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How change in residential built form influences travel behaviour in Scotland.

By

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This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

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Abstract

This research seeks to shed light on the relationship between urban-form and travel behaviour. There is a large body of literature on those factors that affect travel behaviour at the disaggregate level of the individual. These studies have suggested that numerous and varied factors can influence travel behaviour such as car ownership, income, workplace location and family structure. However, many unanswered questions remain as to the causal mechanisms by which urban form and travel behaviour relate. This thesis describes analyses using a current and retrospective recall dataset of households, including a high proportion of households who had recently moved home to explore possible causal paths in more detail. Data were collected from six case study areas in Glasgow and Edinburgh, Scotland. A set of regression equations were developed including those derived from generalized estimating equations to explore how urban form, car ownership and travel behaviour relate. Cross sectional analyses based on the current home showed little in the way of statistically significant associations between urban forms and vehicle miles driven after car ownership and other socio-demographic factors were controlled for. However, change in urban form was significantly associated with reported change in miles driven in the expected directions for people who had recently moved home. Cross sectional and longitudinal analyses of urban form and car ownership showed significant associations, especially so for those who had moved home. Population to jobs ratio, ward population density and distance to urban centre were all significant. This analysis goes some way to supporting the theory that changing urban form characteristics can influence travel behaviours, which underpins various planning policies in Scotland and elsewhere; albeit more strongly through car ownership decisions than directly. Effects may however be temporary with the relationship between urban form and car ownership dissipating over time since relocating home.

With thanks to Neil.

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1. Introduction

High, and growing, demand for travel has lead to increasing interest into the effectiveness of land use policy as a tool to manage this demand. Some of the earliest research in this field, such as that by Newman and Kenworthy (1989), suggested that some aspects of this configuration (what has become known as *Urban Form*), including, for example population density, were strongly associated with travel demand. Such associations have led policy makers to consider ways in which settlements may be shaped in order to try to reduce or limit the growth in demand for travel by car. However, many questions remain unanswered as to whether or not land use policy is an effective travel demand management (TDM) tool. Doubts about the effectiveness of land use policy as a TDM tool can be broadly divided into questions over whether or not policy can bring about changes to the built form required and questions over whether or not such changes to built form would create the desired changes in travel behaviour. The focus of this thesis is on the second of these two points.

This study aims to shed light on whether, and in what way, urban form relates to car use in the context of Scottish urban areas. It should be noted that this thesis does not address the question of whether decreasing car use is a sensible policy. While many argue that the benefits of increased mobility reaped from increasing car use outweigh any negative consequences in terms of emissions, congestion etcetera (Echenique, 2001), this thesis discusses only whether or not particular urban forms can influence travel behaviours, with the premise that minimising car use is something many policy makers wish to achieve.

Subsequent work has been carried out, notably by Handy (2005) and Cevero (2002) in the United States and Naess (2005), Snellen et al (2002) and Banister (1997, 2007) in Europe and the UK, which also suggest that various aspects of urban form do appear to have some association with travel behaviour. There is however, still not a substantial body of evidence that urban form influences travel behaviour, and lesser still as to any relationship in the context of Scotland. No such substantial body of literature exists as many of the studies have been focussed on urban areas in the US or continental Europe, with very few set in a British or Scottish context. Context here refers to Scottish planning, public transport provision, housing markets, congestion, fuel pricing, socio-economics, lifestyles etcetera, which may be important issues in the role urban form may have on shaping travel behaviour.

Most studies have also not considered the role of car ownership and many studies have been cross sectional in time; hence cannot demonstrate causality between changes in urban form and travel behaviour. Cross sectional studies enable inter-personal variation to be examined. Longitudinal studies allow intra-personal (i.e. within the person) as well as inter-personal differences. Furthermore, sample selection bias resulting from subjective definitions of case study areas or as a result of self selection into study groups, calls into question the validity of much of the literature.

In order to address these gaps in the literature and to determine whether urban form influences travel behaviour and if urban form influences car ownership in the context of Scottish urban areas, the following objectives need to be met:

- To estimate the effect of urban form on travel behaviour,
- To estimate the effect of car ownership on travel behaviour,
- To estimate the effect of a change in urban form on individual and household travel behaviour following residential relocation,
- To estimate the effect of urban form on car ownership,
- To estimate the effect of a change in urban form on car ownership following residential relocation.

