

EXPLORING THE RELATIONSHIPS BETWEEN LAND-USE SYSTEM AND TRAVEL BEHAVIOUR: SOME FIRST FINDINGS

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Veronique Van Acker¹, Frank Witlox²

¹ Department of Geography, Ghent University, Krijgslaan 281 - S8, B-9000 Gent.
e-mail: Veronique.VanAcker@UGent.be (corresponding author)

² Department of Geography, Ghent University, Krijgslaan 281 - S8, B-9000 Gent.
e-mail: Frank.Witlox@UGent.be

Abstract

Theories on the reciprocal relationships between land-use and transport address changes in location decisions and travel behaviour of private actors (households and firms) due to alternations in the transport system, respectively land-use system.

Although the impact of land-use system on travel behaviour has been the subject of much research (for reviews, see, e.g. Handy, 2002; Stead and Marshall, 2001; Crane, 2000; Wegener and Fürst, 1999), there is still no consensus about the strength of this relationship. One explanation may be the changing impact of different types of variables influencing the problem. Initially only land-use variables were taken into account, but nowadays socio-economic variables are also incorporated. Still, within 'homogeneous groups', there may be attitudes, lifestyles, perceptions, and preferences which can have an impact on land-use and/or travel behaviour. Academic literature on the latter remains scarce and the main focus of the existing behavioural literature is the impact of residential location on travel choices, especially modal choice. However, little work has thus far been done on other dimensions of travel choices (e.g., distance, time) and other location types (e.g., commercial, industrial, recreational).

Less is known about the reverse relationship, e.g. the impact of the transport system on location decisions of households and firms (land-use system). A difference in time-scale is a problem. After all, transformations in land-use occur much slower (years) compared to transformations in travel behaviour (days, weeks, months).

In this paper we explore several possibilities to fill in some of the gaps in the knowledge on the land-use/transport system. Understanding the two-way interaction between land-use and travel behaviour involves having (i) data on land-use patterns, socio-economic background of individuals and their attitudes, perceptions and preferences towards land-use and travel; and (ii) a methodology, dealing with potential multiple directions of causality. The first issue can be achieved by combining empirical, revealed and stated preference research. The second methodological question can be solved using structural equation modelling (SEM). This is a modelling technique which can handle a large number of endogenous and exogenous variables. Because of the multiple directions of causality that can be explored, SEM can help us to define the relationship between revealed preference data and stated preference data.

Key words

Land-use/transport system, Travel behaviour, Attitude measurement, Structural equation modelling.

INTRODUCTION

Theories on the reciprocal relationships between land-use and transport address changes in location decisions and travel behaviour of private actors (households and firms) due to alternations in the transport system, respectively land-use system. Although the land-use/transport system (often referred to as LUTS) has been subject of many research studies, almost none of these studies present a clear definition of this system.

The large body of literature on the LUTS reports on the impact of the land-use system on travel behaviour on the one hand, and on the effects of the transport system on land-use on the other hand. Both directions of impact are hardly ever incorporated in one single study. The research done by Mitchell and Rapkin's (1954) is considered to be one of the first studies that deal with trying to explore the impact of the land-use system on travel behaviour. Although it is clear that up till now our knowledge on the travel consequences of land-use has certainly increased, there is no consensus on the strength of this relationship. Some studies (e.g. Newman & Kenworthy, 1989; Frank & Pivo, 1994; Ewing, 1995; Cervero & Kockelman, 1997; Meurs & Haaijer, 2001) indicate that various aspects of land-use are linked with travel behaviour, while others (e.g. Kitamura et al., 1997; Boarnet & Sarmiento, 1998; Bagley & Mokhtarian, 2002; Schwanen, 2003) found lower effects or virtually no effect at all. A possible explanation may be found in that different research techniques have been applied, and that different types of explanatory variables were included in the research. Based on a literature review, a three-fold distinction could be made of this research. Initially only land-use variables were taken into account, although soon results were controlled for socio-economic and socio-demographic variables. At present researchers agree on the incorporation of these control variables. However, within so-called 'homogeneous groups' (i.e. respondents that are to be considered more or less identical - van Wee, 2002) there may be attitudes, lifestyles, perceptions and preferences which also have an impact on land-use and/or travel behaviour. It seems that nowadays more attention is paid to these behavioural aspects of land-use and transport. The reverse relationship, the impact of the transport system on land-use, has less been subject of research. Here the research mainly concentrated on accessibility and how it influences land-use patterns. Hansen's contribution (1959) on the impact of accessibility to employment, population and shopping opportunities may be considered path breaking.

The two above mentioned approaches clearly demonstrate the difficulty of the problem whereby initial focus, type of model, and methodology used may differ a lot. The aim is to try to summarise what is commonly accepted when analysing the relationships between land-use and transport. First, in section 1, we define the problem. Section 2 gives an overview of different methodological approaches applied. This helps us to define the gaps in our knowledge, presented in section 3. Finally, suggestions for further research are made in order to attain a better understanding of the land-use/transport system.

1. DEFINING THE LAND-USE/TRANSPORT SYSTEM PROBLEM

The spatial distribution of activities such as living, working, recreating or education, implies that people have to travel. Therefore, the land-use configuration is thought to be able to generate particular travel patterns. Consequently, the theoretical foundation for the impact of land-use on travel behaviour can be found in the theory of utilitarian travel demand (Lancaster, 1957). This theory postulates that the demand for travel does not derive its utility from the trip itself, but originates from the need to reach the locations where activities take place (van Wee, 2002). In other words, the greater part of our travel trips is derived (although a limited part is undirected travel - Mokhtarian & Salomon, 2001). On the other hand, changes in the transport system can alter location decisions of households and firms, resulting in a land-use change. For instance, an investment in transport infrastructure changes the accessibility of a region, which has an impact on housing values, economic development, ... This two-way interaction between land-use and transport composes the land-use/transport system (LUTS).

Wegener & Fürst (1999) entitle the LUTS as the 'land-use transport feedback cycle'. The set of relationships implied by this term can be summarized as follows:

- (i) The distribution of land-uses, such as residential, industrial or commercial, over the urban area determines the locations of human activities such as living, working, shopping or education.
- (ii) To overcome the distance between the locations of human activities spatial interactions or trips in the transport system are required.
- (iii) The distribution of infrastructure in the transport system allows spatial interactions and can be measured as accessibility.
- (iv) The distribution of accessibility in space co-determines location decisions and so results in changes of the land-use system.

