The Relationships between Urban Form and Travel Patterns. An International Review and Evaluation

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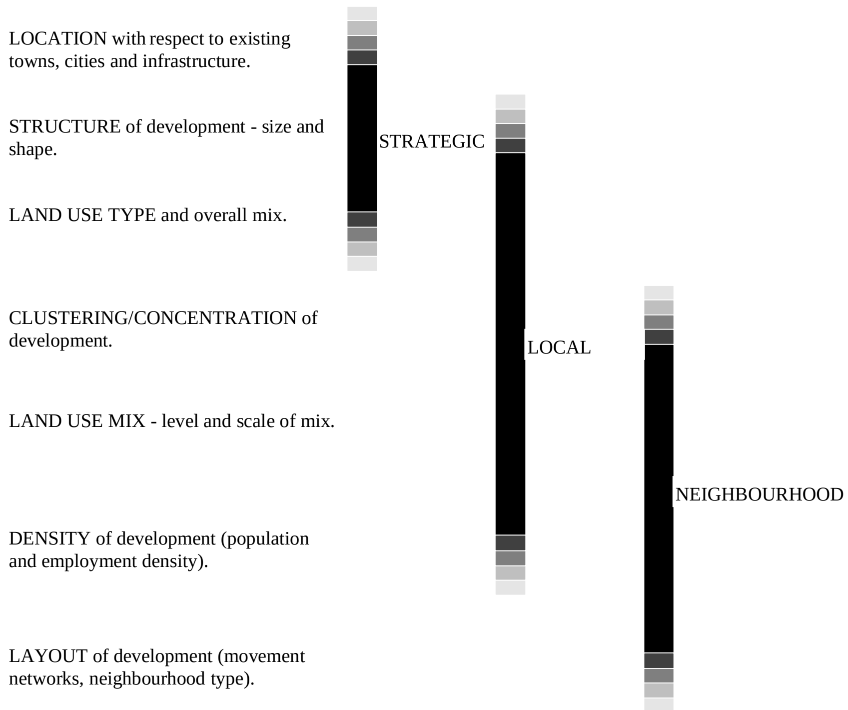
There is a growing body of research concerned with the relationship between urban form and travel patterns. Studies originate from a diversity of sources, and encompass a variety of geographic scales and locations. To add to this diversity, many different characteristics of urban form to have been examined in these studies, and travel patterns have been measured in a number of different ways. This paper brings together in a systematic way the results of many recent studies on urban form and travel patterns over the last 20 years. As well as this systematic approach, other key aspects of this review paper include the identification of where research has been concentrated (and where there are gaps in research), and in the critique of the studies, which includes issues of data accuracy, reliability and quality, the applicability of research methods and data interpretation. The critique focuses in some detail on the interaction of socio-economic factors with urban form and travel patterns.

1. Introduction

The search for sustainable transport policies has witnessed increasing attention to patterns of mobility, in the interests of reducing the adverse environmental impacts of increasing travel. In recent years there has been much interest in tackling travel growth by promoting forms of sustainable urban development in which the design and layout of urban areas can assist in reducing travel (see for example Barton et al., 1995; Banister and Marshall, 2000; ECOTEC, 1993). In particular, advocacy for various forms of neo-traditional urbanism, compact cities, urban villages and public transport oriented development all aim explicitly to use land use policy and urban design to assist in promoting more sustainable patterns of travel (see for example Aldous, 1992; Calthorpe, 1993; Ryan and McNally, 1995; Urban Task Force, 1999).

Accordingly, there is a growing body of research concerned with the relationship between urban form and travel patterns. Studies originate from a diversity of sources, and encompass a variety of geographic scales and locations. To add to this diversity, many different characteristics of urban form to have been examined in these studies, and travel patterns have been measured in a number of different ways. This paper brings together the results of recent studies on urban form and travel patterns over the last 20 years (from 1980 onwards).
Research has examined the relationships between a number of urban form characteristics, ranging from regional to local in scale, and travel patterns. At the strategic level, urban form concerns the location of new development in relation to existing towns, cities and other infrastructure, and the size and shape of new development and the type of land use (whether for example it is used for housing, commercial and industrial purposes or a mixture of these purposes). At the local level, urban form concerns the level and scale of land use mixing and the extent to which development is clustered or concentrated into nodes (Figure 1).



Adapted from Owens, 1986

Figure 1. Land use characteristics that can affect travel patterns

2. Approach

The paper focuses on nine aspects of urban form, ranging from regional strategic planning level (at the top of the list) down to specific local planning issues at the neighbourhood scale (at the bottom of the list)[1]:

i. distance of residence from the urban centre
ii. settlement size
iii. mixing of land uses
iv. provision of local facilities
v. density of development
vi. proximity to transport networks
vii. availability of residential parking
viii. road network type
ix. neighbourhood type

This paper reviews evidence for the influence of land use on travel patterns from empirical studies only[2]. In looking at travel patterns, the focus is individual travel as a whole, rather than individual modes (such as car or public transport) or certain types of journeys (such as commuting). The review is international although most of the studies reported in this paper originate from either Western Europe or the United States.

This review has necessitated a certain amount of compartmentalism into discrete categories of urban form and it is recognised that there is no definitive way of deciding the categories. Definitions may be overlapping or nested within each other. For example, the term 'concentration' implies density but may also imply a nodal or 'focal' element which relates to layout; the term 'urban structure' is often related to the layout of transportation networks (e.g. 'grid structure'), of which street pattern may be regarded as a local subset. As shall be seen, neighbourhood type can be regarded as a composite measure which may incorporate network type. Furthermore, the significance of each variable is likely to depend on context. For example, the significance a variable such as 'distance to urban centre' will vary according to how monocentric or dispersed a settlement is, both in terms of overall layout and in terms of location of employment relative to residences.

There are a number of reasons for the focus on empirical studies. First, empirical studies are fundamental and often provide data for use in the construction or testing of models. Second, empirical studies illustrate real examples and rely on fewer assumptions than modelling studies. Third, they are often more understandable and transparent in approach than modelling studies and allow a wide variety of land use characteristics to be examined, whereas modelling studies are often seen as 'black box' exercises which lack transparency about the complexity, subjectivity and assumptions of the model. They rely on mathematical formulations that are often incomprehensible to most people, including many land use policy-makers. It would be unfair however to point to the weaknesses of modelling studies without also recognising that there are weaknesses of empirical studies. Empirical studies do

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[1] It is recognised, however, that putting these nine elements in order of scale is difficult since some are relevant to more than one scale. For example, road networks can be local or regional, density can apply at the city-scale or at the neighbourhood level.

[2] For literature on land use and transport modelling studies and their application to land use planning, see for example Webster et al (1988), Wegener (1994) or Wilson (1998).

not easily lend themselves to establishing the causality of relationships or conclusive results. The empirical investigation of relationships between selected land use characteristics and travel patterns relies on examples of land use characteristics being found in the ‘field’. There are often confounding factors (such as socio-economic characteristics) which make comparisons between different areas difficult in empirical studies. Certain land use characteristics are difficult to classify in the ‘real world’ since they often lie between different classification systems (centralised or dispersed employment, mixed or segregated land uses for example). These issues are discussed in more detail later in the critique.

3. Review

There is a large amount of literature on the relationships between land use and travel characteristics. A summary of the review is presented in tabular form (Table 1) in which land use characteristics form one axis and travel characteristics form the other axis. Different studies have examined different travel patterns and five measures of travel patterns are distinguished in this review:

i. travel distance
ii. journey frequency
iii. modal split
iv. travel time
v. transport energy consumption

Using this tabular approach it is possible to identify where research has been concentrated and where there are gaps in the research. It is also possible to examine where findings are similar and where they differ.