The study will follow the process outlined below in order to meet these objectives and answer the questions set out in this thesis:

- To measure urban form at different geographic scales using measures widely referred to in planning policy,
- To measure travel behaviour for all cohabiting adults within a household,
- To gather socio-economic data relating to the household,
- To gather information on the previous residential location for those households who had recently moved home,
- To gather information on the previous socio-economics, urban form and travel behaviour for those households who had recently moved home,
- To use novel applications of statistical techniques to investigate the relationship between urban form and travel behaviour.

By studying households who have relocated, change in residential urban form can be captured. While the decision to change urban form is made by the household as opposed to be imposed on the household through urban planning, studying organic changes in urban form over time, would not have been practicable, given the long time periods over which such changes occur. Therefore, in terms of guidance to policy makers, the results of this study relate to how the residential urban form selected by households, relates to their travel behaviour, and how by constraining the choice set of urban forms available to households, policy might be able to shape travel behaviour.

The remainder of this thesis is structured as follows. Firstly, Chapter 2, Literature Review highlights why the research question is of interest including the implications for policy and land use transport modelling. The review describes the existing literature of studies into the relationships in both directions between urban form and travel behaviour. There are a large number of studies into the area often using similar study designs to address similar questions to one another. For this reason, the key studies are critiqued in detail, while more than one hundred other cited studies are described in a tabular form so as to make comparisons easily between the questions being asked in each study, the methodology and data used and their key findings. The key research issues of self selection, compensation and time order criterion are explained and explored with reference to the literature. Differences in results from studies carried out in various parts of the world are discussed along with their implications for the UK and Scotland; similarly for urban-form car-ownership specific studies. The literature review concludes with a summary of literature, highlighting the gaps in knowledge.

A hypothetical urban form-travel behaviour relationship is then presented in Chapter 3, Research Hypotheses and Methods, describing how the hypotheses were developed and how they fit within a wider travel behaviour causal model, along with a description and justification of methods chosen and of the data collection exercise.

A description of the data collected is presented in Chapter 4, Descriptive Statistics including response rates, variability of the data and a consideration of correlation within the data.

The statistical modelling of both the cross sectional data and quasi-longitudinal data is then described in Chapter 5, Analysis, including the statistical form of the models with reference made to benefits or otherwise of the modelling regimes utilised in the literature and available from other disciplines. The outcomes of these analyses are then discussed, including their limitations and their impact in terms of policy.

Finally, Chapter 6 Conclusions evaluates how the study addressed the unanswered questions as to the role of urban form on travel behaviour and car ownership (and changes in both), in the context of Scottish urban areas, what the nature of any such relationships are and what impact this has for urban/spatial planning policy in Scotland, UK.

2. Literature Review

In this chapter a review is presented that highlights why the research question addressed in this thesis is of interest, including the implications for policy, with particular reference to UK and Scottish planning and spatial policy. The review then describes the existing body of studies which have examined the association between urban form and travel behaviour, divided into primarily US based research, European and finally UK work. Differences in results from studies carried out in various parts of the world are discussed along with their applicability to the UK.

Much of the research in this field has been interested specifically in the built form of urban areas as opposed to a rural setting, hence the use of the term "urban" form. The term "urban" is used instead of "city" as cities are often defined by administrative boundaries that may include a mixture of both urban and rural locals. The Office for National Statistics (2001) describes the objective factors such as settlement size and subjective means by which urban areas are defined in the UK.

Issues relating to causality in the relationship between urban form and travel behaviour such as residential self-selection, compensation and time-order are explained and explored with reference to the literature. Different methodological and statistical techniques used in the literature to address these issues are discussed in brief with a more detailed discussion in the following chapters accordingly. The measures of urban form used and data sources available are noted in this review and explored in more depth as part of section 3.3.2 and section 3.3.3. The limitations of existing work are then highlighted with reference to the unanswered research question of whether urban form influences travel behaviour and car ownership in Scottish urban areas.

