# Commuting trips within tours: how is commuting related to land use?

**Veronique Van Acker · Frank Witlox**

**Abstract**   Studies that model the effects of land use on commuting generally use a trip-based approach or a more aggregated individual-based approach: i.e. commuting is conceptualized in terms of modal choice, distance and time per single trip, or in terms of daily commuting distance or time. However, people try to schedule activities in a daily pattern and, thus, consider tours instead of trips. Data from the 2000 to 2001 Travel Behaviour Survey in Ghent (Belgium) illustrate that car use and commuting times significantly differ between commuting trips within work-only tours and more complex tours. Therefore, this paper considers trip-related decisions simultaneously with tour-related decisions. A multiple group structural equation model (SEM) confirmed that the relationship between land use and commuting differs between work-only tours and more complex tours. Trips should be considered within tours in order to correctly understand the effect of land use scenarios such as densifying on commuting. Moreover, the use of multiple group SEM enabled us to address the issue of the complex nature of commuting. Due to interactions between various explanatory variables, land use patterns do not always have the presumed effect on commuting. Land use policy can successfully influence commuting, but only if it simultaneously accounts for the effects on car availability, car use, commuting distance and commuting time.

**Keywords**   Commuting · Land use · Multiple group structural equation model · Ghent

## Introduction

In Belgium, like in other countries, the influence of land use on commuting remains an important issue for planners, urban policy makers and transport researchers. This concern is fed by the notable increase in commuting distances and times. In 2001 an average

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commuter travelled 19 km and spend 29 min on the journey to work (one-way trip to work), which is an increase of 1.8 km (or almost 10%) and 2 min (or almost 7%) compared to 1981 (Verhetsel et al. 2007). If this trend continues, Belgians will commute for about one hour per day in 2010 (N.N. 2001). Recent time use studies confirm this: Belgians commute on average 64 min to and from their workplace (Glorieux et al. 2008). These (slightly) increasing commuting times are mainly due to increasing commuting distances (especially long-distance commuting), but also due to more severe road congestion and, thus, decreasing commuting speeds (Mérenne et al. 1997; Verhetsel et al. 2007).

In order to find a solution to these growing transport problems in general, and commuting problems in particular, urban planners and transport policy makers have tried to integrate land use planning and transport planning. Because most travel is derived from the activities a person wants to participate in, changing the locations of these activities and modifying the design characteristics of these locations will alter travel patterns. Therefore, an integrated land use and transport policy would allow us to better alleviate today's transport problems. Illustrative are the New Urbanism movement in the USA (e.g., Greenwald 2003; Handy 2005) and the Compact City Policy in Europe (e.g., Maat et al. 2005; Schwanen et al. 2004a). The basic idea is that high-density and mixed-use neighbourhoods are believed to be associated with shorter trips and more non-motorized trips; hence, indicating a clear relationship between land use and travel behaviour.

Numerous studies have measured the strength of this relationship (for a review, see, e.g. Badoe and Miller 2000; Crane 2000; Ewing and Cervero 2001 for the USA; Stead and Marshall 2001; van Wee 2002 for Europe). Some studies (e.g., Cervero and Kockelman 1997; Meurs and Haaijer 2001) indicate that various land use characteristics are linked with travel behaviour, while others (e.g., Bagley and Mokhtarian 2002; Schwanen 2002) question whether these links indicate direct causality. These conflicting results might be caused by, among others, different research designs (e.g., cross-sectional versus longitudinal) and the use of a variety of geographical scales (e.g., neighbourhoods versus larger metropolitan areas), contexts (e.g., Western cities versus rapidly evolving cities), and conceptual and theoretical models (e.g., models with causal relations versus correlation models). Moreover, empirical studies often use a trip-based approach (e.g., Guo et al. 2007; Rajamani et al. 2003) or a more aggregated individual-based approach (e.g., Buliung and Kanaroglou 2006; Giuliano and Dargay 2006): i.e. travel behaviour is conceptualized in terms of modal choice, travel distance or travel time per trip or these aspects are aggregated into summary measures such as daily travel distance and daily travel time. However, activity-based studies point out that people do not make separate decisions considering only trips, but they try to schedule activities in a daily pattern and, thus, think about tours instead of trips (Bhat and Koppelman 1999; Jones et al. 1990; McNally 2000; Primerano et al. 2008). Consequently, trip characteristics might depend on tour characteristics. To our knowledge, tour characteristics such as tour frequency and tour complexity are generally used as dependent variables explained by land use patterns (e.g., Krizek 2003; Limanond and Niemeier 2004; Maat and Timmermans 2006). Only a few studies consider tour-related characteristics simultaneously with trip-related characteristics. For example, Frank et al. (2008) and Srinivasan (2002) analyzed how land use influences modal choices for trips in different tour types. This paper also focuses on trips *within* tours by comparing modal choice, more specifically car use, between work-only tours (i.e. home-work-home) and more complex tours (i.e. tours in which commuting trips are combined with other trips such as shopping or leisure trips). Moreover, we statistically test the differential influence of land use on car use between tour types.

The remainder of the paper is organized as follows. "Land use and commuting" section provides a brief literature review on land use and commuting. The dataset and the applied research design are described in "Research design" section. This is followed by "Methodological framework" section which describes the methodology of multiple group structural equation modelling. "Results" section describes the model results and, finally, in "Conclusions" section, some major conclusions are drawn.

## Land use and commuting

For most people, living and working are two spatially separated activities that necessitate some form of commuting. Changes in the spatial configuration of these activities are likely to influence commuting (Cervero and Seskin 1995; Handy 1992).

Many studies found density to be negatively associated with car ownership, car use, commuting distances and commuting times. For example, using Metropolitan Adelaide travel data, Soltani (2005) found that as density increases with 100 persons per hectare, the likelihood of owning more cars decreases with 4–6%. Similar results with respect to modal choice and commuting distance have been found by Schwanen et al. (2004b). Based on the 1998 Netherlands National Travel Survey, they stated that an increase in density of 100 residences per square kilometre is likely to result in 10% less commuting by car. Moreover, increasing job density at the residence is associated with shorter commuting distances. However, other studies such as Crane (2000) and Handy (1996) questioned the impact of density and emphasized that density might be merely a proxy for other correlated land use characteristics. Moreover, the influence of density on tour complexity (i.e., the number of stops per tour) is not well-understood. Some studies (e.g., Maat and Timmermans 2006; Strathman et al. 1994) suggest that higher densities are associated with more complex tours and less simple tours (out and back), whereas other studies find the opposite indicating that trips are chained into complex tours in order to compensate for locational deficiencies (e.g., Noland and Thomas 2007).

Another important aspect of land use is diversity. Higher diversities are believed to result in lower car ownership levels, lower car use, shorter commuting distances and shorter commuting times. For example, Potoglou and Kanarolgou (2008) calculated an entropy index and a mixed density index. The entropy index referred to the mixing of several land use types within walking distance (500 m) of the residence. The mixed density index, a combination of residential and employment density, can be considered a proxy of the jobs-housing balance (Ewing et al. 1994; Peng 1997). Using the CIBER-CARS survey (Hamilton, Canada), their results indicated that diversity negatively influences car ownership, especially the probability of owning two or more cars. Frank and Pivo (1994) also used an entropy index, but in relationship with modal choice for commuting. Based on travel data of the Puget Sound Area (USA), land use mixing was found to be significantly related to less car use and more walking and transit usage. Cervero (1996) investigated how the presence of retail shops within residential neighbourhoods influences commuting. The presence of nearby commercial land-uses was found to discourage car ownership, motorized commuting and long-distance commuting.

A third important land use characteristics is accessibility; a frequently used concept referring to the ability "to reach activities or locations by means of a (combination of) travel mode(s)" (Geurs and van Wee 2004). This definition already indicates to the relation with other land use characteristics, especially density. Higher densities increase the likelihood of having several opportunities within reach. Consequently, the impact of density

might be mediated through accessibility variables (e.g., Badoe and Miller 2000; Miller and Ibrahim 1998). Most studies agree on the effects of accessibility. For example, based on a sample from the Sacramento County (USA), Gao et al. (2008) found that households living in residential locations with higher job accessibility are likely to own fewer cars. Kitamura et al. (1997) found for five neighbourhoods in San Francisco that better accessibility levels by public transport result in more trips by public transport. Several studies also point out that accessibility is negatively associated with commuting times (e.g., Ewing et al. 1994; Shen 2000; Susilo and Maat 2007) and tour complexity (e.g., Krizek 2003; Limanond and Niemeier 2004).