Table 1. Studies Classified According to Land Use Characteristics and Travel Patterns

	Land use characteristics → Travel patterns ↓	Distance of residence from the urban centre	Settlement size	Mixing of land uses	Provision of local facilities	Density of development	Proximity to main transport networks	Availability of residential parking	Road network type	Neighbourhood type
DISTANCE	Average journey distance	Gordon et al., 1989a Johnston-Anumonwo, 1992 Spence and Frost, 1995	Orfeuil and Salomon, 1993		Cervero and Landis, 1992 Hanson, 1982 Winter and Farthing, 1997	ECOTEC, 1993				
DISTANCE	Average journey distance by car		Hillman and Whalley, 1983		Cervero and Landis, 1992 Farthing et al., 1997	ECOTEC, 1993 Hillman and Whalley, 1983 Levinson and Kumar, 1997	Levinson and Kumar, 1997		Marshall and Banister, 2000	Crane and Crepeau, 1998
DISTANCE	Travel distance (all modes)	Næss et al., 1995 Curtis, 1995 Stead, 1999	ECOTEC, 1993 Hillman and Whalley, 1983 Stead, 1999	Stead, 1999	Stead, 1999	Dunphy and Fisher, 1996 ECOTEC, 1993 Hillman and Whalley, 1983 Kenworthy and Laube, 1999 Stead, 1999	Headicar and Curtis, 1994 Stead, 1999	Stead, 1999		Crane and Crepeau, 1998 Rutherford et al.,1996
FREQUENCY	Journey frequency	Curtis, 1995		Ewing et al., 1996	Hanson, 1982; ECOTEC, 1993	Dunphy and Fisher, 1996 ECOTEC, 1993 Ewing et al., 1996				Berman, 1996 Cervero and Gorham, 1995 Crane and Crepeau, 1998 Friedman et al., 1994 McNally and Kulkarni, 1997

	Land use characteristics → Travel patterns ↓	Distance of residence from the urban centre	Settlement size	Mixing of land uses	Provision of local facilities	Density of development	Proximity to main transport networks	Availability of residential parking	Road network type	Neighbourhood type
MODE	Proportion of car journeys	Curtis, 1995 Næss and Sandberg, 1996	Gordon et al., 1989a		Cervero and Landis, 1992	ECOTEC, 1993 Gordon et al., 1989a Levinson and Kumar, 1997	Headicar and Curtis, 1994 Kitamura et al., 1997	Kitamura et al., 1997		Cervero and Gorham, 1995 Crane and Crepeau, 1998 Friedman et al., 1994 McNally and Kulkarni, 1997
	Proportion of public transport journeys				Cervero and Landis, 1992	ECOTEC, 1993 Frank and Pivo, 1994 Levinson and Kumar, 1997 Baker, 1995 Kenworthy and Laube, 1999	Cervero, 1994		Ewing, 1996 Fleming and Pund, 1994 Messenger and Ewing, 1996 TRB, 1996	Cervero and Gorham, 1995 Crane and Crepeau, 1998 Ewing, 1996 Fleming and Pund, 1994 Friedman et al., 1994 McNally and Kulkarni, 1997 TRB, 1996
	Proportion of journeys by foot or cycle			Cervero, 1989 and 1996a	Winter and Farthing, 1997	ECOTEC, 1993 Kitamura et al., 1997 Baker, 1995 Frank and Pivo, 1994		Balcombe and York, 1993	Ewing, 1996 Handy, 1992	Crane and Crepeau, 1998 Ewing, 1996 Friedman et al., 1994 Handy, 1992 and 1996 McNally and Kulkarni, 1997
TIME	Travel time		Gordon et al., 1989a	Giuliano and Small, 1993	Cervero and Landis, 1992	Gordon et al., 1989a Gordon et al., 1991 Levinson and Kumar, 1997	Levinson and Kumar, 1997			

Land use characteristics → Travel patterns ↓		Distance of residence from the urban centre	Settlement size	Mixing of land uses	Provision of local facilities	Density of development	Proximity to main transport networks	Availability of residential parking	Road network type	Neighbourhood type
ENERGY	Transport energy con-sumption		Næss et al., 1995 Mogridge, 1985 Newman and Kenworthy, 1988	Banister et al., 1997		Næss, 1993 Newman and Kenworthy, 1989 Kenworthy and Laube, 1999				

3.1 Distance of residence from the Urban Centre

Spence and Frost (1995) describe the changes in commuting distance between 1971 and 1981 in the three largest cities in Great Britain, London, Manchester and Birmingham and show how commuting distance changes with increasing distance between home and the urban centre. In London commuting distance increases almost linearly with distance between home and urban centre. At a distance of 20 kilometres from the centre of London commuting distance continues to increase with increasing distance from the centre of the city. In Manchester and Birmingham however the relationship is different. Commuting distance in Birmingham first increases with increasing distance between home and the urban centre but at a distance of around 7 kilometres from the urban centre commuting distance reaches a plateau. At a distance of around 9 kilometres from the centre commuting distance begins to decrease as distance from the urban centre increases. Commuting distance in Manchester first increases with increasing distance from the urban centre. At a distance of around 5 kilometres from the centre commuting distance reaches a plateau and does not change with further increases from the city centre unlike the trend in commuting distance in Birmingham which begins to decrease at a distance of 9 kilometres from the city centre. The trends in commuting distance by distance from home to the urban centre in the three cities between 1971 and 1981 are similar. Gordon et al. (1989a) describe the changes in average travel distance in the United States between 1977 and 1983 of people residing inside and outside cities. In various sizes of city journey distances for both work and non-work journeys in 1977 and 1983 were almost always lower for residents inside cities than for residents outside cities.

Næss et al. (1995) identify a statistical relationship between the distance from the urban centre and travel distance per person in Oslo in which total distance increases with increases between home and the urban centre. It is claimed that the distance between home and the urban centre is an important determinant of travel distance in addition to factors such as car ownership and the proximity to local facilities from the home. In a study of travel patterns in various locations in and around Oxford, Curtis (1995) shows that average work journey distance may be linked to the distance between home and urban centre. A link between average non-work journey distance and the distance from home to urban centre is much less apparent. Average work journey distance is lowest in the two locations closest to the centre of Oxford (Botley and Kiddlington) and highest in the two locations furthest from the centre of Oxford (Bicester and Witney). As for non-work journeys, average travel distance is highest in Witney, Bicester and Botley, the first two locations being most distant from the city centre and the latter being closest to the centre of Oxford. The lowest average non-work travel distance was recorded in Kiddlington, a location close to the centre of Oxford. According to the data collected by Curtis (1995) the frequency of work and non-work journeys does not vary significantly according to the distance between home and the urban centre. The proportion of journeys by car may be related to some extent to the distance between home and city centre. The proportion of car journeys is lowest in the two locations closest to the centre of Oxford and highest in the two locations furthest from the city centre. Stead (1999) examines the relationship between the proximity of homes to high street shops as a proxy for the distance between home and the urban centre (recognising that this measure may not accurately reflect the proximity to the nearest urban centre, since high street shops are not always found in central urban areas – they can also be found in out of town shopping centres and along the radial routes of larger cities for example) but finds no relationship between the distance between home and high street shops.