2.1. Motivations for Study

It is important to consider the motivations and likely benefit of this study. Motivations for the sustained interest of researchers into the link between urban form and travel behaviour, from many parts of the world, are increasingly diverse. For example, some studies have focussed on urban form-travel behaviour research as a possible solution to urban air quality issues (Frank et al, 2000) or from a point of view of health (Badland and Schofield, 2005; Handy et al, 2002; Forsyth et al, 2008 & 2008a; Samimi et al, 2009) in order to investigate whether or not measures of urban form can improve health through encouraging walking and cycling or even through psychological benefits of using different modes of transport (Macintyre et al, 1998; 2001). The majority of studies have, however, been motivated by sustainability concerns such as reducing carbon emissions from transport and it is these studies that are of most interest to this study. By better understanding the determinants of travel behaviour, policy makers can be better informed as to how more sustainable behaviours can be encouraged through land use/urban form policies in order to reduce energy consumption and greenhouse gas emissions from transport. Energy consumption and hence carbon dioxide emissions from transport have increased almost continuously since the 1970s and indeed Gaparatos et al (2008) found results which suggest that transport has single-handedly been responsible for the increase in overall energy consumption within the UK over the past 36 years.

2.1.1. Policy

One of the earliest aspects of urban form to be studied was population density. Early work, such as the much cited work of Newman and Kenworthy (1989), revealed a striking non-linear and negative association between population density and gasoline consumption for a number of cities across the world. For some time, increasing residential density and the mixture of different land uses has been used as a policy tool in order to control car use (Williams, 2004). However, the precise nature of the relationship between urban form and travel behaviour has obvious implications for the design of appropriate policy interventions.

In order to give useful guidance to policy makers the measurement of urban form, must be readily calculable from available statistics, while at the same time, describe variation in travel behaviours. For example, measures of the perception of the compactness of urban form by residents in an area may be good at explaining their travel behaviour but will not be particularly helpful to policy makers when determining the form that development should take in order to bring about changes in travel behaviour.

In Scotland, the National Planning Framework, which gives guidance for the spatial development of Scotland up to the year 2025, states in section 134 that, "The planning system can promote more environmentally sustainable patterns of transport and settlement by focusing new development on places which are well located in relation to existing public transport infrastructure. Urban renewal can help to counter out-migration from the cities and the trend towards long-distance car-based commuting. Development plans should identify key locations where well-planned, integrated development can benefit from and contribute to the further development of public transport services." (National Planning Framework for Scotland, 2004).

Also, Scottish Planning Policy (2010) which replaced NPPG17 – Transport and Planning (1999), gives guidance to local authorities in Scotland on the content of development plans, and is also a material consideration when determining planning applications. It states that, "Land use planning can contribute to achieving the Government's broad policy objectives for integrated transport and land use planning through:

- reducing the need to travel by regulating the pattern of land uses in relation to each other and to transport facilities;
- enabling people to access local facilities over local networks by short walking or cycling trips, in turn contributing to social inclusion;

- supporting provision of high quality public transport access to development, in order to persuade motorists that public transport is more attractive to them than car use; and
- supporting the management of motorised travel to enable it to undertake its essential role effectively, but in all other respects to contribute to sustainable transport objectives. "

These two policy documents are clearly based on the premise that built form influences travel behaviour.

In other parts of the United Kingdom, planning policies with the aim of promoting more sustainable travel behaviours have been in existence for some time. PPG 13 (2001) which covered England, is equally premised upon the ability of the planning system to influence travel behaviour through shaping built form; has been applied for a number of years and is by no means the first of its kind. However, empirical research on the effectiveness of such planning policies to support a reduction car use over the last decade is rare and there is a lack of empirical evidence supporting the notion that urban form can effect a change in travel behaviour, especially in the context of the UK. Williams (1999) reviews the body of research into urban form and sustainability. The paper argues that, "..although the policies may have benefits in terms of sustainability, their effects may be so complex, and their potential to be implemented so riddled with problems, that they are unlikely to produce the planned outcomes" (Williams, 1999). The paper also refers to the unpublished PhD thesis results (Williams, 1997), which found that "…three London Boroughs which had been intensified over a ten year period showed no reductions in car use. Travel patterns were so complex, due to lifestyle shifts such as cross-London commuting for work, and increased journeys for leisure, that no relationship could be found." It should be noted that this study looked at the effects of intensification or densification on travel behaviour rather than the effect of urban form on travel behaviour per se. However, this study is still one of very few carried out in the UK where the effects on travel behaviour of a change in urban form, resulting from policy implementation, have been investigated.