Although there seems to be a lot of literature confirming the relationship between land use and commuting, the empirical evidence is somewhat contradictory and inconclusive. For example, others found personal and household characteristics to be more important determinants of modal choice and commuting distances (Dieleman et al. 2002), commuting time (Schwanen et al. 2002) and tour complexity (Cao et al. 2008).

Most studies only include residential land use characteristics since the residence is the origin of most trips. A limited amount of studies also include land use characteristics of the destination. For example, Chen et al. (2008) studied modal choices for commuting trips in the New York Metropolitan Region. They found that car use is discouraged by higher employment densities at work, in contrast to density measures at home which did not obtain a significant effect. Similar results were obtained by Chatman (2003), Ewing and Cervero (2001), and Shiftan and Barlach (2002).

Also, most recently, there is a growing interest in the issue of residential self-selection (e.g., Bagley and Mokhtarian 2002; Bhat and Guo 2007; Cao et al. 2006, Pinjari et al. 2007). This refers to the potential problem that people might self-select themselves into different residential neighbourhoods. People's residential choice might be based on their travel preferences, so that they are able to travel according to these preferences. Consequently, the connection between land use and travel behaviour is more a matter of residential choice. After controlling for residential self-selection, Bagley and Mokhtarian (2002) and Cao et al. (2006) found little effect of land use on travel behaviour, whereas Bhat and Guo (2007) and Pinjari et al. (2007) found the opposite. The results reported in this paper will be controlled for residential self-selection by considering a link between personal characteristics and residential land use characteristics, but it will not be discussed into detail.

Figure 1 summarizes the previously described relationships between land use and commuting. It includes all relationships that will be estimated and discussed in "Results" section.

Relationships also exist between several commuting aspects. Whereas most studies focus on one specific aspect of commuting, it might also be useful to consider several commuting aspects simultaneously. For example, some studies indicated that car ownership mediates the relationship between land use and modal choice (e.g., Chen et al. 2008; Schimek 1996; Simma and Axhausen 2003; Van Acker and Witlox 2010). Similar to Schwanen et al. (2002) and Susilo and Maat (2007), we suppose that modal choice is influenced by commuting distance, and commuting time is influenced by both commuting distance and modal choice. In most cases, workers always commute to the same workplace and, thus, commuting distance is unchangeable and might become a determinant of modal choices. Longer commuting distances will favour the decision to commute by car (e.g., Bhat 1997; Cervero 1996; Cervero and Kockelman 1997). Aside from the disturbing influence of congestion, commuting time is related to the velocity of the chosen travel mode and commuting distance. The car is a faster travel mode than public transport,
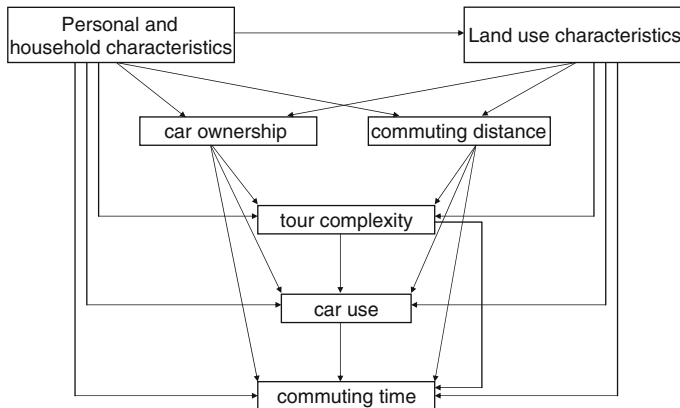
**Fig. 1** Land use and commuting

walking or biking, and will result in shorter commuting times. Being all else equal, shorter commuting times can also be the result of short commuting distances. Our analysis will clarify this aspect. Another example of interrelations among commuting aspects relates to tour complexity. Studies suggest that the tendency to undertake complex or simple tours varies systematically with car ownership and commuting distance (e.g., Krizek 2003; Maat and Timmermans 2006) and that the participation in complex tours increases the propensity to use the car (e.g., Chen et al. 2008; Hensher and Reves 2000; Ye et al. 2007).

## Research design

### Study area and data source

Our analysis is based on data from the 2000 to 2001 Ghent Travel Behaviour Survey. The study area comprises the urban region of Ghent which consists of the city of Ghent itself, a medium-sized city in Flanders, Belgium, and the surrounding urbanized villages (see Fig. 2). In 2000, the total population in this study area was about 315,166 inhabitants and the overall population density was 960.8 inhabitants/km$^2$. The survey yielded data on the travel behaviour of approximately 5,500 persons, including children over the age of six. In addition to information on personal and household characteristics, all participants had to complete a trip diary for two consecutive days. However, trips on the second day are reported less correctly (Witlox 2007; Zwerts et al. 2001) and, thus, omitted in further analyses.

### Study sample

We first classified each trip to the type of tour to which it belongs. A tour is defined as a sequence of trips that starts and ends at home. A work-only tour only includes trips for working activities (68.5% of all tours). Most work-only tours (88.6%) are very straightforward: one leaves home for work, stays at the workplace and returns in the evening. A small percentage of commuters (7.0%) spends, e.g., their lunch break at home and have multiple work-only tours during a single day. A small percentage of work-only tours include tours with multiple workplaces (11.4%). Most of these tours combine two stops for working purposes, but some tours might become complicated (i.e., up to ten work stops per tour).
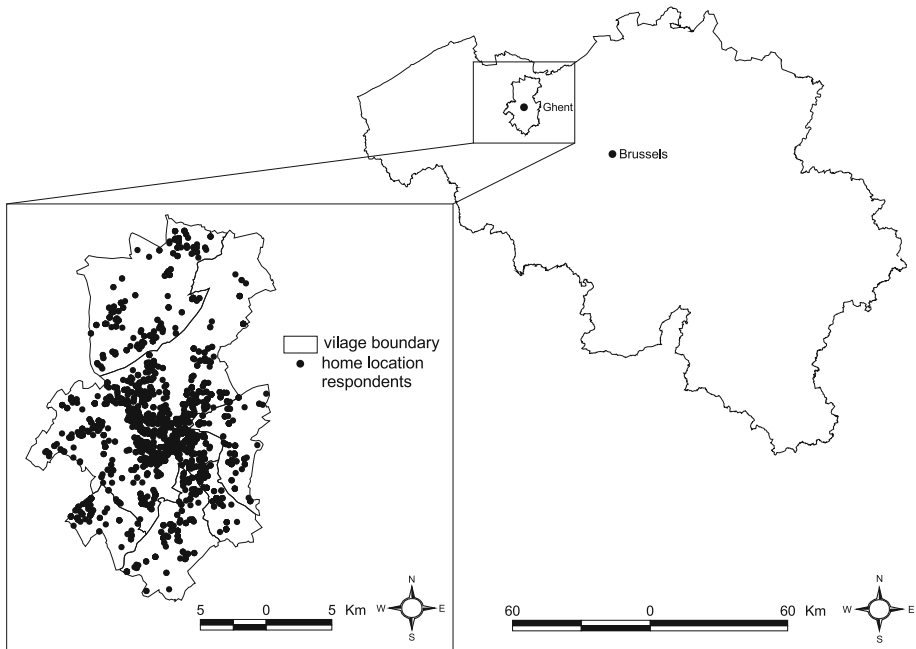
**Fig. 2** Study area and home locations of the selected respondents

A more complex tour combines trips for working ánd non-working activities (31.5% of all tours). For example, children are dropped off at school before going to work or some grocery shopping is done during lunch break. Second, we excluded the effects of long-distance commuting by selecting only trips less than 70 km's. This equals 95% of all commuting trips. Finally, only commuting trips of persons aged 18 years or older were selected ($N = 2,174$ trips). These persons are considered to undertake trips relatively independently. Moreover, in Belgium, the legal age at which one is allowed to drive is 18 years.

Land use characteristics, personal and household characteristics

Variables used in the analysis include land use characteristics of the residence and the workplace, personal and household characteristics and aspects of commuting (see Table 1).