Comparable to Wegener & Fürst (1999), Geurs & Ritsema van Eck (2001) start their study on accessibility measures with a description of the LUTS. They consider a similar two-direction between the land-use system and transport system. Furthermore, they define the concepts of the land-use system and the transport system. According to them, the land-use system comprises: (i) the spatial distribution of land-uses and the characteristics of the land-use, such as density, diversity and design, (ii) the locations of human activities, and (iii) the two-way interaction between land-uses and activities. The transport system comprises: (i) travel demand, i.e. the volume and characteristics of travel and movement of goods, (ii) infrastructure supply, i.e. the physical characteristics of infrastructure (e.g. road capacity, speed limits), the characteristics of infrastructure use (e.g. distribution of traffic levels over time, the time-table of public transport), and the costs and prices of infrastructure, vehicles and fuels, and (iii) the two-way interaction between travel demand and infrastructure supply.

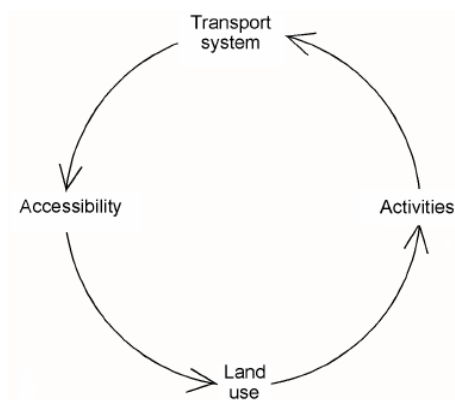


Figure 1: The 'land-use transport feedback cycle'

Source: Wegener & Fürst (1999).

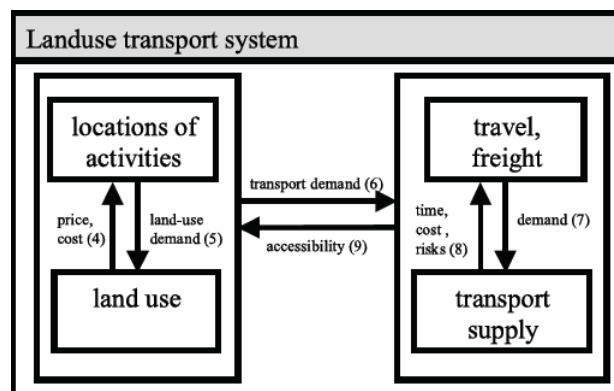


Figure 2: The 'Land-use/Transport system'

Source: Geurs & Ritsema van Eck (2001).

Like Geurs & Ritsema van Eck (2001), most definitions of the transport system have a *transport economic* background in which supply of and demand for transport are opposed to each other (White & Senior, 1983; Cascetta, 2001, Rodrigue, 2004). However, it is not sufficient to oppose travel demand and supply to each other. The resulting travel behaviour of this two-way interaction needs to be stressed as well. This behavioural component can be found in a definition put forward by Korsmit & Houthaeve (1995). They distinguished several ways to describe the transport system: (i) by the infrastructure network (e.g. the network of facilities for public transport), (ii) by the use of the facilities (e.g. expressed in number and type of movements) and (iii) by the travel behaviour (e.g. modal choice).

Recently, a more *technological approach* of the transport system is given by Donaghy et al (2004, p. 680). They define a transport system as ‘a complex system composed of infrastructure, logistics and information systems that manage and direct the actual movement of vehicles, ships and airplanes’. Note that this definition only includes the supply-side of transport. Besides traditional infrastructure, such as roads and train lines, logistics and information systems can also be considered as infrastructure to guide travel trips.

Other definitions for the land-use system than the one of Geurs & Ritsema van Eck (2001) are hard to find. A notable exception is made by Rodrigue (2004). He makes a distinction between urban form, urban (spatial) structure and land-use. Urban form refers to “the spatial imprint of an urban transport system as well as the adjacent physical infrastructures and activities”, whereas urban (spatial) structure is defined as “the set of relationships related to the urban form and its interactions of people, freight and information”. In this way, urban form is the spatial and visible representation of the urban structure, which consists of functional relationships. Although these definitions make a clear distinction between urban form and urban structure, they emphasize transport too much. Land-use types others than transport can influence urban form and urban structure too. Land-use is defined as

follows: “While the urban form is mostly concerned by the patterns of nodes and linkages forming the spatial structure of a city, urban land-uses involves the nature and level of spatial accumulation of activities. The nature of land-use relates to which activities are taking place while the level of spatial accumulation indicates their intensity and concentration. Most human activities, either economic, social or cultural imply a multitude of functions, such as production, consumption and distribution. These functions are occurring within an activity system where their locations and spatial accumulation form land-uses”.

2. REVIEW OF DIFFERENT METHODOLOGICAL APPROACHES

A large body of literature on several aspects of the LUTS exists, involving empirical and modelling studies. In this literature review, we focus on empirical studies only. Although empirical studies do not easily lend themselves to establish the causality of relationships, they have some advantages (Stead, 1999). First, empirical studies are based on real examples or case-studies and rely on fewer assumptions than modelling studies. Second, they are often easier to interpret and transparent in approach, whereas modelling studies are often seen as ‘black box’ exercises. Third, empirical studies provide data for use in the construction or testing of models.

Research studies seldom consider the LUTS in its totality. Most studies analyze the impact of the land-use system on travel behaviour, whereas a smaller part of the research is concerned about the reverse impact. This distinction is taken to structure the current review. Although the review was aimed to be international, most of the reported studies originate from either the United States or Western Europe. Particular attention was paid to spatial scale, method of analysis and, most of all, variables taken into account.

2.1 The impact of the land-use system on the transport system

In spite of the extended body of literature on the impact of the land-use system on travel behaviour, a three-fold distinction was found, in accordance with Naess (2003), based on the type of variables included.

2.1.1 The spatial dimension in travel behaviour research

Hurst (1970) focused on trip generation of non-residential land-uses in the CBD in Perth, Scotland, and on some sites outside the CBD. Regression analysis was used with city size and density as

explaining variables¹. He concluded that location and intensity of land-use are important variables to understand the relationship between land-use and the volume of urban travel.

