological sciences, educational research, political science and marketing research. SEM has been applied in built environment-travel behavior research only recently. It is a confirmatory method guided by prior theories about the structures to be modeled. Therefore, section 4.2 describes the conceptual model and the hypotheses that will be tested within this paper.

A SEM-model is represented by a series of simultaneously estimated structural (i.e., regression) equations. Hence, a SEM can include mediating variables and, consequently, direct, indirect and total effects can be distinguished. Because a variable can be an independent variable in one equation but a dependent variable in another equation, we distinguish 'endogenous' variables from 'exogenous' variables. Exogenous variables are not caused by any other variable. Instead, exogenous variables influence other variables. In a graphical representation of a model, no paths (symbolized by arrows) will point towards exogenous variables and paths will only depart from exogenous variables towards other variables. Endogenous variables are influenced by exogenous variables, either directly or indirectly (*35, 36, 37*).

A SEM can be composed of up to three sets of simultaneous models: (i) a measurement model for the endogenous variables, (ii) a measurement model for the exogenous variables, and (iii) a structural model (*38*). This full model is known as 'SEM model with latent variables'. Latent variables are constructs which cannot be observed directly. Thus, latent variables must be defined in terms of underlying variables which are believed to represent the latent variable. These underlying and observable variables are called 'indicators' or 'manifest variables'. The measurement model, therefore, defines the relationship between a latent variable and its indicators. The structural model represents the relationships between exogenous and endogenous variables. This structural model is defined by the matrices:

$$Y = \mathbf{B}\, Y + \mathbf{\Gamma}\, X + \zeta \qquad [1]$$

with Y = L x 1 matrix with endogenous variables
X = K x 1 matrix with exogenous variables
B = L x L matrix with regression coefficients relating endogenous variables to other endogenous variables

$\mathbf{\Gamma}$ = K x K matrix with regression coefficients relating exogenous variables to endogenous variables
ζ = L x 1 matrix with residues of the endogenous variables

The estimation of a SEM-model is (usually) based on matching the observed covariances with the model-based covariances.

Figure 1 is a simplification of possible relationships between characteristics of the built environment, socio-economic status and travel behavior. We are aware that reality is much more complex, but Figure 1 is used to illustrate some commonly used concepts in SEM-models. It represents a structural model between three latent variables that are defined by their measurement models. Measurement models are defined for one exogenous variable (socio-economic status) and two endogenous variables (built environment and travel behavior). This full model is seldom applied. A 'SEM-model with observed variables' consists only of a structural model. No measurement models are needed if all exogenous and endogenous variables are manifest variables. Such SEM-model is obtained by conducting a path analysis (*38*).

Direct effects points from one variable to another and are represented by an arrow in the path (flow) diagram. For example, Figure 1 represents three direct effects: from built environment to travel behavior, from socio-economic status to travel behavior and from socio-economic status to built environment. Indirect effects occur between two variables that are mediated by one or more intervening variables, such as the relationship between socio-economic status and travel behavior through built environment. The combination of direct and indirect effects determines the total effect. It needs to be stressed that arrows between the construct and its indicators do not correspond to direct effects. For example, income is not explained by socio-economic status but it rather contributes to the construct socio-economic status.