Land use patterns of both the residence and the workplace are characterized by (i) job density, (ii) built-up index, (iii) land use mix, (iv) distance to the nearest bus stop and railway station, (v) distance to the CBD of Ghent, and (vi) accessibility by car. Job density at the TAZ level is defined as the number of jobs per square km and is obtained from the Multimodal Model Flanders, a regional travel demand forecasting model for 2001 in Flanders, Belgium. The size of TAZ's in this model equals to the size of one or a pair of census tracts. Job density is used here as an indicator for the density dimension; however, for the residence end of the commute trip it has also been used as a measure of the diversity dimension (e.g., Boarnet and Sarmiento 1998). Our data suggest that job density at the residence is statistically significant correlated with population density. However, since a job-related measure seems more relevant for commuting than an inhabitant-related measure, we preferred to use job density instead of population density. The built-up index at the

**Table 1** Summary of variables included in the analysis

|  | Minimum | Maximum | Average | SD |
|---|---|---|---|---|
| Land use characteristics at home |  |  |  |  |
| Job density (jobs/km$^2$) | 0.75 | 18,176.83 | 1,135.07 | 2,354.098 |
| Built-up index | 1.91 | 99.37 | 50.03 | 27.647 |
| Land use mix | 0.00 | 0.56 | 0.18 | 0.126 |
| Job/housing balance | 0.08 | 38.83 | 1.21 | 3.888 |
| Distance to bus stop (km) | 0.00 | 2.38 | 0.29 | 0.223 |
| Distance to railway station (km) | 0.21 | 16.99 | 5.47 | 3.724 |
| Distance to CBD (km) | 0.20 | 14.21 | 7.14 | 3.001 |
| Job accessibility, 15 min | 40,604 | 133,390 | 92,550.28 | 20,200.380 |
| Job accessibility, 30 min | 131,482 | 282,641 | 209,548.58 | 38,340,688 |
| Land use characteristics at work |  |  |  |  |
| Job density (jobs/km$^2$) | 3.85 | 44,777.24 | 2,734.67 | 6,053.266 |
| Built-up index | 0.32 | 100.00 | 55.11 | 29.968 |
| Land use mix | 0.00 | 1.00 | 0.18 | 0.131 |
| Job/housing balance | 0.08 | 2855.00 | 16.84 | 167.063 |
| Distance to bus stop (km) | 0.00 | 6.96 | 0.30 | 0.420 |
| Distance to railway station (km) | 0.15 | 19.41 | 4.21 | 3.165 |
| Distance to CBD (km) | 0.12 | 25.53 | 5.97 | 3.533 |
| Workplace accessibility, 15 min | 31,652 | 894,616 | 141,085.68 | 115,945.251 |
| Workplace accessibility, 30 min | 141,040 | 1,213,724 | 413,831.42 | 171,679.045 |
| Household characteristics |  |  |  |  |
| Household size | 1 | 11 | 2.86 | 1.299 |
| Children −6 years | 0 | 3 | 0.26 | 0.606 |
| Car availability | 0 | 5.0 | 0.80 | 0.390 |
| Personal characteristics |  |  |  |  |
| Age | 19 | 71 | 40.54 | 10.158 |
| Commuting characteristics |  |  |  |  |
| Commuting distance (km) | 0.00 | 90.00 | 15.77 | 20.096 |
| Commuting time (min) | 1 | 90 | 22.94 | 18.145 |
| Tour complexity (stops per tour) | 2 | 10 | 2.84 | 1.349 |
| *Frequency* |  |  |  |  |
| Land use characteristics at work |  |  |  |  |
| Parking difficulties | 79.8% no, 20.2% yes |  |  |  |
| Personal characteristics |  |  |  |  |
| Gender | 57.6% male, 42.4% female |  |  |  |
| Marital status | 72.8% married/cohabiting, 27.2% single |  |  |  |
| Car needed during work hours | 25.4% always, 28.1% often, 46.5% never |  |  |  |
| Employment | 83.4% full-time employed, 16.6% part-time employed |  |  |  |
| Household characteristics |  |  |  |  |
| Household income | 32.4% 0–1859 €, 47.2% 1860–3099 €, 20.4% +3100 € |  |  |  |

**Table 1** continued

|                  | Minimum | Maximum | Average | SD |
|------------------|---------|---------|---------|-----|
| Commuting characteristics | | | | |
| Car use | 29.4% no, 70.6% yes | | | |
| Tour type | 68.5% work only tour, 31.5% more complex tour | | | |

2,174 trips; 1,627 tours; 1,521 persons; 1,144 households; 217 residential neighbourhoods, 458 workplace neighbourhoods

census tract equals the percentage of built-up surface, and can be considered as a proxy for built-up density. It is derived from the land use database of the Agency of Spatial Information Flanders. The land use diversity index quantifies the degree of balance across residences, services and commerce, recreation and tourism, nature (parks, nature reserves and forests), agriculture, regional industry and local industry. Information is obtained from regional zoning plans and recalculated at the census tract level in ArcGIS 9.2 according to the equation (Bhat and Gossen 2004):

*Land use diversity* $=$

$$1 - \left[ \frac{\left|\frac{r}{T} - \frac{1}{8}\right| + \left|\frac{c}{T} - \frac{1}{8}\right| + \left|\frac{t}{T} - \frac{1}{8}\right| + \left|\frac{n}{T} - \frac{1}{8}\right| + \left|\frac{a}{T} - \frac{1}{8}\right| + \left|\frac{ri}{T} - \frac{1}{8}\right| + \left|\frac{li}{T} - \frac{1}{8}\right| + \left|\frac{o}{T} - \frac{1}{8}\right|}{\frac{14}{8}} \right] \quad (1)$$

with $r$ km$^2$ in residences; $c$ km$^2$ in services and commerces; $t$ km$^2$ in recreation and tourism; $n$ km$^2$ in nature; $a$ km$^2$ in agriculture; $ri$ km$^2$ in regional industry; $li$ km$^2$ in local industry; $o$ km$^2$ in other land use types; and $T = r + c + t + n + a + ri + li + o$.

A value of 0 means that the land use pattern is exclusively determined by a single land use, whereas a value of 1 indicates perfect mixing of different land uses. Distance to the nearest bus stop is calculated in ArcGIS 9.2 as the shortest path by car along the road network between the residence or the workplace and the nearest bus stop. Distances to the nearest railway station and the CBD of Ghent are similarly defined. Accessibility by car is calculated using the previously mentioned Multimodel Model Flanders. Residential job accessibility by car is expressed as the number of jobs that can be reached by car. It is basically the sum of the number of jobs of every TAZ in the region, weighted by the travel time from the residence to these TAZ's. Travel times are calculated in ArcGIS 9.2 as the fastest path by car along the road network. We restricted this travel time to 15 and 30 min in order to detect differences in local and more regional job accessibility. Workplace accessibility by car is defined in a similar way. But since workplace locations can encounter competition effects for employees, we express workplace accessibility as the number of employees (and not jobs) available for the workplace. Finally, land use patterns of the workplace are also characterized by the level of parking difficulties. Respondents were asked to report whether they encountered difficulties parking their car at work (0 = no, 1 = yes).

Personal characteristics include gender (0 = male, 1 = female), age, marital status (0 = married/cohabiting, 1 = single), car needed during work hours (three classes). Household characteristics include household size, number of children aged below 6 years, monthly household income (three classes) and the number of cars per person able to drive. The latter is the ratio between the number of cars and the number of people with a driving license in the household, and is a measure of car availability. Other personal and household characteristics such as education were not significant in our analysis. Therefore, these variables are not reported in Table 1.

Commuting is characterized by tour type, car use, commuting distance, commuting time and tour complexity. Tour type and car use are binary variables (tour type: 0 = work-only tour, 1 = more complex tour, car use: 0 = no car used, 1 = car used). As mentioned previously, a tour is defined as a sequence of trips that starts and ends at home. A work-only tour solely exists of commuting trips, whereas a more complex tour combines commuting trips with non-commuting trips. If the commuting trip within the tour is undertaken by car, the car use variable obtains a value of 1. Consequently, car use refers to the chosen mode for only the commuting trip. Commuting distance and commuting time refer to the travel distance and travel time of the work trip (home-work) within the tour. Finally, tour complexity represents the number of trips in the tour. For example, a home-work-home tour composes of two trips.

## Methodological framework

The variables discussed in the previous section will now serve as input for the estimation of a structural equation model (SEM). Structural equation modelling is a suitable methodological technique for handling complex relationships, which exist between land use and commuting as the brief literature review in "Land use and commuting" section has illustrated.