Næss et al. (1995) examine the effect of distance from the home to the urban centre on transport energy consumption. Transport energy consumption increases as the distance between home and the urban centre increases. A causal model containing a variety of land use and socio-economic variables is constructed. It is claimed car ownership has the greatest influence on transport energy consumption, followed by the distance between home and the urban centre, the proximity to local facilities from the home, income per capita and various other socio-economic factors. Mogridge (1985) demonstrates a near linear relationship between distance from home to the centre and transport energy consumption. The relationship is shown to be very similar in both London and Paris. On average, residents living at a distance of 15 kilometres from the urban centre consume more than twice the transport energy consumed by residents living 5 kilometres from the urban centre. Similarly, Newman and Kenworthy (1988) identify the relationship between transport energy consumption and the distance from the central business district in Perth. Like Mogridge (1985), Newman and Kenworthy demonstrate a linear relationship although the latter is not as steep. It is reported that residents living at a distance of 15 kilometres from the central business district consume approximately 20 per cent more transport energy than residents living 5 kilometres from the central business district.

In summary, in many studies, increasing distance from home to the urban centre is associated with increasing travel distance, an increasing proportion of car journeys and increasing transport energy consumption. Trip frequency however does not vary significantly according to the distance between home and the urban centre. It is recognised here that urban areas are not monocentric and there are often urban locations outside of the centre where major employment, services and facilities can also be found. Thus the distance between home and urban centre may only be a rough indicator of the remoteness of development.

3.2 Settlement Size

The size of settlements affects the range of local jobs and services that can be supported and influences the range of public transport services which can be provided. Thus small settlements that are unable to support a large range of services and facilities may force local residents to travel longer distances in order to access the services and facilities that they require. Very large, centralised settlements may on the other hand lead to longer travel distances as the separation between homes and the urban centre becomes large. Large settlements with a very large range of jobs and services may also attract people living long distances away to travel to them. These factors may all influence travel patterns. According to Owens (1986 p.29) and ECOTEC (1993 p.39) it is unlikely that there is a simple relationship between settlement size and travel patterns. Banister (1996) argues that a diversity of services and facilities requires a population size of at least 10,000. Barton et al. (1995) share similar views on settlement size thresholds.

Orfeuil and Salomon (1993) conclude from their study of French cities that the size of the urban area is associated with a U-shaped distribution of trip lengths. Long trip distances are observed in rural areas and the largest conurbations, while short distances are observed in medium-sized cities. In Great Britain, ECOTEC (1993) report that travel distance is highest in the smallest category of settlements (containing fewer than 3,000 residents) and travel distance is lowest in large metropolitan areas (excluding London), according to analysis of national travel data. Residents of London travel larger distances on average than the residents of the six next largest metropolitan areas (West Midlands, Greater Manchester, West Yorkshire, Glasgow, Liverpool and Tyneside). Hillman and Whalley (1983) report similar findings in their analysis of data from 1978/79 National Travel Survey of Great Britain. They also report that the total distance travelled per person by car is lowest in conurbations (metropolitan areas) and highest in rural areas. The average journey distance by car is also lowest in conurbations and highest in rural areas. Research by Stead (1999) suggests that travel distance is often lower in large urban areas containing more than 250,000 residents, after socio-economic differences are taken into account.

Figures from research by Gordon et al. (1989a) show no easily identifiable relationship between urban population size and modal choice. In a study of commuting patterns in the ten largest urbanised areas in the United States, the proportion of car journeys was found to be least in New York (which has the largest population of the areas studied) and highest in Detroit (which has the sixth largest population of the areas studied).

Breheny (1995) uses estimates of typical specific energy consumption by mode and data from the 1985/86 National Travel Survey of Great Britain to calculate transport energy consumption by population size. He reports that transport energy consumption is lowest in metropolitan areas (excluding London) and highest in the smallest category of settlements (containing fewer than 3,000 residents). Transport energy consumption is one third lower than average in the metropolitan areas (excluding London) and more than one third higher than average in the smallest settlements. Breheny’s work shows that the trends in transport energy consumption and travel distance trends by settlement size are very similar despite significant variations in modal split across different sizes of settlement. Although there are significant differences in energy consumption across different sizes of settlement, Breheny estimates that counter-urbanisation trends between 1961 and 1991 have only been responsible for a small increase (approximately 2 per cent) in passenger transport energy consumption.

In summary, there has been a relatively large amount of research concerning the relationship between settlement size and travel patterns. The relationship between settlement size and travel patterns is unlikely to be simple due to the interplay of competing factors. Evidence from Great Britain shows that large metropolitan settlements are associated with low travel distance and transport energy consumption. Evidence from the ten largest urban areas in the United States however shows no easily identifiable relationship between urban population size and modal choice.

3.3 The Mixing of Land Uses

The mixing of land uses affects the physical separation of activities and is therefore a determinant of travel demand. Some evidence suggests that the mixing of land uses is not as important as density in influencing travel demand (Owens, 1986; ECOTEC, 1993). Nevertheless the level of mixed use may contribute to travel demand particularly through the decentralisation of less specialised employment (ECOTEC, 1993). The mixing of land uses is commonly measured using job ratio, the ratio of jobs in the area to workers resident in that area.

Ewing et al. (1996) have investigated the effect of the various land use mix characteristics on trip generation including the balance of homes and jobs. They report that there is no statistically significant relationship between the balance of homes and jobs and journey frequency. In a study of commuting patterns in San Francisco, Cervero (1989) reports a negative relationship between job ratio and the proportion of journeys undertaken by foot and cycle: where there are many more jobs than houses the proportion of journeys by foot or cycle falls. Cervero concedes that the statistical relationship is not very strong but suggests that the encouragement of balancing houses and jobs may encourage walking and cycling. Giuliano and Small (1993) question the importance of job ratio on travel patterns and present the results of a commuting study in the Los Angeles region to show that job ratio has a statistically significant but relatively small influence on commuting time. They conclude that attempts to alter the metropolitan structure of land use are likely to have small impacts on commuting patterns even if jobs and housing became more balanced. Stead (1999) reports that higher job ratios are associated with lower travel distance but recognises that is not possible to achieve high job ratios in all areas (since this would require a surplus of jobs or a deficit of employable residents). In a study of transport energy consumption in various locations in Great Britain, Banister et al. (1997) identify a relationship between job ratio and energy use per trip in one of their case studies (Oxford). An aggregate measure of land use mix (termed ‘diversity’) is examined by Cervero and Kockelman (1997), who report a link between land use mix and total non-work travel distance but no link between land use mix and total distance travelled.

To summarise, there are relatively few studies concerning the effect of job ratio on travel patterns. On first examination evidence from existing research may appear contradictory but this is not necessarily the case. The three studies summarised above use different measures of travel patterns in their analysis. Thus it is quite consistent that the relationship between job ratio and modal share (examined by Cervero, 1989) is not the same as the relationship between job ratio and travel time (examined by Giuliano and Small, 1993), job ratio and travel distance (Stead, 1999) or the relationship between job ratio and transport energy use per trip (examined by Banister et al., 1997).

3.4 The Provision of Local Facilities

The provision of local facilities and services may clearly reduce travel distance and increase the proportion of short journeys capable of being travelled by non-motorised modes. Little evidence has been collected on this subject however and some of the precise impacts of local facilities and services on travel patterns are unknown.