A frequently quoted study in this respect is Newman & Kenworthy (1989), who analysed 32 cities in four continents. They found a significant negative statistical correlation between residential density and transport-related energy consumption per capita. Their work has become very influential, however, but is not spared from criticism (e.g. Gordon & Richardson, 1989). During the 1990s, Kenworthy et al. (1999) updated the original data. Cities in the USA, Canada, Australia and Asia were added to the original dataset. A wide variety of data on land-use and transport in 1960, 1970, 1980 and 1990 was collected. Recently, the collected data was supplemented with data on population, economy and urban structure in 1995.

Gordon et al. (1989) examined the LUTS for several cities in the United States. The subject of their research was the influence of metropolitan spatial structure on commuting time by car and public transit. Two regressions were run using density, economic structure, urban size, polycentricism, and income measures as independent variables², plus the addition of carpooling in the regression model for automobile commuting time. The addition of income in the regression analysis indicated the limited interest for socio-economic variables. Polycentric and dispersed metropolitan areas were found to facilitate shorter commuting times and differentiation among types of densities originated to be important. Results for public transport and automobile were found to be similar.

Six neighbourhoods in Palm Beach County, Florida were used by Ewing et al. (1994) to examine the impact of density, diversity, percentage multifamily dwellings and accessibility on travel time for work trips and non-home based trips³. Because study samples were small and differences in travel behaviour could be solely due to chance, analysis of variance was performed to test for significant differences. Originally more travel behaviour aspects were included, but only travel time seemed to differ significantly across neighbourhoods. Then, those differences were tried to explain by making use of the land-use variables mentioned before. Households in sprawling suburbs were found to generate almost two-thirds more vehicle hours of travel per person than comparable households in traditional neighbourhoods. Besides that, sprawl dwellers compensate for poor accessibility by linking trips in multipurpose tours.

¹ City size was expressed in number of inhabitants, employees and jobs, whereas industrial and commercial floor space are density measures.

² Density was measured by residential and (commercial and industrial) employment density; urban size by number of inhabitants and surface; and economic structure included industrial and commercial economic structure.

³ Density was measured by residential density and employment density; diversity included job-housing ratio.

From the nineties onwards, a renewed interest in the effects of neighbourhood design on travel behaviour could be noticed. Neo-traditional neighbourhood design developments received increasing attention as an alternative community design to standard suburban developments.

Friedman et al. (1994) used data from the San Francisco Bay Area to examine the relationship between neighbourhood type and modal choice. They distinguished two neighbourhood types: standard suburban and neo-traditional neighbourhoods. Despite the description of these types, it remains unclear which land-use variables were taken into account. A higher total household trip rate and automobile trip rate was found among residents of standard suburban neighbourhoods. This difference is explained not only by different neighbourhood design, but also by 23% income disparity between both study groups. Like Gordon et al. (1989), income is the only socio-economic variable included in the research on the LUTS. Hess et al. (1999) carried out research on pedestrian volumes in 12 neighbourhoods around small commercial centres sites in the Puget Sound Area, United States. The neighbourhoods studied are selected to be similar in terms of population density, land-use mix and income. But they were also selected to have very different neighbourhood design as measured by block size and by the length and completeness of sidewalk systems. Urban neighbourhoods with small blocks and extensive sidewalk systems were found to have, on average, three times the pedestrian volumes of suburban sites with large blocks and short, incomplete sidewalk systems. Previous studies compared two distinct neighbourhood types: neo-traditional and standard suburban neighbourhoods. However, such a binary categorization oversimplifies reality. McNally & Kulkarni (1997) developed a methodology for identifying a range of neighbourhood types by a clustering technique with transport network and land-use inputs. Therefore, land-use and socio-economic data for 20 neighbourhoods from Orange County, California were used. Land-use variables included several aspects of the transport network, accessibility measures and density measures.⁴ Socio-economic variables included only income, which was considered to be a proxy for the observed socio-economic differences between the neighbourhood types. The hypothesis that neighbourhood types display differences in travel behaviour was verified, but it seems that those differences are explained by income.

While most studies use cross-sectional data, Krizek (2000) managed to use highly disaggregate longitudinal data for the Puget Sound Area. This permitted him to carry out a pretest-posttest analysis of households' travel behaviour before and after they changed residential location. Density, street pattern and land-use mix were used to explain travel distance (per trip, per tour), travel time (per trip, per tour) and percentage trips by transit, bicycle or on foot. These dependent variables are used to gain also insight in trip chaining. Results show, however, few changes in household travel behaviour after a move, suggesting that attitudes toward travel are more important than land-use

⁴ Transport network was described by number of cul-de-sacs, T- and X-crossroads, access points, ...; accessibility was measured by access to residential, commercial and other land-uses; and density by density of single and multiple families, residential density,

Note that all above mentioned studies are based on US evidence. One important exception is except Hurst (1970). Note also that some studies stress the need to correct for socio-economic factors, but only a few do so. From the mid-nineties researchers agree on the incorporation of socio-economic and socio-demographic factors. But due to lack of data, some recent studies still concentrate only on land-use variables. In this respect, Schwanen (2002) carried out a cross-European comparison of 11 European cities. Three travel behaviour indicators were examined: commuting distance, commuting time and modal split for commuting. The effect of density, urban structure and city size on these three travel behaviour indicators was investigated by variance and regression analysis. Average commuting distances was found to be strongly and negatively correlated with population density, while average commuting time and modal split are more associated with the distribution of employment and population across the urban area and with urban size.

From the above mentioned studies we conclude that measures for density, diversity and design were analyzed frequently, mostly in relationship to modal choice, travel volume and travel time. City size, urban structure and accessibility were taken less into consideration as explaining land-use variables.

2.1.2 The socio-economic dimension in travel behaviour research

Pas (1984) was one of the first to mention the effect of socio-demographic characteristics of travellers on their daily travel-activity behaviour. He analyzed a much larger range of socio-demographic variables than has been done before. Land-use variables, however, were not included in his research.