A SEM consists of a set of simultaneously estimated equations representing relationships between several exploratory and predicted variables. This results in one of the main advantages of SEM (e.g., compared to regression analysis): the modelling of mediating variables and, consequently, the distinction between total, direct and indirect effects. The fact that a variable can be an exploratory variable in one equation but a predicted variable in another equation, makes it necessary to distinguish between 'endogenous' and 'exogenous' variables rather than between 'dependent' and 'independent' variables. Exogenous variables are not influenced by any other variable. Contrary to endogenous variables which are influenced by other variables, either directly or indirectly (Kline 2005; Raykov and Marcoulides 2000; Van Acker et al. 2007). The relationships between exogenous and endogenous variables are represented by the structural model and are defined by the matrices (Hayduk 1987; Oud and Folmer 2008):

$$\boldsymbol{\eta} = \mathbf{B}\boldsymbol{\eta} + \boldsymbol{\Gamma}\boldsymbol{\xi} + \boldsymbol{\zeta} \tag{2}$$

with $\boldsymbol{\eta} = L \times 1$ matrix of endogenous variables, $\boldsymbol{\xi} = K \times 1$ matrix of exogenous variables, $\mathbf{B} = L \times L$ matrix of coefficients of the endogenous variables, $\boldsymbol{\Gamma} = K \times K$ matrix of coefficients of the exogenous variables, and $\boldsymbol{\zeta} = L \times 1$ matrix of residuals of the endogenous variables.

We used the software package M-plus 4.21 (Muthén and Muthén 2006) because it offers more facilities than other SEM software packages. For example, we defined car use as a binary variable and M-plus can model categorical endogenous variables. Moreover, M-plus has several estimation procedures that account for skewed distributed data. Given the fact that car use, commuting distance and commuting time are not normally distributed, the weighted least squares mean and variance adjusted (WLMSV) estimator is used to estimate the model. This estimator accounts for non-normally distributed data (Muthén and Kaplan 1985, 1992).

The estimation of a SEM is (usually) based on matching the observed covariances among $\boldsymbol{\eta}$ and $\boldsymbol{\xi}$ with the model-based covariances. The $\chi^2$-statistic measures the discrepancy between these observed and model-based covariance matrices and is a widely used index to evaluate model fit. However, $\chi^2$ values increase with sample size and, thus, models based on large sample sizes might be rejected even though small differences exist

between the observed and model-based covariance matrices. Therefore, SEM literature reports various alternative model fit indices which are mostly variations on the $\chi^2$-statistic (for an overview, see Cao et al. 2007; Van Acker and Witlox 2010). Tables 2 and 4 in "Results" section mention several of these model fit indices. Cut-off criteria for these model fit indices are: $\chi^2$ with $p$-value >0.05, Comparative Fit Index (CFI) >0.90, Tucker-Lewis (TLI) >0.90, Root Mean Square Error of Approximation (RMSEA) <0.05, Weighted Root Mean Square Residual (WRMR) <0.90 (Byrne 2001; Hu and Bentler 1999; Kline 2005; Yu 1999).

In this paper, we do not only focus on the relationships between variables depicted in Fig. 1. We also want to know whether these relationships differ between work-only tours and more complex tours. We assume that commuting trips in work-only tours are more influenced by land use patterns than commuting trips in more complex tours. In work-only tours, land use characteristics of merely the workplace should favour commuting decisions, and workplace characteristics should have a very straightforward influence on commuting. In more complex tours, working is combined with other non-working activities and, commuting decisions will, thus, not be based on the workplace characteristics only but also on the land use characteristics of all stops in this tour. For example, although the workplace offers good access by public transport, Vande Walle and Steenberghen (2006) found that someone will not commute by public transport if there is no easy access to public transport at other stops in the tour. A commonly used approach would be to consider tour complexity as an explanatory variable of commuting (as illustrated by Fig. 1). But this approach only estimates the magnitude and the significance of the effect of tour complexity on commuting. It remains unclear how the effects of land use characteristics on commuting vary *across* different tour types. The latter question could be addressed by performing analyses for each tour type separately, but instead, we advance a *multiple group* SEM. This model performs one single analysis in which parameters are estimated for both groups and hypotheses about both groups are tested *at once*. In this way, we can determine whether the relationship between land use and car use for commuting trips really differs between work-only tours and more complex tours and, thus, if trip characteristics are influenced by tour characteristics. As illustrated by Fig. 3, tour complexity is no longer considered as an
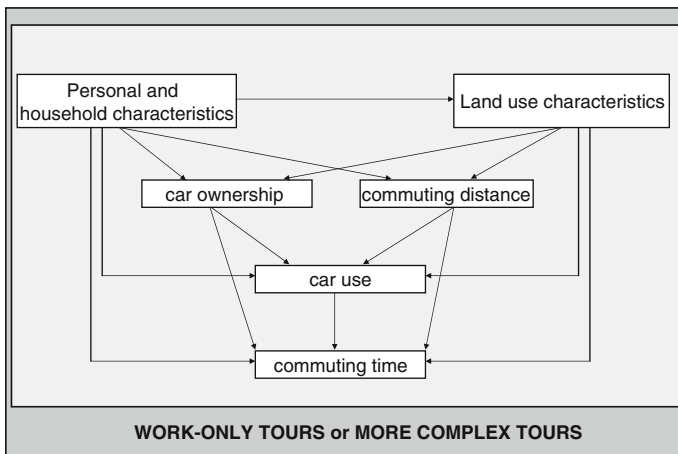


**Fig. 3** A multiple group SEM

endogenous variable in the model, but rather as outside the model defining the groups for which the model is tested.

A multiple group SEM is performed by the specification of one model with cross-group equality constraints and another model without such constraints. The fit of the constrained and unconstrained model can then be compared. A significantly worse fit of the constrained model indicates that parameters are not equal across groups (Kline 2005). In this analysis, we first constrained all parameters to be equal across commuting trips within work-only tours (=group 1) and more complex tours (=group 2). Second, we unconstrained the parameters of car use only. Contrary to car use, we assume that car ownership and commuting distance are not affected by the characteristics of the tour. The decisions to own a car and to commute over a specific distance are long-term decisions and happen at a very different level than the daily decision to perform a simple or complex tour (Salomon and Ben-Akiva 1983; Van Acker et al. 2010). Therefore, the parameters of car ownership and commuting distance were still constrained across both tour types.

## Results

In what follows we discuss several aspects of the multiple group SEM. Results are always controlled for the issue of residential self-selection by estimating the effect of income, household size and the presence of young children (−6 years) on residential land use characteristics.

Tour complexity as an endogenous variable or not?

A first question that has to be addressed is whether tour complexity should be considered as an endogenous variable (as depicted in Fig. 1) or as a variable outside the model that defines tour type (as depicted in Fig. 3). Both models have reasonably good model fit, so there are no reasons to favour the SEM with or without tour complexity based on model fit. Furthermore, neglecting tour complexity as an endogenous variable does not result in a misspecification of the land use effects on commuting. The magnitude and the significance levels of most model parameters are comparable for both models. Moreover, it does not result in lower values of explained variances (see Table 2). Consequently, it seems reasonable considering the less complicated model without tour complexity as an endogenous variable for further analyses.

Differences between work-only tours and more complex tours

Previous section confirmed tour complexity as a variable outside the model that defines tour type without introducing biases in the parameters in other equations of the SEM. Such a basic SEM reports the effect of tour complexity and land use separately from each other. But we are also interested in the "combined" effect of tour complexity and land use on commuting. Consequently, we also estimate a multiple group SEM which describes how coefficients of the land use variables differ between simple work-only tours and more complex tours. This difference is important since it is likely that land use effects commuting differently for various tour types. A multiple group SEM will, thus, depict which land use scenarios likely influence commuting for specific tour types.