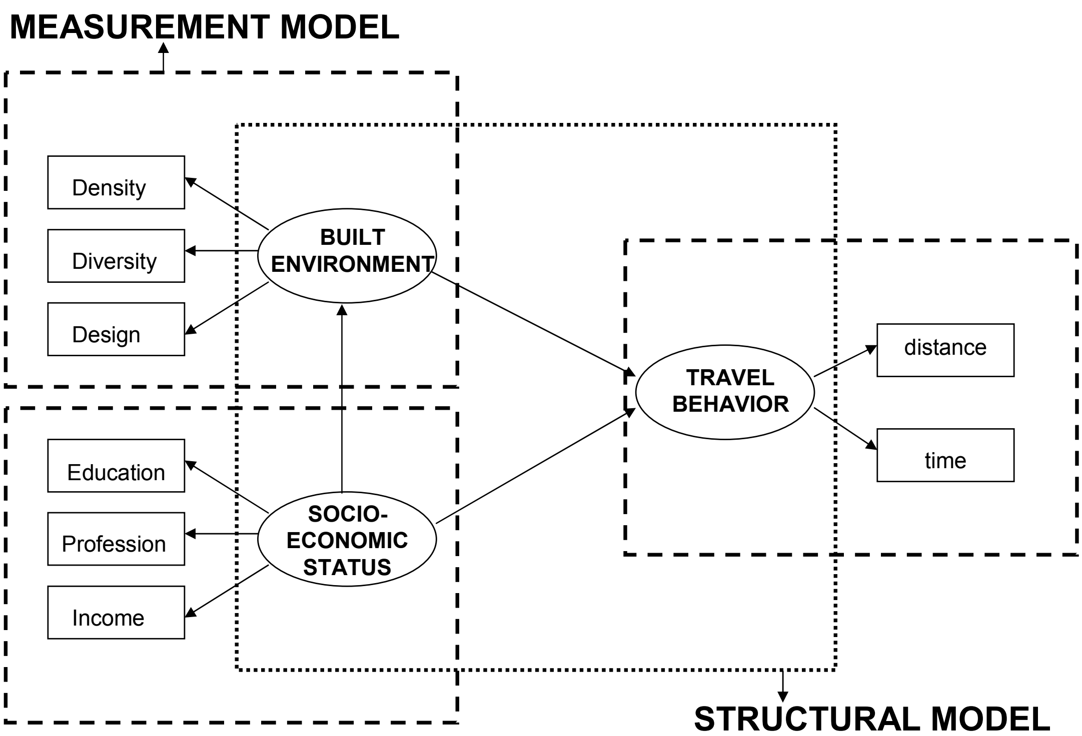

FIGURE 1: An example of a SEM-model with latent variables

4. RESEARCH DESIGN

4.1 Data

Data from the 2000-2001 Ghent Travel Behavior Survey (Onderzoek Verplaatsingsgedrag (OVG) Gent) were used to address the research questions posed. Ghent is a medium-sized city in Flanders, Belgium. Since 1994-1995, the OVG survey is carried out every five years in Flanders. Between 1999 and 2001, surveys were held in several urban regions, among others in Ghent. In every survey, about 2,500 households are asked to participate. The survey yields data on the travel behavior of approximately 5,500 persons, including children over the age of six. In addition to information on personal and household characteristics, individuals have to complete a trip diary for two consecutive days. This resulted in 39,712 trips reported in the 2000-2001 OVG Gent survey (*39*).

This paper focuses on car ownership as a mediator of the relationship between the built environment and travel behavior. The analysis is based on all trips of persons aged 18 years and older. These persons are considered to undertake trips relatively independently. Furthermore, these persons have a potentially larger choice set of travel modes than younger persons since the legal age at which a driver's license can be obtained is 18 years in Belgium.

Variables used in the analysis include characteristics of the built environment, personal and household characteristics and aspects of travel behavior (see Table 1):

- The built environment is characterized by a built up index and an entropy index. Information on these characteristics is only available for the residential location, where most trips depart from. Such information is, however, not available for the various trip destination locations. The built up index equals the percentage of built up surface in a neighborhood. It can be considered as a proxy for built up density. The entropy index quantifies the degree of balance across residential use, commercial use and other land uses. It is defined by the equation (*40*):

$$entropy \equiv 1 - \left[\frac{\left|\frac{r}{T} - \frac{1}{3}\right| + \left|\frac{c}{T} - \frac{1}{3}\right| + \left|\frac{o}{T} - \frac{1}{3}\right|}{\frac{4}{3}} \right] \qquad [2]$$

with r = km² in residential use
c = km² in commercial use
o = km² in other land uses
T = r + c + o

A value of 0 means that the built environment is exclusively determined by a single land use, whereas a value of 1 indicates perfect mixing of the different land uses.

- Personal and household characteristics include age, gender (0 = male, 1 = female), educational level (five classes), possession of a driving license (0 = no, 1 = yes), number of children aged below 6 years, monthly household income (five classes), marital status (0 = not married, not cohabitating, 1 = married, cohabiting), employed (0 = no, 1 = yes) and car ownership (number of cars per household).

- Travel behavior is characterized by travel distance and car use. Car use is defined as a binary variable with 0 = no car used for the trip, 1 = car used for the trip.

Based on the selected variables, a SEM-model is estimated to determine the meaning of car ownership as a mediating variable. Therefore the software package M-plus 4.21 is used.