Frank and Pivo (1994) conducted research in the Puget Sound Area, on census tract level. They tested the impact of density and diversity on the modal choice for both work trips and shopping trips. Urban form measures were density and land-use mix. Control variables included a limited number of socio-economic variables and mobility constraints.⁵ Statistical methods were selected on the basis of the nature of the hypothetical relationship being tested. Pearson correlation was used to test presence, strength and nature of the linear relationships between urban form and modal choice. The presence of a relationship between urban form and modal choice while controlling for non-urban form factors was analyzed by means of a regression analysis. Nonlinear relationships between urban form and modal choice were described by cross-tabulation. Findings from this research indicated that density and land-use mix are both related to modal choice, even after controlling for non-urban form factors. Nevertheless, relationships between modal choice and land-use mix remained relatively weak. Research at a smaller geographic unit of analysis is thought to be more useful.

⁵ Density was measured by residential and employment density. Socio-economic variables included household type, age and employment outside the home; mobility constraints included possession of a driver's licence or bus pass, number of cars per household and number of cars at destination.

Another study in the Puget Sound Area was carried out by Krizek (2003). Krizek (2002) already reported on the changes in travel behaviour after a household had moved to another residential location.⁶ As in his earlier research, regression analysis was done with density, land-use mix and street pattern as independent land-use variables. Other travel aspects were however chosen as dependent variables: travel distances (per person, per vehicle), number of trips per tour and number of tours. As in his earlier research, attention was paid to trip chaining behaviour. Most socio-demographic variables, as well as accessibility, had a statistically significant effect on the travel changes. Households who had relocated to neighbourhoods with higher accessibility reduced their vehicle miles travelled and increased the number of tours.

Because of its widely used 1990 travel survey, San Francisco Bay Area has become a well studied region.

Kockelman (1997) investigated the influence of urban form on household vehicle kilometres travelled, automobile ownership and modal choice. Instead of taken only density into account, which is relative easily to compute, more complex measures of the built environment focussing on the intensity, balance and mix of land-uses were used. After controlling for socio-demographic variables⁷, results of regression analysis illustrated the significance of measures of accessibility, land-use mixing and land-use balance, computed for both trip origin and destination.

Cervero & Kockelman (1997) focused particularly on the effects of density, diversity and design on trip rates and mode choice, mainly for non-work trips. Same socio-economic variables as in Kockelman (1997) were accounted for. Furthermore, housing tenure and variables on transportation supply and services were added.⁸ Factor analysis was used to measure the relative influence of each dimension as well as their collective impacts. Results indicated that density, diversity and pedestrian-oriented design generally reduce trip rates and encourage non-auto travel in statistically significant ways, though their influences appear to be fairly marginal. Thus, it supports the belief of the New Urbanism⁹ that compact, diverse and pedestrian-oriented neighbourhoods can influence travel behaviour.

Gorham (2002) examined whether similar neighbourhoods in San Francisco and Stockholm have common travel behaviour characteristics. San Francisco represents a region which has minimal planning intervention, whereas Stockholm has had a tradition of strong urban and regional planning. Neighbourhood type was the only land-use variable taken into account, to which every respondent was

⁶ Socio-economic variables included household income, number of vehicles and number of adults, children and employees per household.

⁷ Age, gender, ethnicity, household size, income, full- or part-time employment, professional occupation, car ownership and driver's licence

⁸ Transit service intensity, proximity of public transport and parking places described transportation supply and services.

⁹ Supporters of the New Urbanism believe that the right neighbourhood design will encourage walking, thereby encouraging interaction and a greater sense of community, and discouraging automobile dependence (Handy, 1996).

assigned. Socio-economic variables controlled for were lifecycle and income. A descriptive analysis illustrated the differences between neighbourhoods according to trip generation, trip distance, modal choice, trip duration and carbon budgets. This is a larger set of travel aspects examined before for the San Francisco Bay Area. Only for carbon budgets ANOVA-tests were performed to illustrate the significance of differences among neighbourhoods. Results suggested that there are similarities in travel behaviour between equivalent neighbourhood types in the two regions.

Other evidence from North-American studies stems from research conducted by Boarnet & Sarmiento (1996) for Southern California, Rajamani et al. (2003) for Portland, and Zhang (2004) for Boston.

Boarnet & Sarmiento (1996) studied the demand for non-work travel. Both travel volume and travel distance for car trips were modelled as a function of land-use and socio-economic variables near the person's place of residence¹⁰. Results of regression analysis showed little influence of the land-use variables. In their study, the topic of residential self-selection was dealt with to a limited degree. Residential location choice was modelled as function of workplace location, preferences toward commuting, non-work travel and non-transportation location-specific amenities, land-use characteristics and location-specific amenities which are not related to transportation (e.g. school quality, municipal fiscal policy). Land-use characteristics were found to be endogenous to residential location choice. This indicates a first step into the research of preferences and attitudes toward transport and land-use.

A GIS-based method was used by Rajamani et al. (2003) to develop land-use measures at the neighbourhood level of each household. Whereas other studies used only a handful of simple land-use measures, their database on the local built environment included a more extensive set of variables. Land-use was described based on four categories: (i) land-use type and mix, (ii) accessibility, (iii) residential density and (iv) local street network. Besides socio-economic variables, results were also controlled for trip characteristics.¹¹ The results of a multinomial logit mode choice model indicated that mixed-uses promote walking behaviour for nonwork activities. Easily accessible locations by bicycle or on foot seemed to encourage walking and cycling for recreational purposes. The analysis confirms the principles of the New Urbanism: traditional neighbourhood street design seems to have potentials to promote walking.

Another comparative study, tot the one done by Gorham (2000), was carried out by Zhang (2004) for Boston and Hong Kong. Two sets of discrete-choice models (for work and non-work trips) were estimated in order to analyse the influence of land-use on modal choice. Three classes of explanatory variables were considered: travel costs (time and monetary), traveller socio-economic characteristics,

¹⁰ Socio-economic variables included: age, gender, ethnicity, level of education, income and the number of children under age 16 in the household. Population density, percentage of the street grid within a square mile radius of a person's residence, density of total, retail and service employment were used to describe land-use.

¹¹ Socio-economic variables comprised: age, gender, ethnicity, student status, employment status and presence of a physical handicap. Trip characteristics comprised level-of-service variables: travel time and travel cost.

and land-use variables. Each set of models contained a base model and an extended model. The base model included variables typically considered in the analysis of mode choice (e.g. travel time, costs and traveller socio-economic variables). In the extended model, land-use variables were added into the list of independent variables. Results showed that, for both work and nonwork trip purposes, land-use explained additional variation in modal choice. Travellers in both cities responded in the same way to costs of travel, personal and family responsibilities and spatial constraints.