Other studies have tended to focus on whether or not such planning policies can be fully implemented at all, against a backdrop of obstacles such as market forces, which suggest that residents prefer rural or suburban residential locations as opposed to the compact urban form promoted by policy. Notable examples of such studies include those by Stead and Hoppenbrouwer (2004), Breheny (1997), Hull (2007) and Senior et al (2004).

Clearly there is a need for more research into the relationships between urban form and travel behaviour in order to inform policy makers across the UK.

2.1.2. Land Use Transport Modelling

A second and related motivation for studies into urban form and travel behaviour is to give guidance to those working in the area of land use – transport modelling. The ability to estimate travel behaviour from the configuration of land use is fundamental to transport planning techniques which are largely predicated on the notion that travel is a derived demand. Techniques have arisen that often explicitly use land-use (locations of residential, retail, employment etcetera), and in some cases urban form metrics (residential density, land use mix, street pattern configuration, size of urban area etcetera) to predict trip generation and trip distribution rates. These techniques and software are based on assumptions that land-use and some urban form metrics influence travel behaviour along with measures of socio-economics and the transport system. However, these techniques only work well at an aggregate level where the variability between individuals or households is, to some extent, masked through the use of averages. Also, such models often require considerable calibration and engineering judgement before they reflect actual travel patterns. Clearly research into the effect of urban form on travel behaviour is critical to transport planning theory and techniques and is another motivation for this study

2.2. Travel as a Derived Demand

Transport is often referred to as a derived demand. That is to say, people only travel because of a need to undertake activities that are spatially separate. If one accepts this premise, then one must accept a relationship between the spatial arrangement of where different activities can be undertaken and transport; or more simply, between urban form and travel behaviour.

It is worthwhile noting that the premise that transport is a derived demand is not universally accepted. For example, Lyons et al (2007), Mokhtarian and Salomon (2001), Paez and Whalen (2010) and Ory and Mokhtarian (2008) suggest that some residents have a positive utility towards some travel, whereas conventionally, travel itself is usually considered a cost that is minimised. It is discussed by the authors that the travel itself should, in some cases, be considered an activity as opposed to a means by which a different activity can be carried out.

Also studies such as McCormack et al (2001) suggest that time savings associated with shopping and other chores in neo-traditional neighbourhoods may simply be more time in the travel budget for additional longer distance travel. The notion of travel time budgets suggests maximum amounts of travel time that people are prepared to undertake and that savings in travel time undertaking one activity, such as commuting to work, are reinvested in travel for other purposes, such as leisure, calls into question policy aimed at reducing travel through spatial planning as discussed in Banister (2007) and later in this chapter. Positive utilities towards travel or travel time budgets questions the validity of the premise in the hypothetical urban form travel behaviour relationship presented here, that transport is a derived demand.

2.3. Research into the relationship between Urban Form and Travel Behaviour.

The continued interest in land use planning policies as a means to influence travel behaviour has stimulated a high level of research into the exact way in which urban form and travel behaviour might interact. Since the early work by Newman and Kenworthy (1989), who studied 33 cities from across Europe, North America, Asia and Australia, most studies have focussed on one or more urban areas within a particular region or country, although there are a small number of more recent trans-national studies such as Timmermans et al (2003) and Souche (2010). Newman and Kenworthy (1989) suggested a possible cause and effect relationship between urban sprawl and petroleum use for transport; in the process popularising the term "automobile dependence." The study suggested that the lower density cities found in North America and Australia had higher levels of petroleum consumption per capita compared with denser European cities and high density East Asian cities that had progressively lower levels of petroleum consumption per capita. However, their study was not longitudinal in nature and hence could not prove that the density caused different levels of petroleum consumption and failed to control for many characteristics of the national context.

Gordon and Richardson (1989) in their counterpoint suggested that, when comparing cities as different as Houston to Hong Kong, the number of other factors influencing behaviour such as public transport provision/subside, income, cultural differences, levels of fuel and other car related taxation, congestion etcetera grow to a considerable number. Also, sources of comparable data from different countries are hard to come by; hence many subsequent studies have tended to focus on one or more urban areas within a particular country or region.