Winter and Farthing (1997) report that the provision of local facilities in new residential developments reduces average trip distances but does not significantly affect the proportion of journeys by foot. Evidence from the same study reported elsewhere indicates that the provision of local facilities reduces the average journey distance by car (Farthing et al., 1997). ECOTEC (1993, p.47) report from neighbourhood case studies that a clear relationship emerges between the distance from a local centre, the frequency of its use and average journey distance. Hanson (1982) and Stead (1999) report similar findings, showing that the proximity to local facilities is positively associated with average distance after taking into account the effects of various socio-economic differences of the areas studied. Hanson also shows that the provision of local facilities is associated with increased journey frequency although the effect of increasing journey frequency is not as strong as the effect of reducing trip length.

Thus, there is broad consensus from these studies about the effects of local facilities and services on travel patterns. The provision of local facilities may overall contribute to less travel overall but might not contribute to any more travel by less energy intensive modes, namely walking and cycling.

3.5 The Density of Development

The density of development is commonly measured in terms of population density and to a lesser extent employment density. Much of the research into land use and travel patterns has focused on the relationship between population density and travel patterns. ECOTEC (1993 p.33) put forward four reasons why population density may be linked to travel patterns. Firstly, higher population densities widen the range of opportunities for the development of local personal contacts and activities that can be maintained without resort to motorised travel. Secondly, higher population densities widen the range of services that can be supported in the local area, reducing the need to travel long distances. Thirdly, higher density patterns of development tend to reduce average distances between homes, services, employment and other opportunities which reduces travel distance. Fourthly, high densities may be more amenable to public transport operation and use and less amenable to car ownership and use which have implications for modal choice.

Figures derived from ECOTEC (1993, pp.33-34) indicate that average journey distance by car, bus and rail decreases with increasing population density, whilst the average journey distance by foot is more or less constant regardless of population density. Hillman and Whalley (1983) report similar findings from their analysis of data from the 1978/79 National Travel Survey of Great Britain. They show that the total distance by all modes decreases with increasing population density and show that residents of very low-density areas (less than 5 persons per hectare) travel by car more than twice the distance of residents of high-density areas (more than 60 persons per hectare). Stead (1999) also reports that low population densities are often associated with high travel distances.

According to ECOTEC (1993), total journey frequency does not show a clear gradation with population density and there is little variation in trip frequency according to population density. The average journey frequency is reported to be close to 14 journeys per person per week. The highest trip frequency is 14.8 journeys per person per week in areas where population density is between 1 and 5 persons per hectare. The lowest trip frequency is 13.0 journeys per person per week in areas where population density is more than 50 persons per hectare. Ewing et al. (1996) report that there is a weak significant statistical link between trip frequency and population density.

Figures from ECOTEC (1993) show how modal choice is associated with population density. The proportion of trips by car decreases with increasing population density whilst the proportion of trips by public transport and foot both increase. Car trips account for 71 per cent of journeys in low-density areas (more than 50 persons per hectare) but only 51 per cent of trips in high-density areas (less than 1 persons per hectare). There is a fourfold difference in public transport trips and almost a twofold difference in walk trips between very low density areas and very high density areas. Frank and Pivo (1994) show how the proportion of shopping trips by public transport and the proportion of commuting trips by foot are both positively linked with population density. Kitamura et al. (1997) show how population density is linked to the proportion of public transport trips after accounting for socio-economic differences. Gordon et al. (1989a) however produce evidence which shows that there is no clear relationship between the proportion of car trips and population density. There are a number of reasons for the apparently contradictory findings of these studies. First, the definitions of density are different in the work of Gordon et al. than in most of the other studies. Second, Gordon et al. (1989a) only focus on journeys to work whereas ECOTEC (1993) and Kitamura et al. (1997) examine all journey purposes.

Newman and Kenworthy (1989) illustrate the correlation between urban population density and transport energy consumption in a study of 32 cities from around the world. Using Swedish data, Næss (1993) also identifies a link between population density and transport energy consumption.

There is much less evidence concerning the relationship between travel patterns and employment density, a second measure of the intensity of land use and activities. It is possible that similar relationships between population density and travel patterns exist between employment density and travel patterns. Frank and Pivo (1994) for example show that employment density, like population density, is connected to the proportion of public transport trips for both shopping and work journeys after controlling for socio-economic variations.

In summary, there is a growing body of research that suggests a link between population density and many measures of travel patterns. There is little evidence however of much variation in journey frequency by population density. In contrast to the amount of research into the relationship between population density and travel patterns, there has been little recent research concerning the relationships between employment density and travel patterns.

3.6 Proximity to Main Transport Networks

The proximity to transport networks also influences travel patterns and consequently transport energy consumption. Better access to major transport networks, particularly road and rail networks, increases travel speeds and extends the distance which can be covered in a fixed time. Major transport networks can be a powerful influence on the dispersal of development – both residential and employment development. The proximity to major transport networks may lead to travel patterns characterised by long travel distances and high transport energy consumption.

Headicar and Curtis (1994) report that the proximity to major transport networks has a substantial effect on work travel distance. They conclude that the proximity to either a motorway or a main road is associated with longer travel distances and a higher proportion of car journeys. They also report that the proximity to a railway station is associated with long distance commuting but fewer car journeys. Kitamura et al. (1997) report that the distance from home to the nearest bus stop and railway station affects the modal share. The proportion of car journeys increases and the proportion of non-motorised journeys decreases with increasing distance from the nearest bus stop; the proportion of rail journeys increases with increasing distance from the nearest railway station. Cervero (1994) shows how the proportion of rail journeys decreases with increasing distance from the railway station. Residents living within 500 feet (approximately 150 metres) of a railway station in California typically use rail for approximately 30 per cent of all journeys. The further the distance from the railway station, the lower the proportion of rail journeys is made. Residents living at a distance of around 3,000 feet (approximately 900 metres) from the nearest railway station are likely to make only about half the number of rail journeys than residents living within 500 feet of a railway station. Cervero reports that this pattern of rail use is similar in Washington, Toronto, Edmonton and California. However, Stead (1999) finds little evidence in Britain of a link between the proximity of homes to a railway station and travel distance.

Thus, the proximity to transport networks influences travel patterns and consequently transport energy consumption. Better access to major transport networks, particularly road and rail networks, increases travel speeds and extends the distance which can be covered in a fixed time. Major transport networks can be a powerful influence on the dispersal of development – both residential and employment development. The proximity to major transport networks may lead to travel patterns characterised by long travel distances and high transport energy consumption. The availability of residential car parking is linked to both trip frequency and modal choice. As the availability of residential car parking increase, the proportion of car journeys increases.

3.7 The Availability of Residential Parking

Evidence from Kitamura et al. (1997) shows that the availability of residential car parking is linked to both trip frequency and modal choice. As the availability of residential car parking increases the average number of trips per person decreases: an observation that is perhaps counter-intuitive. Kitamura et al. suggest that residents with more parking spaces make fewer, longer journeys, whilst residents with fewer parking spaces make more journeys but these tend to be short. It is also reported that as the availability of residential car parking increases the proportion of car journeys increases. This would imply that residents with more parking spaces not only make fewer, longer journeys but also that these journeys are more car-based. Conversely, the research implies that residents with fewer parking spaces make more journeys but which are short and less car-based.