Previous studies mainly show evidence from the United States. However, evidence from Western Europe, especially Great-Britain and the Netherlands could be found.

Stead (2001) was one of the first to introduce socio-economic characteristics in the analysis of the LUTS in Great-Britain. His research concentrated on the impact on travel distances. Data from national travel surveys and two local travel surveys (Kent and Leicestershire) were analyzed by two main research methods. First, multiple regression analysis was applied, allowing identification of the main socio-economic and land-use variables associated with travel distance. Second, case-studies with similar socio-economic profiles but different land-use patterns were described¹². Results indicated that the variation in travel patterns often owes more to socio-economic reasons than to land-use characteristics.

Gargay and Hanly (2004) carried out research on the link between land-use variables, socio-economic variables and modal choice and car ownership.¹³ Land-use was defined in terms of the characteristics of the residential location of the individuals. Two logit models were constructed: (i) a multinomial logit model for mode choice and (ii) a binomial logit model for car ownership. Unlike Stead (2001), the estimation results strongly supported the importance of the land-use variables considered on modal choice and car ownership.

Dieleman et al. (2002) explored the determinants of modal choice and travel distance for different trip purposes by making use of the Netherlands National Travel Survey. A wider set of purposes, generally used in mobility studies, was considered: trips to work, for shopping and leisure activities. The residential environment of the respondents was described by (i) the location of the municipality within or outside the Randstad, and (ii) the urbanization level of the municipality. Socio-economic variables were gathered at the disaggregate level of individual respondents and their households.¹⁴ Multivariate statistical analyses found an almost equal importance of personal and land-use characteristics for

¹² Land-use variables included: development density, diversity, distance from the urban centre, settlement size, provision of local facilities, proximity to the main transport network (main road network, railway station) and availability of residential parking. Socio-economic variables included: age, gender, household size and composition, working status, socio-economic status, possession of a driver's licence.

¹³ Land-use variables included: population density, urban size, accessibility to public transport and local amenities (e.g. shops and services). Socio-economic variables included: age, gender, income, household structure and employment status.

¹⁴ Socio-economic variables included: income, household type, education and car ownership.

modal choice and distance travelled. However, these relationships modify considerably when trip purposes are taken into account. For each travel purpose, a multinomial logit model was constructed for modal choice as well as for travel distance. The three models explaining modal choice showed the same pattern. Even after compensating for socio-economic variables, the influence of residential environment on modal choice for work trips remains high. The modal choice pattern for shopping trips and leisure activities was found to be more or less the same. A different conclusion was made for distance travelled. For work and shopping trips, the distance travelled by car depends mostly on car ownership and income level. However, the model for leisure trips showed fewer strong relationships and less clear patterns.

As in Dieleman et al. (2002), Schwanen et al. (2002a) studied the impact of metropolitan structure on commuting behaviour, especially mode choice, travel distance and travel time by car. Multilevel regression modelling was used to deal with several levels of analysis, ranging from the individual worker to the metropolitan region. Several land-use variables were collected on the level of the metropolitan region and the residential municipality, whereas more disaggregate data was found on the household and individual level.¹⁵ The analysis revealed longer commuting distances and times by car in the majority of polycentric regions when compared to monocentric regions. Furthermore, a limited set of spatial variables seemed to be useful in the explanation of the variation in commute behaviour at the more aggregate levels, whereas the largest part of the variation at the individual level remained unaccounted for. Therefore, other additional and personal household attributes are needed which probably rely to job characteristics, housing tenure and attitudes towards commuting by car.

The greater part of previous studies concentrates on distance travelled and modal choice. Travel time has received less attention. Schwanen et al. (2002b) considers this as an unfortunate oversight as people's travel decisions are determined by time rather than by distance. The joint effects of socio-economic and land-use variables were determined in regression analyses.¹⁶ However, results needed to be corrected for selectivity bias because the decision to travel for a trip purpose with a given mode is not unrelated to the decision regarding to travel time. Therefore two types of regression models were constructed. First, a participation model was used to estimate the probability that someone travels for a trip purpose (work, shopping, leisure) by a given mode (car driver, bicycle, walking, bus/tram/metro, train). This likelihood was then transformed and incorporated in a second model, the substantial model for travel time. Travel time was found to be influenced by socio-economic variables and, to a lesser extent, the residential context.

¹⁵ Polycentrism, job density and development in number of jobs were used as land-use variables. Age, gender, household type, income, education, car availability are considered as socio-economic variables.

¹⁶ City size, residential density, land-use mix and the structure of the urban system are used to identify the residential environment. Age, gender, education, car ownership and income are considered as socio-economic variables.

Meurs and Haaijer (2001) tried to contact respondents from a former study (*Tijdsbestedingsonderzoek 1990*). In this way, a pretest-posttest analysis could be carried out in which three groups of respondents were distinguished: (i) those who did not move, but of which the spatial situation has changed, (ii) those who did not move, but of which the spatial situation has not changed, and (iii) those who did move. Regression analysis was used to examine the relationship between the spatial structure and mobility, in general, and modal choice, in particular.¹⁷ The results indicated that certain aspects of land-use do indeed have an impact on mobility. These effects are particularly apparent in trips made for shopping and social or recreational purposes. Commuter traffic, however, is largely or almost entirely determined by personal characteristics. Modal choice is influenced to a small degree by spatial characteristics, from about 10% for car trips to 40% for journeys on foot

Previous studies have examined the direct effects of urban form characteristics on travel behaviour. However, travel is considered to be derived from the activities in which individuals and households participate, thus it cannot be understood independent of the activities that cause it. Therefore Maat & Arentze (2002) carried out a survey on activity participation in 57 Dutch neighbourhoods. First, they identified activity patterns based on activity frequency and duration. Second, they retrieved the influence of the spatial context on these activity patterns. Seven activity patterns were obtained by cluster analysis. Two different approaches were used to examine how activity participation varies with land-use variables, expressed by accessibility, and socio-economic variables.¹⁸ The concept of accessibility was thought to be useful because it takes into account both transportation costs, such as distance or time, and the attraction of an activity. First, the effects on duration and frequency per activity, as well as in total, were examined using ordinary least square regression. Then, to avoid only testing separate effects, the clustered activity patterns were studied using multinomial logistic regression. Unlike the socio-demographic variables, they found little evidence that activity patterns vary across spatial characteristics.