**Table 2** Comparison of unstandardized total effects of two models with or without tour complexity

| | Model with tour complexity | | | | | Model without tour complexity | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Commuting distance | Car availability | Tour complexity | Car use | Commuting time | Commuting distance | Car availability | Car use | Commuting time |
| **Land use characteristics at home** | | | | | | | | | |
| Job density | – | –0.559* | –0.167* | –4.574* | 0.017 | – | –0.566* | –4.583* | 0.003 |
| Land use mix | – | – | – | –0.164* | 0.005* | – | – | –0.164* | 0.005* |
| Distance to bus stop | 0.168* | 0.288* | –0.067 | 0.461* | 0.123* | 0.170* | 0.294* | 0.470* | 0.123* |
| Distance to railway station | – | 0.177* | –1.216* | – | – | – | 0.171* | 0.118* | –0.004* |
| Job accessibility, 30 min | – | 0.129* | – | – | – | – | 0.129* | 0.089* | –0.003* |
| **Land use characteristics at work** | | | | | | | | | |
| Built-up index | – | – | 0.475* | – | –0.076* | – | – | – | –0.079* |
| Distance to railway station | 0.309* | – | –0.279* | 0.482* | 0.237* | 0.312* | – | 0.490* | 0.238* |
| Distance to CBD | – | – | – | – | –0.205* | – | – | – | –0.205* |
| Workplace accessibility, 15 min | 1.127* | – | 1.591* | 1.758* | 0.847* | 1.121* | – | 1.757* | 0.855* |
| Workplace accessibility, 30 min | – | – | –1.638* | – | – | – | – | – | – |
| Jobs/housing balance | – | – | – | – | 0.005* | – | – | – | 0.005* |
| Parking difficulties | – | –0.150* | –0.045* | –0.958* | –0.007 | – | –0.152* | –0.959* | –0.007 |
| **Household characteristics** | | | | | | | | | |
| Household size | – | –0.023** | –0.034* | 0.050* | 0.001 | – | –0.024* | 0.049* | 0.001 |
| Children −6 years | – | 0.065* | 0.236* | 0.045* | –0.003* | – | 0.065* | 0.045* | –0.001* |
| Income, 0–1,845 € (ref.) | – | – | – | – | – | – | – | – | – |
| Income, 1,860–3,099 € | 0.031** | 0.021* | 0.249* | 0.173* | 0.022* | 0.030** | 0.021* | 0.173* | 0.023** |
| Income, +3,100 € | 0.031** | 0.100* | 0.458* | 0.117* | 0.018 | 0.029** | 0.100* | 0.115* | 0.020 |
| Car availability | – | – | 0.298* | 0.689* | –0.023* | – | – | 0.693* | –0.022* |

**Table 2** continued

| | Model with tour complexity | | | | | Model without tour complexity | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Commuting distance | Car availability | Tour complexity | Car use | Commuting time | Commuting distance | Car availability | Car use | Commuting time |
| Personal characteristics | | | | | | | | | |
| Age | – | 0.182* | –1.660* | 0.125* | 0.007 | – | 0.188* | 0.130* | 0.054** |
| Gender, female | –0.023** | – | 0.021 | –0.036** | –0.018** | –0.024** | – | –0.037** | –0.018* |
| Marital status, single | – | 0.110* | 0.033* | 0.076* | –0.002* | – | 0.107* | 0.074* | –0.002* |
| Employment, part-time | – | 0.054** | 0.016 | 0.037** | –0.001 | – | 0.053* | 0.037** | –0.004 |
| Car work, never (ref.) | | | | | | | | | |
| Car work, often | – | 0.062** | 0.019 | 0.528* | –0.016* | – | 0.058** | 0.527* | –0.016* |
| Car work, always | – | 0.224* | 0.067* | 1.406* | –0.043* | – | 0.207* | 1.403* | –0.044* |
| Commuting characteristics | | | | | | | | | |
| Commuting distance | – | – | –0.904* | 1.560* | 0.808* | – | – | 1.567* | 0.811* |
| Tour complexity | – | – | – | – | –0.006* | – | – | – | – |
| Car use | – | – | – | – | –0.030* | – | – | – | –0.031* |
| $R^2$ | 24.7% | 16.9% | 10.8% | 47.5% | 73.8% | 24.6% | 16.2% | 47.5% | 73.3% |
| Model fit | | | | | | | | | |
| $X^2$ (df) p | 208.242 (89) 0.000 | | | | | 179.286 (80) 0.000 | | | |
| CFI, TLI | 0.941, 0.928 | | | | | 0.951, 0.939 | | | |
| RMSEA, WRMR | 0.038, 1.279 | | | | | 0.036, 1.248 | | | |

\* Significant at $\alpha = 0.05$, \*\* significant at $\alpha = 0.10$

*Descriptive analysis*

First, we highlight the differences in commuting between work-only tours and more complex tours. In work-only tours 67% of all commuting trips are undertaken by car, whereas this is somewhat higher in more complex tours (74%). On the other hand, commuting time is slightly longer in work-only tours (21.6 min) than in more complex tours (18.2 min). This is logical because of competing time demands: the time someone spends at non-working activities is less time that one has to commute. Although differences are small, a non-parametric Mann–Whitney U test specifies that these differences are indeed significant.

*Multiple group SEM*

Significant commuting differences exist between tour types. Therefore, we also check by means of a multiple group SEM whether the influence of land use on commuting trips differs between work-only tours and more complex tours.

   In a first step, the results of a fully constrained model are compared with an unconstrained model. Model fit is reasonably good for both models. However, a $\chi^2$ difference test ($\chi^2 = 90.89$, df = 11, $p = 0.000 < 0.050$) confirms that model parameters are not equal across work-only tours and more complex tours. Table 3 illustrates the consequences of neglecting the tour-based nature of travel. The direction of the relationship between land use and commuting are similar for the constrained and the unconstrained model. However, the size of the coefficients might differ significantly. Neglecting the tour-based nature of travel seems to result in an underestimation of the influence of residential characteristics for commuting trips within work-only tours (or an overestimation for commuting trips within more complex tours). This finding indicates the differential impact of land use when individuals travel in simple patterns or in more complex ways. Consequently, it is useful to examine the modelling results of the unconstrained model more into detail (see "Direct, indirect and total effects of work-only and more complex tours" section).

*Direct, indirect and total effects of work-only and more complex tours*

We assumed that commuting trips in more complex tours are less influenced by land use patterns, which is partly confirmed by our model results (see Table 4). Coefficients of land use characteristics at home are generally smaller in magnitude and less significant for commuting trips in more complex tours. Moreover, the opposite seems true for land use characteristics at work, but this only holds for car use. The differential influence of land use is less pronounced for commuting time. Workplace locations close to the nearest railway station, with poor car accessibility and difficult parking situations are associated with lower car use, even if the commuting trip is combined with other non-commuting trips. Such workplace locations are probably also characterized by more diversity. Non-commuting activities might, therefore, be performed nearby the workplace and individuals are not necessitated to commute by car after all. The differential influence of land use is less pronounced for commuting time.

   Land use does influence commuting, but not all commuting aspects are influenced in the same way. Residing in a high-density neighbourhood close to public transport is associated with fewer cars available and lower car use. More diversity is also associated with lower car use, but only for commuting trips in work-only tours. Due to the interaction between land use, car use and commuting, time, diversity also results in longer commuting times.

**Table 3** Model estimation results for car use and commuting time (unstandardized total effects)

| | Constrained model | | Unconstrained model | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | | | Work-only tour | | More complex tour | |
| | Car use | Commuting time | Car use | Commuting time | Car use | Commuting time |
| Land use characteristics at home | | | | | | |
| Job density | −4.373* | 0.022 | −6.412* | 0.043 | −2.993* | 0.014 |
| Land use mix | −0.172* | 0.005* | −0.335* | 0.013* | −0.056 | 0.001 |
| Distance to bus stop | 0.268* | 0.151* | 0.221* | 0.189* | 0.276* | 0.117* |
| Distance to railway station | 0.159* | −0.004* | 0.179* | −0.007* | 0.065 | −0.001 |
| Job accessibility, 30 min | 0.093** | −0.003** | 0.105 | −0.004 | 0.038 | 0.000 |
| Land use characteristics at work | | | | | | |
| Built-up index | – | −0.027 | – | −0.049** | – | 0.001 |
| Distance to railway station | 0.495* | 0.279* | 0.401* | 0.342* | 0.501* | 0.212* |
| Distance to CBD | – | −0.267* | – | −0.312* | – | −0.191* |
| Workplace accessibility, 15 min | 1.610* | 0.908* | 1.340* | 1.144* | 1.673* | 0.710* |
| Parking difficulties | −0.996* | 0.026* | −1.018* | 0.038* | −0.913* | 0.010** |
| Household characteristics | | | | | | |
| Household size | 0.047* | 0.000 | 0.071* | 0.000 | 0.036* | 0.000 |
| Children −6 years | 0.064* | −0.002* | 0.081* | −0.003* | 0.029** | 0.000 |
| Income, 0–1,845 € (ref.) | | | | | | |
| Income, 1,860–3,099 € | 0.126* | 0.003** | 0.190* | 0.004 | 0.093* | 0.003 |
| Income, +3,100 € | 0.083* | 0.004* | 0.098* | 0.005 | 0.044* | 0.005* |
| Car availability | 0.883* | −0.024* | 1.096* | −0.041* | 0.397* | −0.004 |
| Personal characteristics | | | | | | |
| Age | 0.149* | −0.004* | 0.193* | −0.007* | 0.070 | −0.001 |
| Gender, female | −0.026** | −0.015** | −0.023 | −0.019* | −0.028** | −0.012* |
| Marital status, single | 0.057* | −0.002* | 0.074* | −0.003* | 0.027 | 0.000 |
| Car work, never (ref.) | | | | | | |
| Car work, often | 0.600* | −0.016* | 0.464* | −0.017* | 0.950* | −0.011** |
| Car work, always | 1.400* | −0.038* | 1.457* | −0.055* | 1.324* | −0.015** |
| Commuting characteristics | | | | | | |
| Commuting distance | 1.343* | 0.757* | 1.123* | 1.001* | 1.402* | 0.611* |
| Car use | – | −0.027* | – | −0.038* | | −0.011** |
| Model fit | | | | | | |
| $X^2$ (df) $p$ | 336.883 (137) 0.000 | | 299.915 (133) 0.000 | | | |
| CFI, TLI | 0.930, 0.921 | | 0.942, 0.932 | | | |
| RMSEA, WRMR | 0.051, 1.841 | | 0.047, 1.732 | | | |