Balcombe and York (1993) identify a correlation between the availability of residential parking (expressed as the ratio of vehicles to spaces) and the proportion of car owners making short journeys by foot (in order to retain their parking space). The research indicates a greater tendency to walk in areas where residential parking is limited. Similarly, Valleley et al. (1997) suggest a relationship between the modal split of commuting and parking provision at work. Stead (1999) reports that limited residential parking is associated with lower travel distance and suggests that the limited availability of parking may lead to more ‘rational’ car use as residents seek to reduce the number of journeys and hence the number of times they have to search for a parking space on their return home. Limited residential parking may also indirectly contribute to less travel by suppressing car ownership which the study identifies as a strong determinant of travel distance. However, Balcombe and York (1993) report that difficulties in finding a parking space may not necessarily deter car ownership or intentions to acquire additional vehicles even with increasing parking problems.

3.8 Road network type

The form or structure of an urban area may be characterised to some extent by the pattern of its road network. Road networks may be described using qualitative labels for their overall pattern or by descriptions based on some component properties. Qualitative labels can give a reasonable intuitive impression of network shape (e.g. grid, radial, and so on), while component properties are more easily quantified and hence used as the basis for systematic comparison (e.g. the composition of the network in terms of route type or junction type—see Marshall, 2001a).

Maat (2000) reports the case of Houten, a Dutch town laid out with permeable pedestrian and cycle routes but with deliberately impermeable, circuitous routes for motor traffic. Here, peak period car trip generation was found to be 10 per cent less than the national average, despite car ownership being amongst the highest in the Netherlands. Use of the car for shopping trips was also found to be between 8 and 13 per cent less than in comparable urban areas (with similar characteristics but different network structure). However, trip distances for those (shopping) trips that are made by car are longer than in the comparator cases (Marshall and Banister, 2000).

Fleming and Pund (1994) report higher bus occupancy (implying a higher proportion of bus use) in networks which allow more direct access to public transport. However, Messenger and Ewing (1996) report that road network design had no apparent effect on bus use. Elsewhere, Ewing (1996) reports finding no relationship between transit use and street network design 'after controlling for other variables such as urban density and service frequency'. Ewing also notes that grid-like patterns can be more transit friendly to the extent that they may allow greater penetration of an area by transit services.

Ewing's study considered to what extent various urban features might be regarded as being 'essential' or 'highly desirable' in terms of contributing to pedestrian and transit friendly design. Among the 'essential' characteristics were short to medium length blocks (relating to network permeability) and continuous sidewalks (relating to the connectivity of the pedestrian network), while having a grid-like street network was considered highly desirable.

Crane and Crepeau (1998) cast doubt on whether the grid pattern has any significant effect on car or pedestrian travel. Indeed, Crane (2000) points out that, to the extent that grids' greater connectivity offers shorter trips, trip frequency may be expected to increase - a finding echoing results of modelling work by McNally and Ryan (1993).

The examples here suggest that the ability to single out the effects of road network type *per se* on travel behaviour may not be straightforward. However, underlying the many contingent factors, there seems to be a basic inverse relationship between the attractiveness of a mode and the distance travelled by that mode. This means, for example, that a grid layout may be associated with sustainable travel insofar as it promotes short and direct routes for pedestrians, including pedestrian access to public transport. But, by the same token, a grid may promote 'unsustainable' travel insofar as it allows short, direct routes for car traffic.

3.9 Neighbourhood type

Neighbourhood type is effectively a composite variable that is used to characterise areas of cities that are relatively homogeneous according to a range of attributes. These attributes typically include the age of development (such as pre-war or post-war), the style of development (traditional, conventional or neo-traditional for example) and the street network type (such as grid or loop and cul-de-sac), as illustrated in Table 2.

Table 2. A selection of neighbourhood types and their component attributes

Source	Neighbourhood types and attributes	
Kulash (1990)	'traditional neighborhood development' • mixed use • connected/gridded streets • reduced street hierarchy	'conventional suburban development' • segregated uses • partially connected streets and cul-de-sacs • hierarchical street networks
Friedman et al. (1994)	'traditional communities' • mostly developed before 1940 • mixed-use downtown commercial district with significant on-street parking • interconnecting street grid • residential neighbourhoods in close proximity to non-residential land uses	'suburban communities' • developed since the early 1950's with segregated land uses • well-defined hierarchy of roads • access concentrated at a few key points • relatively little transit service
Cervero and Gorham (1995)	'transit neighborhoods' • initially built along a streetcar line or around a rail station • primarily gridded (over 50 per cent of intersections four-way or 'X' intersections) • laid out and largely built up before 1945	'auto neighborhoods' • laid out without regard to transit, generally in areas without transit lines, either present or past • primarily random street patterns (over 50 per cent of intersections either 3-way, 'T' intersections or cul-de-sacs) • laid out and built up after 1945
McNally and Kulkarni (1997)[1]	'traditional neighborhood design' (TND) • gridlike transportation networks with few or no access cul-de-sacs • a large number of access points into the neighbourhood • high population densities	'planned unit development' (PUD) • circuitous transportation networks with many cul-de-sacs • a very limited number of access points in the neighbourhood • very segregated land uses • low residential densities

Evidence from Friedman et al. (1994) demonstrated trip frequencies in 'suburban' neighbourhoods to be some 25 per cent higher than in 'traditional' neighbourhoods. Similarly, McNally and Kulkarni (1997) found overall trip rates to be over 30 per cent higher in PUD's compared with TND's.

Both studies also found the traditional neighbourhoods generating a lower proportion of car trips. Similarly, Cervero and Gorham (1995) found that for commute trips, 'transit' neighbourhoods had lower drive-alone modal shares and trip generation rates compared with 'auto' neighbourhoods. Meanwhile Cervero and Kockelman (1997) found that neighbourhoods with a high proportion of four-way intersections and limited on-street parking abutting commercial establishments tended to have on average less drive-alone travel for non-work purposes.

Conversely, TRB (1996) report that transit use may be between 10 and 45 per cent higher in 'transit oriented' traditional neighbourhoods than in newer 'auto-oriented' developments; Friedman et al. (1994) found transit use in 'traditional' neighbourhoods to be more than

[1] McNally and Kulkarni also identify a third, hybrid category of neighbourhood. The list of attributes given is a summary of a longer list of network, land use and design variables.

double that in 'suburban' neighbourhoods. Meanwhile, Handy (1992), Friedman et al. (1994) and Cervero and Gorham (1995) all report higher proportions of journeys by foot in traditional or 'transit' neighbourhoods compared with suburban or 'auto' neighbourhoods.

Although these findings may tend to support the commonly recognised association of 'traditional' neighbourhoods with pedestrian and transit orientation, and 'conventional suburban' neighbourhoods with car orientation, this does not necessarily imply causality between travel behaviour and either the land use or layout components of the neighbourhoods. This is not least due to the influence of socio-economic factors (a point expressly evaluated by McNally and Kulkarni, 1997).

4. Critique

The critique of the literature reviewed is divided into three main sections. The first section concerns issues of data accuracy, reliability and quality. The applicability of various research methods is addressed in the second section and the third section concerns issues of data interpretation.

4.1 Data accuracy, reliability and quality

The question of whether the data is accurate and reliable is fundamental to all research. This paper does not attempt to examine the accuracy and reliability of all the studies whose results are summarised above. Instead, a number of more general issues concerning data accuracy, reliability and quality, which have been directed to these type of empirical studies, are summarised.