Simma and Axhausen (2003) reports one of the few studies on the LUTS in Austria. The aim of their study was to identify spatial factors which determine or at least influence travel behaviour, especially mode choice for different trip purposes (work, shopping). This research was carried out for only one province in Austria, but which covers a wide range of environmental settings. Land-use and socio-economic variables were included in a Structural Equation Model (SEM). Socio-economic variables taken into account were limited because spatial aspects were considered to be more significant.¹⁹

¹⁷ Land-use included characteristics of the dwelling, the street, the neighbourhood and its position in the total urban area. Results were controlled for socio-economic variables, but from their report it remains unclear which variables specifically were accounted for.

¹⁸ Socio-economic variables included age, gender, income, possession of a driver's licence, availability of a car, number of cars per household (one or two), kids < 6 years, kids 6-12 years, household size and number of workers per household.

¹⁹ Socio-economic variables included gender, employment status and number of children per household. Land-use was expressed by several accessibility measures, both at the municipality and household level, distance to

Nevertheless, personal characteristics were found to be more important compared to the moderate effects of the spatial structure.

Modal choice and travel volume remained the most analyzed travel aspects in the above cited studies. However, travel distance was a new travel aspect to be explored. Density, diversity and design remained the most important land-use variables. Measures for design mainly included aspects of the local street network or several measures were combined into one single neighbourhood type. Age, gender, household size, income and level of education were frequently used socio-economic variables. Several variables were sometimes combined into household type or lifecycle. Some studies controlled their results for mobility constraints, which include variables such as ownership of a car, a driver's licence or a bus pass; accessibility or the proximity of transport networks or parking places.

2.1.3 The behavioural dimension in travel behaviour research

In a third dimension lifestyles, perceptions and attitudes towards land-use and travel are accounted for besides the widely used land-use and socio-economic variables. From the mid 1990s onwards there has been some attention to this behavioural component of travel. This new approach has been undertaken in especially North-American and Dutch research.

Handy (1996) was among the first to mention the importance of perceptions and attitudes towards land-use. She studied the influence of urban form of five neighbourhoods in Austin, Texas, on pedestrian choices. Socio-economic variables and perceptions towards urban form characteristics were also taken into consideration.²⁰ Correlation analysis revealed that individual motivations and limitations are central to the decision to walk. Urban form is rather a secondary factor in pedestrian choices. The results suggested that urban form plays a greater role if the walking trip has a destination. In this case, the most obvious aspect of urban form is the distance from home to the destination.

Data of the San Francisco Bay Area remained a source of inspiration. Kitamura et al. (1997) carried out a survey in five neighbourhoods, which were selected on the basis of density, diversity and rail transit accessibility. First, socio-economic and neighbourhood variables were regressed against travel volume by various modes. They concluded that neighbourhood variables add significant explanatory power when socio-economic differences are controlled for. Particularly, measures of residential

the district capital, share of farms, working women and commuters, size of shop base and number of work places, supply of public transport and car.

²⁰ Urban form was described by the neighbourhood transportation system, the level of public transport service, the characteristics of residential streets, housing, neighbourhood commercial areas and types of commercial establishments. Socio-economic variables included: age, gender, number of inhabitants, average years residing in the neighbourhood, number of vehicles per household, household size, children below 12 years, income.

density, accessibility of public transport, land-use mix and the presence of sidewalks are significantly associated with trip generation by mode and modal split. Second, 39 attitude statements regarding urban life, leisure activities and lifestyles were factor analyzed into eight factors. Scores on these factors were introduced in the regression models mentioned before. Assessment of the relative contribution of neighbourhood, socio-economic and attitudinal characteristics revealed that each variable type add some explanatory power to the models. However, the attitudinal variables explained the highest proportion of the variation in the data.

Bagley & Mokhtarian (2002) examined travel demand in the same five neighbourhoods as in Kitamura et al. (1997), using a system of structural equations in which land-use, socio-economic and attitudinal variables are included. In this way, they incorporated not only a new set of variables, but they used a new research technique as well. The survey included questions about attitudes towards several transport aspects, whereas lifestyle has been examined by a list of more than 100 types of activities and interests. A nine equation structural model system was used as a conceptual model of the interrelationships. The nine endogenous variables included two measures of residential location type, three measures of travel demand, three attitudinal measures and one measure of job location. They concluded that attitudes and lifestyles had much more impact on travel demand than residential location type.

Schwanen and Mokhtarian published a series of papers designed to enhance the understanding of the complex relationships among residential location, commute behaviour and attitudes towards land-use and travel. They focussed on the concept of residential neighbourhood type dissonance, or mismatch between preferred and actual type of residential location. The basic question is simple: do mismatched individuals travel more like the matched residents of the neighbourhoods they actually live in, or more like the matched residents of the kind of neighbourhood they prefer to live in ? The former outcome suggests that the effects of the built environment outweigh personal characteristics, the latter outcome suggests the converse. The series of studies begins by exploring the role of attitudes towards land-use and travel in residential location choice (Schwanen & Mokhtarian, 2005c). In Schwanen & Mokhtarian (2004) a model is presented for dissonance as a function of demographic and attitudinal characteristics. The impact of dissonance on travel behaviour is then studied by three papers. Non-commute trip frequencies (Schwanen & Mokhtarian, 2003) and commute mode choice (Schwanen & Mokhtarian, 2005a) were compared between matched and mismatched urban and suburban residents and the role of dissonance in mode-specific distances for all purposes was examined (Schwanen & Mokhtarian, 2005b). All studies are based on data for three neighbourhoods in the San Francisco Bay Area and take into account land-use and socio-economic variables, mobility constraints, personality traits, lifestyle factors and attitudes towards land-use and travel.

Preferences for travel modes, especially car and public transport, were studied by van Wee et al. (2002). Their research attempts to answer four questions: (i) are there preferences for modes, (ii) is

there a relationship between preferences and neighbourhood characteristics, (iii) have preferences for modes played a role in residential choices of households, and (iv) do preferences for modes add explanatory power to models for travel behaviour that include land-use, personal and household characteristics ? Results reveal positive answers to all four questions. Their research was carried out for three different neighbourhoods in the Dutch city Utrecht. Neighbourhoods differed only in terms of attractiveness for travel by car, bicycle or public transport, whereas differences in household characteristics and types of dwellings were limited. Techniques for analysis included cross-tabulations, Chi-square test for significance and multivariate regression.