* Significant at $\alpha = 0.05$, ** significant at $\alpha = 0.10$

More diversity results in lower car use ($\beta = -0.335$) but lower car use does not result in shorter commuting times ($\beta = -0.038$), indicating that commuters travel by slower modes such as public transport and bike. The indirect effect of diversity on commuting time

**Table 4**  Model estimation results of the unconstrained model

| | Commuting distance | Car availability | Work-only tour | | More complex tour | |
|---|---|---|---|---|---|---|
| | | | Car use | Commuting time | Car use | Commuting time |
| Land use characteristics at home | | | | | | |
| Job density | – | −0.577* | −6.412* | 0.043 | −2.993* | 0.014 |
| | | −0.577* | −5.779* | −0.199* | −2.764* | −0.019 |
| Land use mix | – | – | −0.335* | 0.013* | −0.056 | 0.001 |
| | | | −0.335* | | −0.056 | |
| Distance to bus stop | 0.197* | – | 0.221* | 0.189* | 0.276* | 0.117* |
| | 0.197* | | | | | |
| Distance to railway station | – | 0.164* | 0.179* | −0.007* | 0.065 | −0.001 |
| | | 0.164* | | | | |
| Job accessibility, 30 min | – | 0.096** | 0.105 | −0.004 | 0.038 | 0 |
| | | 0.096** | | | | |
| Land use characteristics at work | | | | | | |
| Built-up index | – | – | – | −0.049** | – | 0.001 |
| | | | | −0.049** | | 0.001 |
| Distance to railway station | 0.357* | – | 0.401* | 0.342* | 0.501* | 0.212* |
| | 0.357* | | | | | |
| Distance to CBD | – | – | – | −0.312* | – | −0.191* |
| | | | | −0.312* | | −0.191* |
| Workplace accessibility, 15 min | 1.193* | – | 1.340* | 1.144* | 1.673* | 0.710* |
| | 1.193* | | | | | |
| Parking difficulties | – | −0.155* | −1.018* | 0.038* | −0.913* | 0.010** |
| | | −0.155* | −0.848* | | −0.851* | |
| Household characteristics | | | | | | |
| Household size | – | −0.015 | 0.071* | 0 | 0.036* | 0 |
| | | −0.026* | | | | |
| Children −6 years | – | 0.074* | 0.081* | −0.003* | 0.029** | 0 |
| | | 0.077* | | | | |
| Income, 0–1,845 € (ref.) | | | | | | |
| Income, 1,860–3,099 € | 0.005* | 0.017* | 0.190* | 0.004 | 0.093* | 0.003 |
| Income, +3,100 € | 0.008* | 0.081* | 0.098* | 0.005 | 0.044* | 0.005* |
| | | 0.073* | | | | |
| Car availability | – | – | 1.096* | −0.041* | 0.397* | −0.004 |
| | | | 1.096* | | 0.397* | |
| Personal characteristics | | | | | | |
| Age | – | 0.176* | 0.193* | −0.007* | 0.07 | −0.001 |
| | | 0.176* | | | | |
| Gender, female | −0.020* | – | −0.023 | −0.019* | −0.028** | −0.012* |
| | −0.020* | | | | | |
| Marital status, single | – | 0.067* | 0.074* | −0.003* | 0.027 | 0 |
| | | 0.067* | | | | |

**Table 4** continued

| | Commuting distance | Car availability | Work-only tour | | More complex tour | |
|---|---|---|---|---|---|---|
| | | | Car use | Commuting time | Car use | Commuting time |
| Car work, never (ref.) | | | | | | |
| Car work, often | – | 0.091* | 0.464* | −0.017* | 0.950* | −0.011** |
| | | *0.091* | *0.365* | *–* | *0.914* | *–* |
| Car work, always | – | 0.231* | 1.457* | −0.055* | 1.324* | −0.015** |
| | | *0.231* | *1.204* | | *1.232* | |
| Characteristics | | | | | | |
| Commuting distance | – | – | 1.123* | 0.958* | 1.402* | 0.595* |
| | | | *1.123* | *1.001* | *1.402* | *0.611* |
| Car use | – | – | – | −0.038* | – | −0.011* |
| | | | | *−0.038* | | *−0.011* |

* Significant at α = 0.05, ** significant at α = 0.10, direct effect shown in *italics*, – no effect found

through car use (0.013 = −0.335 × −0.038) consequently suggests that more diversity results in longer commuting times. Commuting distances are less influenced by land use characteristics at home: it is only influenced by the distance between the residence and the nearest bus stop.

We also tested the influence of land use characteristics at work. Parking difficulties at the workplace seem to decrease car availability indicating that workplace characteristics might influence the decision on owning a car, an important factor of car availability. Consequently, people might commute by slower travel modes, resulting in lower car use and, thus, longer commuting times. Longer commuting times might also be the result of longer commuting distances. For example, longer distances to the nearest railway station characterize remote workplace locations and, thus, are likely to be associated with longer commuting distances. Longer commuting distances on its turn are related with longer commuting times, resulting in a positive association between distance to the nearest railway station and commuting times after all. On the other hand, our data also suggest that longer distances between the workplace and the CBD of Ghent are negatively associated with commuting time. Workplace accessibility by car has the presumed effect on car use: workplaces with good car accessibility within 15 min are likely to encourage car use. However, commuting times are not shortened due to higher car use. This is again the result of the interaction between land use, commuting distance and commuting time.

These interactions between commuting aspects clearly illustrate the usefulness of SEM: we are no longer limited to focus on the relationship between land use and one single aspect of commuting (e.g., commuting time). Other commuting aspects can act as mediating variables. For example, in our model car use mediates the relationship between land use and commuting time. Because of such mediating variables, indirect effects of land use occur. Some of these indirect effects have been discussed above and we cannot stress the importance of this finding enough. For example, our analysis supports the view that commuting time can be influenced by land use policies but mainly indirectly. Using a simple regression analysis, researchers might conclude that a relationship exists between land use and commuting time while neglecting the fact that this is particularly an indirect

relationship. Higher densities, more diversity and better access to public transport can result in shorter commuting times but only through the interaction with commuting distance. If such land use policies enable commuters to shorten their commuting distances in the first place, lower commuting times become possible. A relationship between land use and commuting exists, but one should be aware of the direct and indirect nature of this relationship.

## Conclusions

With this paper we aimed to contribute to the existing research debate on the relationship between land use and commuting. In all, three important points can be made. First of all, many empirical studies focus on single trips, whereas activity-based studies recognize that people combine trips for different activities into one single tour (Hanson 2004). This study, therefore, analyzed commuting trips *within* different types of tours. By estimating a multiple group SEM, we found a more pronounced effect of land use on commuting in simple work tours compared to more complex tours, suggesting that research should consider trip-related characteristics together with tour-related characteristics.

Second, empirical studies tend to describe land use by spatial characteristics of the residence only since this is an important origin for most trips. Nevertheless, spatial characteristics of the destination are important as well. Since our analysis focused on commuting, we also included land use characteristics of the workplace. Our analysis confirmed that workplace characteristics significantly influence car availability, car use, commuting distances and commuting times. This corresponds to the results of a limited number of studies that also include workplace characteristics (e.g., Chen et al. 2008; de Abreu e Silva et al. 2006).