In setting out his critique of two studies authored by Newman and Kenworthy (Newman et al., 1985; Newman and Kenworthy, 1989), Troy (1992) raises a number of issues that are also applicable to many other studies of land use and travel patterns. The first issue concerns data accuracy. A number of studies to have examined the effect of land use and travel patterns have involved the calculation of travel distance from trip zone data. Troy (1992) questions the accuracy of travel distance calculations from trip zone data, where trip lengths are calculated from average distances between zone centroids. Studies by Spence and Frost (1995) and Banister et al. (1997) also rely on trip zone data to calculate travel distance. The distance of each journey is calculated according to the distances between the origin and destination zone centroids. Depending on the size of zones, the actual travel distance may be significantly different to the figure calculated using average centroid distances. The calculations also do not account for the configuration of the transport network in order to establish actual route distances, rather than straight-line distances between origin and destination zones. Since most studies are comparative, however, precise distances are not as important as relative distances. Thus, precise calculations of travel are less important than comparable travel distances that have a similar degree of accuracy for each area.

Second, Troy (1992) questions the applicability of average fuel consumption figures to calculate transport energy consumption, without accounting for factors that affect transport energy consumption such driving conditions or the time of day. These sort of assumptions are made in studies by Banister et al. (1997), Breheny (1995) and Næss et al. (1995). The average energy consumption of vehicles is influenced by a number of vehicle, journey and passenger characteristics, such as vehicle age, fuel type, engine size, engine temperature, vehicle speed and passenger loading (or occupancy). To account for each of these factors for every journey would add much complexity to the calculation of energy consumption. It would be necessary to establish information about the vehicle age, fuel type, engine size, engine temperature, vehicle speed, and passenger occupancy for every journey. Evidence from the National Travel Survey data for Great Britain suggests that factors such as driving speed at different times of the day do not show large variations (see section 4.3). Although the use of typical energy consumption values for each mode does not accurately account for the variation in the vehicle, journey and passenger characteristics of each journey, it does represent a reasonable estimate of transport energy consumption under typical conditions.

Third, the issue of the reliability of data from self-completed questionnaires is questioned. Troy (1992 p49) states that there is evidence from several (unspecified) reports to suggest that this kind of travel diary systematically overstates household travel and understates short trips. It is not clear how travel diaries tend to overstate household travel, but it is obvious to see that short journeys may be under-recorded. Studies based on data from self-completed travel diaries include Cervero (1994), Cervero and Landis (1992); Curtis (1995), Kitamura et al. (1997), Næss and Sandberg (1996), Næss et al. (1995), Prevedouros and Schofer (1991), Winter and Farthing (1997). Clearly, the issue of under-recorded short journeys is important when considering travel patterns such as trip frequency or the modal share of non-motorised journeys, since short journeys may be a significant component. The under-recording of short journeys is perhaps of less importance when considering total travel distance or transport energy consumption, since short trips do not often substantially contribute to these two measures of travel.

The representativeness of travel data is related to the sample size, the type of journeys recorded and the time period over which the data is collected. Troy (1992) expresses concern about the representativeness of travel data collected over a short time, questioning whether the typical weekday travel data collected by Newman et al. (1985) provide sufficient travel information to calculate annual transport energy consumption. Similar concerns might be expressed about a number of other studies summarised above. Concerns may also be expressed about the extent to which studies of single journey purposes (work travel, for example) can be used to represent all purposes of travel. Commuting in Great Britain, for example, now accounts for fewer than a quarter of all trips and a similar proportion of total travel distance (Department of Environment, Transport and the Regions, 1999). The search for more sustainable land use patterns, which is the focus of many recent studies of land use and travel patterns, clearly depends on identifying areas which promote fewer journeys, shorter journeys and non-motorised journeys. These characteristics clearly do not just apply to one type of journey but all types. Thus, the extent to which studies of commuting or other single types of journey purpose can identify sustainable land use patterns is only partial.

4.2 Methods of analysis

There are limitations to all methods of analysis and the limitations of empirical studies of land use and travel patterns have been outlined earlier in the paper. Two issues related to the limitations of empirical studies are discussed in this section. The first issue concerns the difficulty in establishing the causality of relationships. The second issue concerns socio-economic factors and the difficulty they pose in making comparisons between different areas.

Cross-sectional analyses of land use and travel patterns, like the ones contained in the studies reviewed above, do not easily lend themselves to establishing causal links. Several studies demonstrate strong correlations between various measures of land use characteristics and travel patterns. Such analysis, however, cannot prove a causal relationship, even where high correlation is demonstrated. Correlation may identify a link between variables, but this link may or may not be direct. It could be that the link is in response to another variable. Even if the link is direct, it is not possible to establish the direction of causality. Therefore, a strong correlation between transport energy consumption and population density, for example, does not imply a direct link between the two variables. The two variables could be linked by one or more intermediate variables, such as car ownership or income. Similarly, the results of regression analyses may identify statistical dependence between variables but do not identify a physical relationship between variables. As with correlation analysis, regression analysis may identify a link between variables but this link may or may not be direct.

In identifying a link between land use characteristics and travel patterns, it is necessary to hold all other variables constant. This is not easy in empirical research, since different land use characteristics are often associated with different socio-economic factors, which also have an effect on travel patterns. The variation in socio-economic factors increases the difficulty in establishing the effect of land use characteristics on travel patterns, and adds complication to the comparison of travel patterns in different areas.

A large number of socio-economic factors may influence travel patterns. There is a substantial amount of literature on this subject. This paper does not present a comprehensive review of the effects of all socio-economic factors on travel patterns. Instead, it identifies the main types of socio-economic factors and illustrates how each of these main types of factors may affect travel patterns. Eleven types of socio-economic factors are identified in this study from the review of literature on travel patterns and socio-economic factors. These eleven types comprise: income; car ownership and availability; possession of drivers' licence; working status; employment type; gender; age; household size and composition; level of education; attitudes; personality type. The effects of these factors on travel patterns are summarised in Figure 2. For a more comprehensive review of the effect of socio-economic factors on travel patterns, see Damm (1981) or Hanson (1982).

These eleven types of socio-economic factors are interconnected, and it is often difficult to separate the effect of one from another (i.e. they are often multicollinear). Household income, for example, is linked to employment type and working status (whether full-time or part-time; how many members of the household are employed). This may influence car ownership and use. Car ownership and use is also influenced by the possession of a driver's licence, age and gender (Figure 3).

Several studies summarised in this review do not explicitly recognise that different land use characteristics are associated with different socio-economic factors, which also have an effect on travel patterns. Consequently, they do not attempt to differentiate between the effects of land use characteristics and socio-economic factors. Other studies recognise the effect that socio-economic factors may have on travel patterns but employ a research method that does not differentiate between the effects of land use characteristics and socio-economic factors. ECOTEC (1993), for example, recognise the relationship between population density, lifestyles, income and car ownership but do not attempt to identify the separate effects of socio-economic factors and land use patterns. They report that:

Hanson (1982) reports that trip frequency is linked to household income: people in higher income households make more journeys than in lower income households. Cervero (1996a) shows how commuting distance increases with increasing income. Næss and Sandberg (1996) identify a positive link between household income and the total distance travelled per person. Transport energy consumption is reported to increase as household income increases (Næss, 1993; Næss et al., 1995). Flannelly and McLeod (1989) show how income is linked to the choice of mode for commuting. Income is also linked to land use patterns, which may explain some of the variation in travel patterns in different locations. Mogridge (1985), for example, shows how average incomes in Paris and London increase with increasing distance from the city centre, with the exception of residents in very central locations (within approximately 4 kilometres of the city centre). Kockelman (1997) also reports a positive correlation between travel distance and income.