Whereas most studies point to a higher significance of attitudes and preferences compared to land-use and socio-economic variables, Naess (2005) concluded the reverse. Residential location within the Copenhagen metropolitan area was found to affect travel behaviour, especially travel volume and modal choice, even after controlling for socio-economic and attitudinal variables. On average, living in a dense area close to downtown Copenhagen contributes to less travel, a lower share of car driving and more trips by bike or on foot. In particular, the length and travel mode of journeys to work are affected by the location of the dwelling relative to the city centre of Copenhagen. But also for a number of non-bounded trip purposes a centrally located residence facilitates less travel and a higher share of non-motorized transport. Furthermore, the respondents emphasize the possibility to choose among facilities rather than proximity. In this way, the amount of travel is influenced to a higher extent by the residential location in relation to concentrations of facilities, rather than the distance to the closest single facility within a category.

Research on this third dimension of travel behaviour seems to add significant explanatory power to previous models on the LUTS. However counterevidence exists, the greater part of the research concludes that attitudes, lifestyles, perceptions and preferences towards land-use and transport are important explanatory variables. Nevertheless, this type of research still is in its infancy.

2.2 The impact of the transport system on locational decisions

The effects of the transport system on location decisions of firms and households are primarily studied by the concept of ‘accessibility’, e.g. new transport infrastructure influences the accessibility of a place which in turn influences location decisions and land-use patterns.

The earliest of these studies is the influential study by Hansen (1956), in which he demonstrated for Washington D.C. that locations with good accessibility had a higher chance of being developed, at a higher density, than remote locations.

A similar conclusion was drawn by Bruinsma & Rietveld (1997). They performed a correlation analysis to study the strength of the relationship between the accessibility of Dutch cities and the cities' valuation as location sites by firms. This relationship was found to be rather strong. Furthermore, a regression analysis was carried out to explain this cities' valuation. Among the explaining variables were 'location', 'infrastructure' and 'accessibility'. The impact of the cities' location in the road network on the valuation of cities as location sites turned out to be considerably important.

Willigers et al. (2002) reviewed studies of the spatial effects of high-speed rail infrastructure. They concluded that only simple measures for accessibility have been used so far. Thus, they proposed further research onto different accessibility measures and accessibility as perceived by firms.

Recently, Mikelbank (2004) analyzed the relationship between smaller road investments made by municipalities and state departments of transportation and housing values in Columbus, Ohio. A first database contained information on all single-family detached houses sold in 1990. A second database included information on all accessibility-changing road investments since 1978. Results indicated that past, current and future road investments have distinct and significant impacts on house price.

However, there is also some counter-evidence. Giuliano & Small (1993) observed that in the Los Angeles metropolitan area commuting cost has little impact on residential location choice. The computed commuting time based on the observed jobs/housing balance in the region does not compare to the observed commuting time.

Linneker & Spence (1996) explored the regional development effects of the M25 London orbital motorway. The M25 has affected levels of accessibility in Britain, which are thought to influence regional development. They constructed a series of measures of both regional development (e.g. differential employment shift, index for demand for labour) and accessibility. Regression analysis also included a number of other potential explanatory factors, such as industrial structure, congestion, employment density and labour availability. However, a negative relationship was found between accessibility and employment change. Areas which are highly accessible are losing employment and vice versa, thus illustrating two types of potential effects of an improved accessibility. It may facilitate local firms to expand their market areas by penetrating more distant markets, potentially increasing employment in the area with improved accessibility. Or it may facilitate expansion in the reverse direction as stronger firms external to the area penetrate the area whose accessibility has been relatively improved, and thus any expansionary developmental effects such as employment growth may occur in areas other than those in which accessibility has largely been improved.

Remarks on the impact of the transport system on land-use are made by Miller et al. (1998). Their review of North-American studies included studies mainly on the impact of light rail, subway and commuter rail lines and stations on residential density, employment density and property values among others. Four main observations could be made: (i) fixed, permanent transit systems have the

most significant effect, (ii) transit's effects are measurable only in the long term, (iii) transit's effects on land and development markets, not land values, must be considered and (iv) transportation facilitates development but does not cause development. Besides the small number of studies, most of them suffer from methodological problems. In virtually no case the study design provided an adequately controlled 'experiment' to properly isolate the impacts of transport investments from other evolutionary factors at work in the urban region.

3. SOME GAPS IN OUR KNOWLEDGE AND HOW TO FILL THEM IN ?

Research studies seldom consider the LUTS in its totality. A large number of empirical studies on the impact of the land-use system on travel behaviour exists. However, the reverse direction of impacts, the impact of the transport system on land-use, has attracted much less attention of researchers. One reason may be a difference in time scale: travel behaviour can change easily, while land-use changes occur much more slowly. Thus, research which wants to capture the impact of transport changes on land-use patterns must be carried out on the appropriate moment of time and not within a too short period after the transport changes (Miller et al., 1998). Furthermore, land-use is subject to many other influences other than transport, such as population growth, economic development, changes in lifestyles, household information, consumption patterns and production technology, and are therefore difficult to isolate (Wegener & Fürst, 1999; Handy, 2002; Martínez, 2002).

Studies on the influence of the land-use system on travel behaviour mainly focus on travel amount, travel distances and modal choice, and recently, travel time. More complex aspects of travel behaviour, such as trip chaining and point in time, have hardly been investigated. Trips for different purposes have been examined, although the main part focuses on commuting trips. Since they take up a large part of our travel behaviour, recreational, shopping, visiting trips should be looked at closer.

Previous studies offer a wide range of explaining land-use and socio-economic variables, on several scales of analysis. At present, researchers agree on the inclusion of socio-economic variables. Furthermore, information about perceptions, attitudes and lifestyles seems to add some explanatory power. Since this kind of information is hard to find in empirical surveys, stated preference is thought to be useful. Studies which do pay attention to attitudes and perceptions regard this either towards land-use, either transport. Almost no studies were found that include this kind of information for both land-use and transport at the same time.