TABLE 1 Summary of variables included in the analysis

	Minimum	Maximum	Average	Standard Deviation
Built environment				
entropy index	0.00	0.99	0.35	0.19
built up index	0.00	0.99	0.65	0.27
Socio-economic characteristics				
age	18	90	44	14
number of children < 6 y.	0	3	0.24	0.59
number of cars	0	7	1.42	0.73
Travel behavior characteristics				
travel distance (km)	0.1	1819.90	9.68	25.20

	Frequency
Socio-economic characteristics	
gender	51.3% male, 48.7% female
education	2.1% none, 5.5% PE, 17.4% SE, L, 29.0% SE, H, 46.0% HE
driving license	11.9% no, 88.1% yes
employed	31.7% no, 68.3% yes
marital status	28.4% not married or cohabiting, 71.6% married or cohabiting
household income	2.4% 0-744 €, 31.1% 745-1,859 €, 46.2% 1,860-3,099 €, 17.0% 3,100-4,959 €, 3.3% +4,960 €
Travel behavior characteristics	
car use	36.0% no, 64.0% yes

Meaning categories "education": PE = primary education, SE, L = secondary education, lower, SE, H = secondary education, higher, HE = higher education

4.2 Conceptual Model and Hypotheses

As already mentioned SEM is a confirmatory method and must, therefore, be guided by a conceptual model and hypotheses about the model structure. Based on the literature review and the available data in the OVG survey, effects can be postulated between the selected variables (see, Figure 2). Table 2 summarizes these postulated effects.

As mentioned in Section 2, car ownership is influenced by the built environment and various socio-economic variables of the individual and its household. Car ownerships is assumed to be positively related to education, owning a driving license, employed individuals, households with young children and high income households. On the other hand, older people and females are believed to own fewer cars. In densely built neighborhoods and neighborhoods characterized by mixed land uses, distance between various locations is shortened. As a result, people are no longer obliged to own a car to be able to reach the activities in various locations. Moreover, within such neighborhoods public transport is organized more efficiently (more routes, higher frequency of services). These facts might encourage people to own fewer cars. Similar results have been found for car use.

Car ownership and car use are associated: individuals and households owning a car will use it more often. Car use might depend on other aspects of travel behavior as well. Travel distance can influence the decisions to use the car or not. If a short trip must be undertaken, other travel modes such as walking or cycling might be considered.

Furthermore, SEM can handle several directions of interrelationships. Consequently, the modeling of in-between relationships of socio-economic characteristics and the built environment becomes possible. Residential location decisions are not only influenced by spatial preferences, but also by other aspects such as socio-economic status of the individual. This refers to the self-selection mechanism. For example, an individual with a high socio-economic status will not prefer to live in a deprived neighborhood of the city, but rather chooses to live in the suburbs.

TABLE 2 Postulated effects within the conceptual model

	Car ownership	**Car use**
Built environment		
entropy index (dominating land use)	+	+
built up index	-	-
Socio-economic characteristics		
age	-	-
gender (female)	-	-
education	+	+
driving license	+	+
employed	+	+
marital status (married/cohabiting)	+	+
number of children < 6 y.	+	+
number of cars		+
household income	+	+
Travel behavior characteristics		
travel distance		+

We are aware that variations on this basic model might exist. Therefore, we have defined three other models as well (see Figure 2). Model 2 does not take into account the effect of residential self-selection. Residential self-selection is assumed to be influenced by socio-economic status, but also by other aspects such as travel preferences. Our dataset lacks information on travel preferences. Thus, we might be unable to correctly measure the effect of residential self-selection. Model 3 comprises the effect of residential self-selection, but does not consider car ownership as a mediating variable. Consequently, this model does not result in indirect effects of the built environment and socio-economic variables on car use. Model 4 neglects the effect of residential self-selection as well as the mediating effect of car ownership. By comparing the overall fit of these models, we are able to detect the true nature of car ownership as a mediating variable.