Hanson (1982) reports that trip frequency increases with car ownership, whereas Prevedouros and Schofer (1991) contend that car availability does not explain the variation in trip frequency. Total travel distance is reported to increase with car ownership (Næss and Sandberg, 1996; Kockelman, 1997), as is transport energy consumption (op. cit.) and the proportion of car journeys (Næss, 1993). Flannelly and McLeod (1989) show that the number of cars per household is linked to the choice of mode for commuting. Ewing (1995) reports that travel time increases as car ownership levels increase. Like income, car ownership is also linked to land use patterns, and may explain some of the variation in travel patterns in different locations. Gordon et al. (1989a), Levinson and Kumar (1997) and Næss et al. (1995) identify links between car ownership and population density. Higher density areas tend to have lower levels of car ownership. According to evidence from the United States presented by Gordon et al. (1989a), car ownership tends to be lower in larger cities. Other studies show that car ownership increases as the distance from the city centre increases (Mogridge, 1985; Næss and Sandberg, 1996).

Flannelly and McLeod (1989) show how the possession of a driver's licence is linked to the choice of mode for commuting. People who use the bus are likely to come from households where fewer members have a driver's licence. Interestingly, it is reported that people who share cars to work are likely to come from households with more drivers' licences than average (op. cit.)

Prevedouros and Schofer (1991) report that work status does not explain the variation in trip frequency. Ewing et al. (1996) report that journey frequency increases as the number of workers per household increases. Ewing (1995) reports that average travel time per person increases as the number of workers per household increases, reflecting the fact that where there is more than one worker in household, home location may not be near to the workplace of each worker

Hanson (1982) reports no difference in total trip frequency according to gender in Sweden. Gordon et al. (1989b) report that the frequency of non-work trips is higher for women than men in the United States, and that women have shorter work trips than men, regardless of income, occupation, marital and family status.

Hanson (1982) reports no difference between trip frequency and age, whilst Prevedouros and Schofer (1991) report that age explains some of the variation in trip frequency. Evidence from Flannelly and McLeod (1989) suggests that age has no significant effect on the choice of mode for commuting. Næss et al. (1995) report that transport energy consumption increases with increasing age. Banister et al. (1997) report a negative correlation between transport energy consumption and the proportion of children within each survey group.

According to Hanson (1982), journey frequency increases as household size increases. Evidence from Ewing et al. (1996), Dunphy and Fisher (1996) and Kockelman (1997) supports this finding. Ewing (1995) reports that travel time per person increases as household size increases. Banister et al. (1997) report that household size is negatively correlated with transport energy consumption.

Evidence from Flannelly and McLeod (1989) suggests that the level of education has no significant effect on the choice of mode for commuting.

Some significant differences in travel patterns are reported according to attitudes to various aspects of urban life (Kitamura et al., 1997). It is reported that higher than average trip frequency is associated not just with pro-car attitudes but also rather inconsistently with attitudes which are either pro-environment or pro-public transport/ridesharing. Perhaps unsurprisingly, people with pro-public transport attitudes make more journeys by public transport than other people. People with pro-car attitudes tend to make fewest journeys by public transport and the most journeys by car. People with pro-environment and pro-public transport attitudes make the most non-motorised journeys, whereas people with pro-car attitudes make the fewest non-motorised journeys. Other attitudes to urban life (termed time pressure, urban villager, suburbanite and workaholic) were also investigated by Kitamura et al. but there were few large differences in travel patterns according to these other attitudes. Flannelly and McLeod (1989) suggest that the choice of mode for commuting is affected by attitudes to travel, such as convenience, reliability, comfort, speed, pleasantness, safety and expense.

Prevedouros (1992) examines the differences in travel patterns according to personality types and reports that trip frequency and total distance travelled increases with increasing sociability. Different personality characteristics are associated with different types of home location. The proportion of 'sociable' personalities was higher in urban areas and lower in suburban areas. Urban dwellers were therefore more likely to make more trips and travel further than suburban dwellers.

Figure 2. Examples of how socio-economic factors affect travel patterns

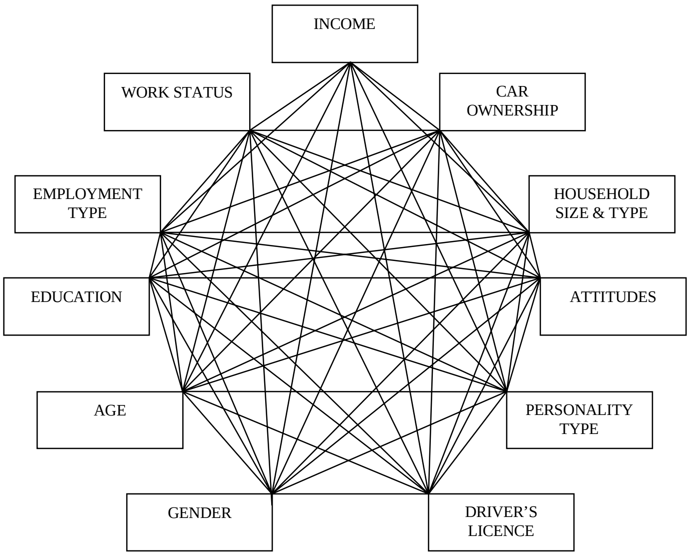

Figure 3. Interactions between socio-economic factors

> *"...in Britain, there is a strong relationship between the population density of residential areas and the average income levels of the residents. Lower income levels in high density areas will have implications for both lifestyles and levels of car ownership. This... warns against making simple conclusions about the independent nature of density and, in particular, on the extent to which a policy favouring higher density in new suburban developments will have beneficial effects on travel behaviour. In principle, the effects of density, location and income levels could be separated by a statistical analysis which controls for the latter two variables. However, the necessary data for this analysis are not available. Some of the data which are available suggests that socio-economic factors - and in particular car ownership - are more significant than density per se in explaining inter-personal and inter-area variations in travel behaviour."*

Several other studies recognise the effect of socio-economic factors and employ research methods that attempt to hold socio-economic variables constant in order to observe the effects of land use and characteristics. These studies tend to have been carried out within the last decade. Two methods have been employed to hold socio-economic variables constant. The first and more popular approach uses multiple regression analysis, in which socio-economic variables and land use characteristics are treated as explanatory variables (examples include: Cervero, 1989; Ewing, 1995; Ewing et al., 1996; Frank and Pivo, 1994; Kitamura et al., 1997; Næss, 1993; Næss et al., 1995; Næss and Sandberg, 1996; Prevedouros and Schofer, 1991). The method allows identification of the main socio-economic and land use characteristics that are associated with certain travel patterns. The method does not, however, allow the identification of causal relationships (as discussed earlier). The second and less popular method employed to hold socio-economic variables constant involves the selection of case study areas which have similar socio-economic profiles but different land use characteristics. In this way, socio-economic differences are

minimised and the variation in travel patterns is assumed to be the result of land use characteristics (examples include Handy, 1992 and Curtis, 1995).
Like the interconnection of socio-economic factors, it is also likely that a number of land use characteristics are also interrelated. Settlement size, for example, may be linked to population density (large cities are denser than small villages), the distance to the urban centre or the availability of residential parking (Figure 4). Establishing the individual effects of these characteristics is therefore difficult.