The third issue relates to the complex nature of commuting. A SEM enabled us to disentangle various commuting aspects (car use, commuting distance and commuting time) and their relationship with each other as well as with land use. Other studies such as de Abreu e Silva and Goulias (2009) also pointed out the utility of SEM in travel behaviour research. They remarked that land use influences daily travel behaviour mainly indirectly through the interaction with long-term decisions on commuting distance, car ownership and transit pass ownership. In our analysis, we also found that the effect of land use on commuting might not be as straightforward as initially expected, due to interactions among various travel aspects. For example, the effects of land use on commuting time could plausibly be in either direction. On the one hand, densely built and mixed-use neighbourhoods are associated with lower car use and, consequently, longer commuting times. On the other hand, these neighbourhoods are also associated with shorter commuting distances and, consequently, shorter commuting times. Our analysis clarified that the first is true for residential land use patterns, whereas the latter seems to hold for workplace locations. For example, residential land use patterns do not seem to have the presumed effect on commuting time: commuting times are longer in residential neighbourhoods with high-densities, mixed-use and easy access to pubic transport. However, this is due to the indirect effect of land use through car use. Commuting times are not directly lengthened because of density, diversity and access to public transport, but because of lower car use. This suggests that land use policies that only focus on reducing commuting times could fail because such policies are also likely to result in less car use and, consequently, more use of slower travel modes. The latter is however without doubt also a positive consequence of these land use policies. On the other hand, the opposite holds for workplace locations. Poor

car accessibility and short distances between the workplace and public transport are associated with shorter commuting distances, and thus shorter commuting times as well. Again, these shorter commuting times are simply and solely the result of the interaction with commuting distance. All these findings suggest that land use policy can successfully reduce commuting times, but only if it accounts for the land use patterns of the residence as well as the workplace, and for the land use effects on car use and commuting distance at the same time.

## References

Badoe, D.A., Miller, E.J.: Transportation—land-use interaction: empirical findings in North America, and their implications for modelling. Transp. Res. D **5**, 235–263 (2000)

Bagley, M.N., Mokhtarian, P.L.: The impact of residential neighborhood type on travel behavior: a structural equation modeling approach. Ann. Reg. Sci. **36**, 279–297 (2002)

Bhat, C.R.: Work travel mode choice and number of non-work commute stops. Transp. Res. B **31**, 41–54 (1997)

Bhat, C.R., Gossen, R.: A mixed multinomial logit model analysis of weekend recreational episode type choice. Transp. Res. B **38**, 767–787 (2004)

Bhat, C.R., Guo, J.Y.: A comprehensive analysis of built environment characteristics on household residential choice and auto ownership levels. Transp. Res. B **41**, 506–526 (2007)

Bhat, C.R., Koppelman, F.S.: Activity-based modeling of travel demand. In: Hall, R.W. (ed.) Handbook of Transportation Science, pp. 39–65. Kluwer Academic Publishers, Norwell (1999)

Boarnet, M., Sarmiento, S.: Can land use policy really affect travel behavior ? A study of the link between non-work travel and land use characteristics. Urban Stud. **35**, 1155–1169 (1998)

Buliung, R.N., Kanaroglou, P.S.: Urban form and household activity-travel behavior. Growth Chang. **37**, 172–199 (2006)

Byrne, B.M.: Structural Equation Modeling with AMOS Basic Concepts Applications and Programming. Lawrence Erlbaum Associated, Mahwah (2001)

Cao, X.Y., Handy, S.L., Mokhtarian, P.L.: The influences of the built environment and residential self-selection on pedestrian behaviour: evidence from Austin, TX. Transportation **33**, 1–20 (2006)

Cao, X.Y., Mokhtarian, P.L., Handy, S.L.: Do changes in neighborhood characteristics lead to changes in travel behavior ? A structural equations modeling approach. Transportation **34**, 535–556 (2007)

Cao, X.Y., Mokhtarian, P.L., Handy, S.L.: Differentiating the influence of accessibility, attitudes, and demographics on stop participation and frequency during the evening commute. Environ. Plan. B **35**, 431–442 (2008)

Cervero, R.: Mixed land-uses and commuting: evidence from the American housing survey. Transp. Res. A **30**, 361–377 (1996)

Cervero, R., Kockelman, K.: Travel demand and the 3D's: density, diversity and design. Transp. Res. D **2**, 199–219 (1997)

Cervero, R., Seskin, S.: An Evaluation of the Relationships Between Transit and Urban Form, National Research Council. Transportation Cooperative Research Program, Washington, DC (1995)

Chatman, D.: How density and mixed uses at the workplace affect personal commercial travel and commute mode choice. Transp. Res. Rec. **1831**, 193–201 (2003)

Chen, C., Gong, H., Paaswell, R.: Role of the built environment on mode choice decisions: additional evidence on the impact of density. Transportation **35**, 285–299 (2008)

Crane, R.: The influence of urban form on travel: an interpretive review. J. Plan. Lit. **15**, 3–23 (2000)

de Abreu e Silva, J., Goulias, K.G.: A structural equations model of land use patterns, location choice, and travel behavior in Seattle and comparison with Lisbon. In: Paper presented at the 88th Transportation Research Board Annual Meeting, Washington, DC (2009)

de Abreu e Silva, J., Golob, T.F., Goulias, K.G.: Effects of land use characteristics on residence and employment location and travel behaviour of urban adult workers. Transp. Res. Rec. **1977**, 121–131 (2006)

Dieleman, F.M., Dijst, M., Burghouwt, G.: Urban form and travel behaviour: micro-level household attributes and residential context. Urban Stud. **39**, 507–527 (2002)

Ewing, R., Cervero, R.: Travel and the built environment: a synthesis. Transp. Res. Rec. **1780**, 87–114 (2001)

Ewing, R., Haliyur, P., Page, G.W.: Getting around a traditional city, a suburban planned unit development, and everything in between. Transp. Res. Rec. **1466**, 53–62 (1994)

Frank, L.D., Pivo, G.: Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit and walking. Transp. Res. Rec. **1466**, 44–52 (1994)

Frank, L., Bradley, M., Kavage, S., Chapman, J., Lawton, K.: Urban form, travel time, and cost relationships with tour complexity and mode choice. Transportation **35**, 37–54 (2008)

Gao, S., Mokhtarian, P.L., Johnston, R.A.: Exploring the connections among job accessibility, employment, income, and auto ownership using structural equation modeling. Ann. Reg. Sci. **42**, 341–356 (2008)

Geurs, K.T., van Wee, B.: Accessibility evaluation of land-use and transport strategies: review and research directions. J. Transp. Geogr. **12**, 127–140 (2004)

Giuliano, G., Dargay, J.: Car ownership, travel and land use: a comparison of the US and Great Britain. Transp. Res. A **40**, 106–124 (2006)

Glorieux, I., Minnen, J., van Tienoven, T.P.: Tijdsbesteding in België. Veranderingen in Tijdsbesteding tussen 1999 en 2005. (Time-Use in Belgium. Changes in Time Use Between 1999 and 2005). Vrije Universiteit Brussel, Vakgroep Sociologie, Onderzoeksgroep TOR, Brussel (2008)

Greenwald, M.J.: The road less travelled—New urbanist inducements to travel mode substitution for nonwork trips. J. Plan Educ. Res. **23**, 39–57 (2003)

Guo, J.Y., Elhat, C.R., Copperman, R.B.: Effects of the built environment on motorized and nonmotorized trip making—subjective, complementary, or synergistic ? Transp. Res. Rec. **2010**, 172–199 (2007)

Handy, S.: How Land Use Patterns Affect Travel Patterns. Council of Planning Librarians, Chicago (1992)

Handy, S.: Methodologies for exploring the link between urban form and travel behavior. Transp. Res. D **1**, 151–165 (1996)

Handy, S.: Smarth growth and the transportation—land use connection: what does the research tell us ? Int. Reg. Sci. Rev. **28**, 146–167 (2005)

Hanson, S.: The context of urban travel: concepts and recent trends. In: Hanson, S., Guiliano, G. (eds.) The Geography of Urban Transportation, pp. 1–29. The Guildford Press, New York (2004)

Hayduk, L.A.: Structural Equation Modeling with LISREL. Essentials and Advances. John Hopkins University Press, Baltimore (1987)