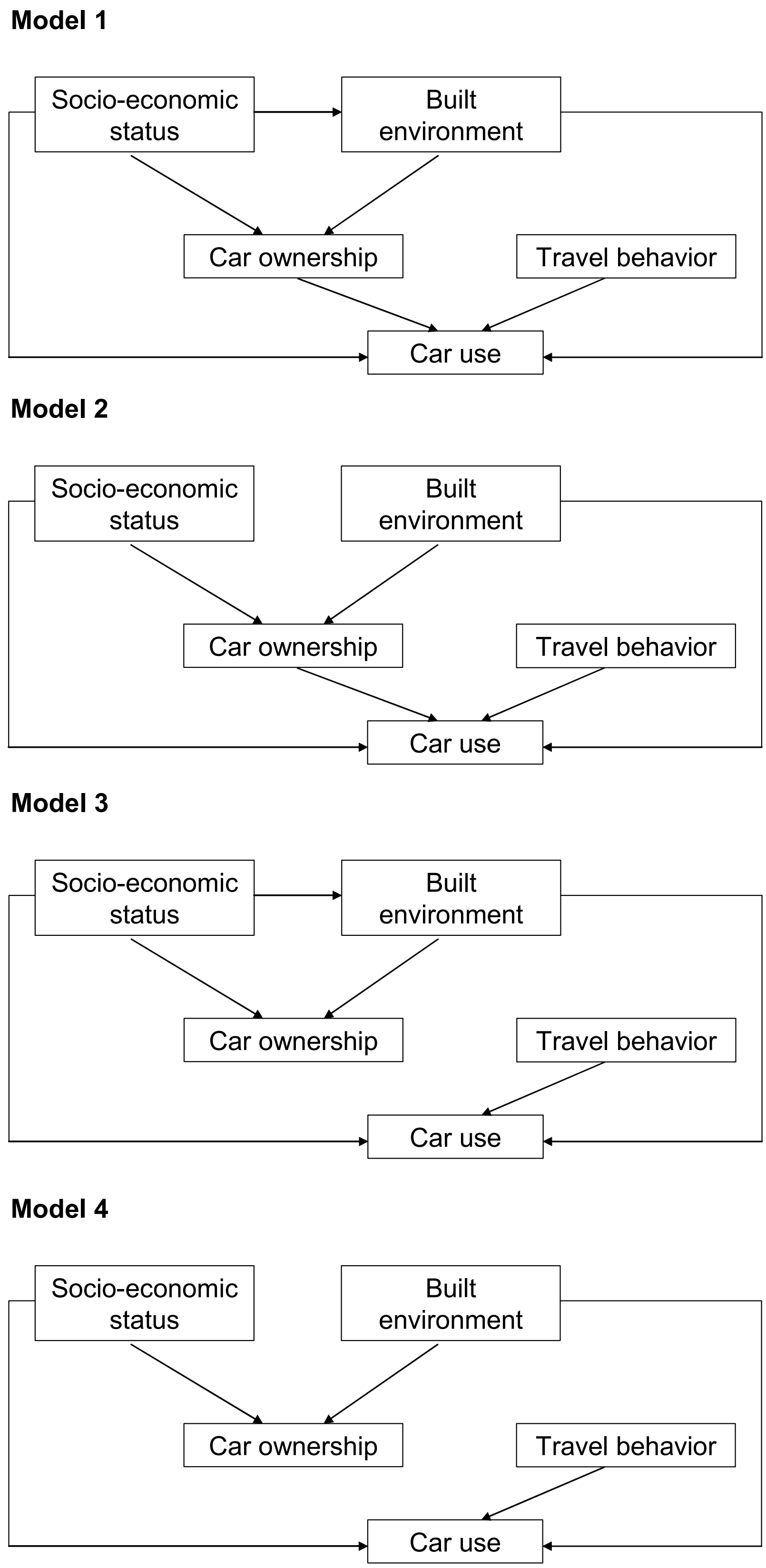

FIGURE 2: Conceptual model of car ownership and car use

5. A SEM-MODEL FOR CAR OWNERSHIP AND CAR USE

First, we have to determine the model that best fits our data. As we already suggested, it seems that our dataset does not include the appropriate information to correctly determine the effect of residential self-selection. Model 1 and 3, including the relationship from socio-economic variables towards built environment, obtain the lowest model fit indices (Model 1 and 3: CFI = 0.884, TLI = -0.163, RMSEA = 0.151). This indicates that other variables than the selected socio-economic variables must be considered. Empirical studies on residential self-selection mention, among other, travel preferences. However, our dataset does not include information on travel preferences.

Best model fit indices are associated with model 2 and 4 (CFI = 0.999, TLI = 0.981, RMSEA = 0.022). However, model 2 explains a larger proportion of variance in car use (R^2 = 0.213) than model 4 (R^2 = 0.164). Unlike in model 4, car ownership mediates the relationship between the built environment and car use in model 2. Defining car ownership as a mediating variable, thus, adds explanatory power to the models. Model 2 is, therefore, discussed into detail.

Based on the analysis of direct, indirect and total effects, hypotheses described in Section 4.2 are verified.

As expected, car ownership is lower among people living in densely built neighborhoods. The same does not hold for land use mixing. Nevertheless, the effect of land use mixing is not significant. Most socio-economic variables obtain the expected effect on car ownership. Car ownership is positively related to education, owning a driving license, being married or cohabiting and household income and it is negatively related to age. Nevertheless, some variables, such as gender and the presence of young children, obtain unexpected effects. Females are found to own more cars, but the effect of gender is not significant. Car ownership is less high among households with young children. It might be argued that car ownership is influenced by the presence of older children (aged above 18 years) rather than the presence of young children. A household may need to own more cars when older children decide to live with their parents. For example, when these children graduate and finally find a job, an additional car is often needed to reach the job location.