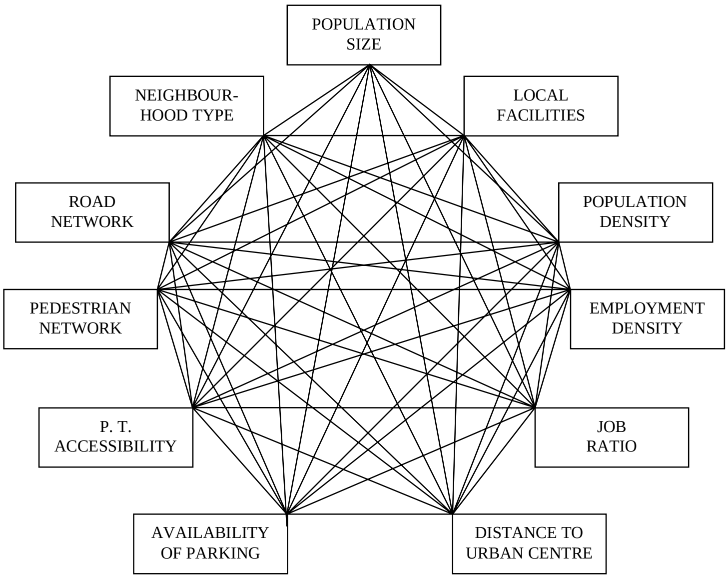

Figure 4. Interactions between land use characteristics

The ability to relate travel behaviour with particular neighbourhood or network types is problematic. For a start, the terminology used is not standard, leading to use of descriptions of neighbourhoods or street patterns which may be ambiguous or otherwise not easily interpretable. Terms such as ‘clear’ or ‘coherent’ or ‘connected street networks’ are used to characterise street pattern, but their precise meaning is not always clear (Marshall, 1998).
The Transport Research Board (TRB) Report on Transit and Urban Form notes that it is ‘difficult to sort out the effects of land use mix and urban design because they are strongly correlated with density’, stating that density has the ‘dominant influence on transit use’ (TRB, 1996). The TRB findings suggest that once density is taken into account, urban design measures generally do not add much explanatory power. This is attributed to the way in which density is characterised as a metric scale ranging over large values, and therefore has a ‘natural predictive advantage’ over other variables of urban design which use a nominal scale or ranking scale.
Ewing (1996) sums up the problem: ‘Urban design characteristics may appear insignificant when tested individually, but quite significant when combined into an overall ‘pedestrian-friendliness’ measure. Conversely, urban design characteristics may appear significant when they are tested alone, but insignificant when tested in combination’. While network type may not influence travel behaviour *per se*, network form can affect other factors such as coverage

of transit routes (Ewing, 1996) or the directness of access paths to public transport routes and stops (Marshall, 2001b).

With more analysis of disaggregated data it might be possible to isolate effects of network type. Ewing (1996) notes the lack of previous multivariate studies which tested urban design variables, and the absence of any testing road network variables *per se*. Neighbourhood type is effectively an aggregate variable that incorporates network type and other urban form variables. Network type, nested within the concept of neighbourhood type, is also to some extent a composite variable. Since there are no standard definitions of these it is difficult to draw generalised conclusions about their effects on travel behaviour.

Results from Kitamura et al. (1994) suggest that a 'place variable, which symbolises a variety of *difficult-to-measure* urban design attributes, is a significant source of explanatory power for transit trip generation' [emphasis added]. The TRB (1996) notes that '... the *bundle of attributes* that makes for a successful pedestrian and transit-friendly station area or neighborhood is *difficult to break apart* through statistical means...' [emphasis added], and states that '… the influence of neighborhood design is particularly problematic to evaluate'. This is illustrated by the observation that the neighbourhood characteristics of American cities tend to equate with particular aggregated types. For example, compact neighbourhoods 'tend to have more varied land uses, average shorter block lengths, narrower streets, more grid-like street patterns, continuous sidewalk networks, and so on' (TRB, 1996). Ewing (1996) notes the degree of inter-relatedness of variables such as higher densities, finer land use mixes and gridded streets. While this may allow reasonable deductions to be made about travel behaviour in existing neighbourhoods (dense traditional neighbourhoods being equated with relatively high transit use, for example), this is not sufficient for predicting the effects of new development forms which may only have some, or have different combinations of, these attributes. Accordingly, these findings would suggest that there is a need to find a wider range of examples to study, which do not follow the 'typical' characteristics like those noted above. By doing so it may be possible to obtain a more detailed picture of the effects of different urban form variables on travel behaviour.

4.3 Interpretation of the results

There is considerable variation between individual definitions of neighbourhood types, and much scope for ambiguity and overlap between extremes of 'suburban/auto' and 'traditional/transit' types. As well as the composite nature of 'neighbourhood type', definitions are not always used consistently, such that different names may be used to describe the same feature, or the same names may be used to account for different embedded variables. In many cases the criteria used are subjective such that two different investigators, using the same criteria, could come up with different designations for a particular area. 'Neo traditional' may be taken to imply both 'griddiness' and density and mixed use. Secondly, griddiness or grain is not explicitly or uniquely defined. Density may be expressed in various ways but, at least, the particular way in any particular case is usually unambiguously defined. Therefore it is necessary to be cautious when interpreting results based on neighbourhood type. This is especially important where the neighbourhood type might include some other major indicator of urban form such as density, which may be used to characterise the area of study. The studies reported on in Cervero (1996b) and Cervero and Gorham (1995) are rare examples of unambiguous specification of both neighbourhood and network type. Ideally, more detailed investigations into network type need to be undertaken in order to clarify its relationship with travel behaviour.

It has been shown that there are links between socio-economic characteristics and travel patterns, as well as between land use characteristics and travel patterns. It is clearly important that the effect of land use and socio-economic characteristics are differentiated in the interpretation of results. Kitamura et al. (1997) conclude that attitudes may be more strongly associated with travel patterns than land use characteristics, and suggest that land use policies associated with more sustainable travel patterns may not significantly alter travel demand unless attitudes are also changed.

5. Conclusions

The review has shown that there is a large amount of literature from around the world on the relationships between urban form and travel characteristics. Much of the evidence contained in the review originates in either Western Europe or the United States. Many of these studies find that urban form characteristics, ranging from regional to local in scale, have an influence on travel patterns and consequently the environmental impacts of transport.

This review has explicitly categorised the literature according to discrete aspects of urban form and travel patterns (albeit at the risk of debate over the choice of categories), which allows for clearer identification of the similarities and differences between studies. However, it is recognised that there is no definitive way of deciding the categories: definitions may be overlapping or nested within each other and the significance of each variable is likely to depend on context.

The critique of these studies has suggested that a number of issues must be taken into account when drawing any conclusions for policy. These issues include the strength of the evidence, the transferability of findings (whether findings in one country apply to another for example), the scale of analysis (regional, urban or neighbourhood and so on) and the causality of relationships. The interactions between socio-economic factors, urban form and travel patterns add further complication to the analysis of relationships between land use and travel characteristics. This issue has not been well explored to date, although more studies are now recognising interactions between socio-economic factors, urban form and travel patterns in their design (see also Stead et al., 2000; Stead, 2001).

So the extent to which urban form might influence travel patterns may be lower than previous studies have indicated (where they have not taken socio-economic characteristics into account). However, this does not mean that urban planning does not have an important role to play in helping to achieve more sustainable travel patterns. Planning policies can influence transport supply and parking as well as the distribution of land uses, and hence provide a way of influencing travel demand and/or modal choice ‘at source’. Furthermore, combinations of several land use measures may have significant effects on travel by creating synergies between measures, and land use policies may be complemented by the effects of other, non-land use measures (see Stead, 1999; Stead, 2000). In other words, urban planning is well placed to co-ordinate the variety of factors which individually and collectively are able to influence more sustainable travel patterns.

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