Hensher, D.A., Reves, A.J.: Trip chaining as a barrier to the propensity to use public transport. Transportation **27**, 341–361 (2000)

Hu, L., Bentler, P.M.: Cutoff criteria for fit indices in covariance structure analysis. Conventional criteria versus new alternatives. Struct. Equ. Model **6**, 1–55 (1999)

Jones, P.M., Koppelman, F.S., Orfeuil, J.P.: Activity analysis: state of the art and future directions. In: Jones, P. (ed.) Developments in Dynamic and Activity-Based Approaches to Travel Analysis, pp. 34–55. Gower, Aldershot (1990)

Kitamura, R., Mokhtarian, P.L., Laidet, L.: A micro-analysis of land use and travel in five neighbourhoods in the San Francisco Bay Area. Transportation **24**, 125–158 (1997)

Kline, R.B.: Principles and Practice of Structural Equation Modeling. Guilford Pres, New York (2005)

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

Limanond, T., Niemeier, D.A.: Effect of land use on decisions of shopping tour generation: a case study of three traditional neighbourhoods in WA. Transportation **31**, 153–181 (2004)

Maat, K., Timmermans, H.: Influence of land use on tour complexity—a Dutch case. Transp. Res. Rec. **1977**, 234–241 (2006)

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

McNally, M.G.: The activity-based approach. In: Hensher, D.A., Button, K.J. (eds.) Handbook of Transport Modeling, pp. 53–69. Pergamon, Oxford (2000)

Mérenne, B., Van der Haegen, H., Van Hecke, E.: België ruimtelijk doorgelicht (Belgium: spatially investigated). Tijdschr van het Gem **51**, 1–144 (1997)

Meurs, H., Haaijer, R.: Spatial structure and mobility. Transp. Res. D **6**, 429–446 (2001)

Miller, E.J., Ibrahim, A.: Urban forms and vehicular travel: some empirical findings. Transp. Res. Rec. **1617**, 18–27 (1998)

Muthén, B., Kaplan, D.: A comparison of some methodologies for the factor analysis of non-normal Likert variables. Br. J. Math. Stat. Psychol. **38**, 171–189 (1985)

Muthén, B., Kaplan, D.: A comparison of some methodologies for the factor analysis of non-normal Likert variables: a note on the size of the model. Br. J. Math. Stat. Psychol. **45**, 19–30 (1992)

Muthén, L.K., Muthén, B.O.: Mplus User's Guide, 4th edn. Muthén & Muthén, Los Angeles (2006)

N.N.: Ontwerp Mobiliteitsplan Vlaanderen (A First Draft of the Mobility Plan Flanders). Ministerie van de Vlaamse Overheid, Brussel (2001)

Noland, R.B., Thomas, J.V.: Multivariate analysis of trip-chaining behavior. Environ. Plan. B **34**, 953–970 (2007)

Oud, J.H.L., Folmer, H.: A structural equation approach to models with spatial dependence. Geogr. Anal. **40**, 152–166 (2008)

Peng, Z.R.: The jobs-housing balance and urban commuting. Urban Stud. **34**, 1215–1235 (1997)

Pinjari, A.R., Pendyala, R., Bhat, C.R., Waddell, P.A.: Modeling residential sorting effects to understand the impacts of the built environment on commute mode choice. Transportation **34**, 557–573 (2007)

Potoglou, D., Kanarolgou, P.S.: Modelling car ownership in urban areas: a case study of Hamilton, Canada. J. Transp. Geogr. **16**, 42–54 (2008)

Primerano, F., Taylor, M.A.P., Pitaksringkarn, L., Tisato, P.: Defining and understanding trip chaining behaviour. Transportation **35**, 55–72 (2008)

Rajamani, J., Bhat, C.R., Handy, S., Knaap, G., Song, Y.: Assessing impact of urban form measures on nonwork trip mode choice after controlling for demographic and level-of-service effects. Transp. Res. Rec. **1831**, 158–165 (2003)

Raykov, T., Marcoulides, G.A.: A First Course in Structural Equation Modeling. Lawrence Erlbaum Associates, Mahwah, New Jersey (2000)

Salomon, I., Ben-Akiva, M.: The use of the life-style concept in travel demand models. Environ. Plan. A **15**, 623–638 (1983)

Schimek, P.: Household motor vehicle ownership and use: how much does residential density matter? Transp. Res. Rec. **1552**, 120–125 (1996)

Schwanen, T.: Urban form and: a cross-European perspective. Tijdschr voor Econ en Soc Geogr **93**, 336–343 (2002)

Schwanen, T., Dijst, M., Dieleman, F.M.: A microlevel analysis of residential context and travel time. Environ. Plan. A **34**, 1487–1507 (2002)

Schwanen, T., Dijst, M., Dieleman, F.M.: Policies for urban form and their impact on travel: the Netherlands experience. Urban Stud. **41**, 579–603 (2004a)

Schwanen, T., Dieleman, F.M., Dijst, M.: The impact of metropolitan structure on commute behavior in the Netherlands: a multilevel approach. Growth Chang. **35**, 304–333 (2004b)

Shen, Q.: Spatial and social dimensions of commuting. J. Am. Plan. Assoc. **66**, 68–82 (2000)

Shiftan, Y., Barlach, Y.: Effect of employment site characteristics on commute mode choice. Transp. Res. Rec. **1781**, 19–25 (2002)

Simma, A., Axhausen, K.W.: Interactions between travel behaviour, accessibility and personal characteristics: the case of Upper Austria. Eur. J. Transp. Infrastruct. Res. **3**, 179–197 (2003)

Soltani, A.: Exploring the impacts of built environments on vehicle ownership. In: Satoh, K. (ed.) Proceedings of the Eastern Asia Society for Transportation Studies, pp. 2151–2163 (2005)

Srinivasan, S.: Quantifying spatial characteristics of cities. Urban Stud. **39**, 2005–2028 (2002)

Stead, D., Marshall, S.: The relationships between urban form and travel patterns. An international review and evaluation. Eur. J. Transp. Infrastruct. Res. **1**, 113–141 (2001)

Strathman, J.G., Dueker, K.J., Davis, J.S.: Effects of household structure and selected travel characteristics on trip chaining. Transportation **21**, 23–45 (1994)

Susilo, Y.O., Maat, K.: The influence of built environment to the trends in commuting journeys in the Netherlands. Transportation **34**, 589–609 (2007)

Van Acker, V., Witlox, F.: Car ownership as a mediating variable in car travel behaviour research using a structural equation modelling approach to identify its dual relationship. J. Transp. Geogr. **18**, 65–74 (2010)

Van Acker, V., Witlox, F., van Wee, B.: The effects of the land use system on travel behaviour: a structural equation modelling approach. Transp. Plan. Techol. **30**, 331–354 (2007)

Van Acker, V., van Wee, B., Witlox, F.: When transport geography meets social psychology: toward a conceptual model of travel behaviour. Transp. Rev. **30**, 219–240 (2010)

van Wee, B.: Land use and transport: research and policy challenges. J. Transp. Geogr. **10**, 259–271 (2002)

Vande Walle, S., Steenberghen, T.: Space and time related determinants of public transport use in trip chains. Transp. Res. **40**, 151–162 (2006)

Verhetsel, A., Thomas, I., Van Hecke, E., Beelen, M.: Pendel in België. Deel I: De Woon-Werkverplaatsingen. (Commuting in Belgium. Par I: Commuting trips). FOD Economie. K.M.O, Middenstand en Energie, Brussel (2007)

Witlox, F.: Evaluating the reliability of reported distance data in urban travel behaviour analysis. J. Transp. Geogr. **15**, 172–183 (2007)

Ye, X., Pendyala, R.M., Gottardi, G.: An exploration of the relationship between mode choice and complexity of trip chaining patterns. Transp. Res. B **41**, 96–113 (2007)

Yu, C.-Y.: Evaluating cutoff criteria of model fit indices for latent variable models with binary and continuous outcomes. PhD dissertation, Graduate School of Education and Information Studies, University of California, Los Angeles, CA (1999)

Zwerts, E., Nuyts, E.: Onderzoek Verplaatsingsgedrag Stadsgewest Gent (januari 2000–januari 2001). Deel 3A: Analyse Personen Vragenlijst (Travel Behaviour Survey Ghent Urban Region (January 2000–January 2001). Part 3A: Analysis Personal Questionnaire). Provinciale Hogeschool Limburg, Hasselt (2001)

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