Furthermore, land-use and socio-economic variables are mainly observed at the place of origin only. Generally, studies do not take into account these variables at the place of destination or alongside the trip. This could be interesting for further research, e.g. the provision of public transport at the place of destination can influence the decision to travel by public transport or not.

Principal component analysis, factor analysis, cluster analysis and especially regression models are commonly used statistical techniques in the research on the LUTS. As more variable types are to be considered, techniques must deal with several directions of interrelationships. As Bagley & Mokhtarian (2002) and van Wee et al. (2002) pointed out structural equation models (SEM) can deal with these multiple relationships, where the same variable that is the outcome (dependent variable) in one set of relationships may be a predictor of outcomes (independent variable) in other relationships. Therefore, it seems a useful research technique to investigate the LUTS in its totality.

SEM is a research technique, dating from the 1970s. Most applications have been in psychology, sociology, the biological sciences, educational research, political science and market research. Applications in travel behaviour stems from 1980. Golob (2003) gives a review of the latter, although applications involving travel behaviour from the perspective of land-use (like Bagley & Mokhtarian, 2002; Simma & Axhausen, 2003) were not included.

SEM is a confirmatory method, which should be guided by prior theories about the structures to be modeled. It is used to capture the causal influences (regression effects) of the exogenous variables on the endogenous variables and the causal influences of endogenous variables upon one another. A SEM can be composed of up to three sets of simultaneous equations (Golob, 2003): (i) a measurement (sub)model for the endogenous (dependent) variables, (ii) a measurement (sub)model for the exogenous (independent) variables, and (iii) a structural (sub)model, all of which are estimated simultaneously. This full model is seldom applied. Generally, one or both measurement models are dropped. SEM with a measurement and a structural model is known as 'SEM with latent variables', whereas 'SEM with observed variables' consists of only a structural model without any measurement models. Many standard statistical procedures can be viewed as special cases of SEM. A measurement model alone equals confirmatory factor analysis. Ordinary regression is the special case of SEM with one observed endogenous variable and multiple observed exogenous variables. In general, a SEM can have any number of endogenous and exogenous variables.

A main reason why SEM is widely used is that it explicitly takes into account measurement error in the observed variables (both dependent and independent). In contrast, traditional regression analysis ignores potential measurement error in all the explanatory variables included in a model. As a result, regression estimates can be misleading. SEM makes also the distinction between direct, indirect and total effects. Direct effects are the effects that go directly from one variable to the target variable. Each direct effect corresponds to an arrow in a path (flow) diagram. Indirect effects occur between two variables that are mediated by one or more intervening variables. The combination of direct and indirect effects determines the total effect of the explanatory variable on a dependent variable. Advantages of SEM compared to most other linear-in-parameter statistical methods can be summarized as follows: (i) treatment of both endogenous and exogenous variables as random variables with errors of measurement, (ii) latent variables with multiple indicators, (iii) separation of

measurement errors form specification errors, (iv) test of a model overall rather than coefficients individually, (v) modeling of mediating variables, (vi) modeling of error-term relationships, (vii) testing of coefficients across multiple groups in a sample, (viii) modeling of dynamic phenomena such as habit and inertia, (ix) accounting for missing data, and (x) handling of non-normal data (Kline, 2005; Golob, 2003; Raykov & Marcoulides, 2000). But, besides the benefits of SEM, a greater knowledge is required about the conditions and assumptions for appropriate usage in order to obtain valid outcomes and conclusions (Chin, 1998).

4. CONCLUSIONS

Theories on the reciprocal relationship between land-use and transport address changes in locational decisions and travel behaviour of private actors (households and firms) due to alternations in the transport system, respectively land-use system. This two-fold relationship is called the land-use/transport system (LUTS).

Research studies seldom consider the LUTS in its totality. A large body of literature exists on the impact of land-use on travel behaviour, in which a three-fold distinction could be made based on the type of variables whether or not taken into account. Initially, only a spatial dimension was considered to influence travel behaviour. Research included land-use variables, mostly on an aggregate level. Some researchers compared several cities, others did research on census tract level or neighbourhood level. However, results were soon controlled for socio-economic variables. At present, researchers agree on the incorporation of these control variables. As a result, research was carried out on a more disaggregate level, specifically on the individual and household level. Thus, resulting in a wide variety of land-use and socio-economic variables included in several empirical research studies. Contrary to the first research phase, the debate on the LUTS found also place in Europe, especially the Netherlands and Great-Britain. Nevertheless, results from various research attempts still did not correspond to each other. Thus, indicating that within so-called 'homogenous groups' other variables must be accounted for. A third dimension, including attitudes, lifestyles, perceptions and preferences, was to be explored. Nowadays more attention is paid to these behavioural aspects of land-use and travel. In this field, revealed and stated preference can contribute to a better understanding of the LUTS. The reverse direction of impacts, the impact of the transport system on land-use patterns, has attracted much less attention of researchers. Furthermore, the greater part of this research focuses on the concept of 'accessibility'. Nevertheless, only simple measures of accessibility have thus far been used in such a complex research issue.

As a result, studies encompass a wide range of explaining variables and variables to be explained. To add to this diversity, many different research approaches have been applied. Initially, research studies were descriptive or used some basic statistic techniques such as factor analysis, correlation, simple regression models and discrete-choice models. Some studies, especially those focussing on the impact of design on travel behaviour, apply a quasi experimental method. Several neighbourhood types were selected to be similar in terms such as socio-economic variables, but different in neighbourhood design. In this way, the observed differences in travel behaviour are thought to be the result of differences in design, and not of socio-economic differences.

Some of this research supports the view that travel behaviour can be explained by land-use (e.g. Newman & Kenworthy, 1989; Frank & Pivo, 1994; Cervero & Kockelman, 1997; Meurs & Haaijer, 2001). Some researchers remarked that this body of research lack a strong methodological approach. Therefore, they applied more sophisticated methods (Maat et al., 2005). However, they have reported lower or virtually no effects than others (e.g. Boarnet & Sarmiento, 1996; Kitamura et al., 1997; Bagley & Mokhtarian, 2002; Schwanen, 2003). As more types of variables need to be included in research on the LUTS, a research technique must be able to deal with more potential relationships between those variables. Structural Equation Modelling (SEM) seems to be useful. However, this technique has hardly been applied.

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