Comparable conclusions can be drawn for car use. Living in a highly built and mixed use neighborhood is associated with less car use. Both aspects have the expected, and significant, effect on car use. Car use is positively related to the total effect of education, owning a driving license, being employed, being married or cohabiting, monthly household income, travel distance and car ownership. It is important to base these conclusions on the total effects. Total effects are the sum of direct and indirect effects. Focusing on direct effects only would lead to inconsistent conclusions in some cases. For example, it is believed that middle and high income families can afford it to own (several) cars and to travel by car. However, the direct effect of monthly household income on car use suggests the opposite. It is only through the indirect effect, caused by the interaction between car ownership and car use, that the total effect obtains the expected sign. As with car ownership, some variables do not have the expected outcome. Older people turn out to travel more by car. An interaction effect between age and having a physical limitation might be responsible for this result. Older people often have physical limitation that prevents them from using public transport and from traveling by bike and on foot. Using the car as a passenger is the only appropriate travel mode and, consequently, car use remains high among older people.

TABLE 3 Standardized direct, indirect and total effects on car ownership and car use

	CAR OWNERSHIP		
	Direct effect	**Indirect effect**	**Total effect**
Built environment			
entropy index (dominating land use)	-0.010	-	-0.010
built up index	-0.344*	-	-0.344
Socio-economic characteristics			
age	-0.006*	-	-0.006
gender (female)	0.004	-	0.004
education	0.009*	-	0.009
driving license	0.449*	-	0.449
employed	-0.133*	-	-0.133
marital status (married/cohabiting)	0.020	-	0.020
number of children < 6 y.	-0.033*	-	-0.033
number of cars	-	-	-
household income	0.427*	-	0.427
Travel behavior characteristics			
travel distance (km)	-	-	-

	CAR USE		
	Direct effect	**Indirect effect**	**Total effect**
Built environment			
entropy index (dominating land use)	0.496*	-0.004	0.492
built up index	-0.386*	-0.140	-0.527
Socio-economic characteristics			
age	0.004*	-0.002	0.002
gender (female)	0.059*	0.001	0.060
education	0.009	-0.008	0.001
driving license	0.723*	0.183	0.905
employed	0.210*	-0.054	0.156
marital status (married/cohabiting)	0.246*	0.008	0.254
number of children < 6 y.	-0.009	-0.013	-0.023
number of cars	0.407*	-	0.407
household income	-0.111*	0.174	0.063
Travel behavior characteristics			
travel distance (km)	0.003*	-	0.003

N = 19,263 trips, CFI = 0.999, TLI = 0.981, RMSEA = 0.022
* significant at $\alpha = 0.05$
\- = no effect defined

Based on the standardized total effects, variables can be distinguished that determine car ownership and car use to a large extent. It seems that car ownership is influenced by the built up density, owning a driving license and monthly household income. Obviously, the effect of owning a driving license is even more important for using a car. The effect of the built environment is more pronounced for car use than for car ownership. Hence, our analysis points out a well-defined influence of the built environment on car ownership and, especially, car use. Analyzing the standardized total effects also suggests a clear relationship between car ownership and car use. This confirms that car ownership can be considered as a mediating variable.

6. CONCLUSION

So far, empirical studies on travel behavior consider car ownership either as an aspect of travel behavior that must be explained or as a variable that explains other aspects of travel behavior (e.g., car use, travel distance, etc.). This paper aimed at combining both approach and deducing the meaning of car ownership as a mediating variable.

Since car ownership is considered as an independent and a dependent variable at the same time, statistical techniques such as regression analysis are no longer suitable. Structural equation modeling (SEM) is a more advanced modeling technique that can be used to disentangle the complexity of travel behavior. Within this paper, SEM is used to estimate the relationships between the built environment, car ownership and car use.

Because SEM is a confirmatory method, the modeling process must be guided by a conceptual model and hypotheses. A basic model is developed, including the effect of residential self-selection and the effect of car ownership as a mediating variable. Three variations on this basic model are identified as well. By comparing the overall fit of these four models, we found that car ownership truly mediates the relationship between the built environment and car use.

Comparing our results to result from other studies on the connection between the built environment and travel behavior points out that our model explains a quite large proportion of variance in car use ($R^2 = 0.213$). However, it also indicates that other variables must be taken into account to fully understand travel behavior. Some studies (e.g., *3, 41, 42*) suggest that personality characteristics, such as lifestyle, perceptions, attitudes and preferences, may add explanatory power.

However, our analysis clearly underlines the importance of the built environment. Unlike other studies (e.g. *4, 9, 19*), living in high density and mixed use neighborhoods is associated with less cars and, consequently, less car use. Urban planning policies can really influence travel behavior.

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