This literature review is organised on the basis of the location of the study - firstly, North American based, then European and the rest of the world and finally those studies relating to the UK. Given that patterns of urban form, behaviour, levels of taxation, car ownership, lifestyles and planning constraints vary greatly between the US, Europe and the UK, it is sensible for the literature relating to each to be considered separately and then overall findings from the research to be discussed. Given the large number of studies carried out in the US into urban form-travel behaviour relationship, it is not practicable to critique each individual study; instead the tables shown in Appendix A outline a large number of the most relevant studies carried out in the US to this study, with European based research shown similarly in Appendix B. A brief description of the study is shown along with key variables collected and any notable results. Key findings and problems associated with these studies are then discussed and those individual studies of particular interest are explored in more detail in this chapter.

Periodically, reviews or summaries of previous research into this field are produced such as those by Steiner (1995), Crane (1999), Ewing and Cervero (2001) and Handy (2005), which were useful in helping to synthesise the key findings and weaknesses of the literature.

2.3.1. US Research

The majority of studies on urban form and travel behaviour conducted in the US have demonstrated that "neo-traditional" attributes of higher population density, more mixed land uses and grid street pattern, are associated with less distance travelled by car, or fewer trips made by car (Cervero and Kockelman, 1997; Cervero, 2002; Ewing et al, 2003; Khattak and Rodriguez, 2005).

However, many problems or unanswered questions still exist and can be organised into the following eight categories. Those studies that have made the most significant contributions in overcoming these problems are then discussed in more detail.

Problem 1 - Cross Sectional Data

Cross sectional data in this instance refers to data collected at a single point in time. The majority of studies listed in Appendices A and B fall into this category unless explicitly stated otherwise. An inherent weakness is that it is difficult for these studies to demonstrate the time order of urban form and travel behaviour. Without understanding how it is that urban form influences travel behaviour, it is not possible to give guidance on how it can be used as tool in order to change behaviour. For instance, if higher density were found to be associated with lower car miles travelled in a city, using a cross sectional study, this does not mean that increasing density will necessarily lead to a reduction in car miles travelled. It is possible that travel behaviour and attitudes are entrenched and not readily accepting of change. If the causal mechanism were understood it may be the case that significant changes to behaviours only occur during significant life changes such as residential relocations, changes in workplaces etc. Such issues can only be fully explored through a longitudinal study.

Problem 2 - Aggregate Analysis

A large number of the studies listed are based on analyses of existing datasets such as a census. Such analyses based on aggregate measures of socio-demographics and travel behaviour include Kain and Fauth (1976), Sasaki Associates (1993), Handy (1993), Franc and Pivo (1994), Holtsclaw (1994), Cervero (1994b), Cervero and Gorham (1995), Rutherford et al (1996), Messenger and Ewing (1996) Morall and Bolger (1996), Douglas and Evans (1997) Moudon et al (1997), Pushkar et al (2000), Ewing et al (2003). The use of aggregate data has benefits; notably that the data sources often used in such studies, are readily available. However, aggregate studies "mask" some of the variation between individuals or households in the study, a knock on effect being that often only less robust statistical analyses can be undertaken on a smaller number of dependent variables (ecological fallacy). Analysis based on groups of households is limited as the eccentricities of behaviour are ignored and only "average" behaviours considered. If the effects of urban form in terms of travel behaviours are to be fully understood then the analysis should be carried out on the decision makers; individuals and households. Moreover, the reliance on such aggregate sources of data more often than not limits the researcher to a set of responses that were probably not designed with an urban form travel behaviour study in mind, omitting many variables that may be of interest. Many other, possibly significant, intermediary factors such as attitudes are unlikely to have been captured in aggregate data sets; possibly leading to spurious results. While analysis of repeated aggregate data sets may help to shed light on the time order of events, without questioning of "agents", it is difficult to prove the time order or give much guidance as to the causal mechanisms by which urban form and travel behaviour may relate.

Problem 3 - Lack of Statistical Control Variables

As already discussed, some studies are based on census and other aggregate data sets that were not necessarily designed for the study in mind and hence do not include other, possibly significant, variables that, if omitted, may lead to spurious results. This problem is not limited to aggregate or cross sectional studies per se. Various study designs often omit variables that have been found to be significant predictors of travel behaviour in other studies, such as income. This can give rise also to the problem of omitted variables bias, where a variable has a direct influence on the dependent variable being tested in any regression analysis but is not included in the model and is also correlated with one of the independent variables included in the model, thus making it appear that the independent variable included has a stronger or different influence than it does in reality. This leads to spurious conclusions being drawn. Examples cited in the lists of studies in Appendices A and B where this could be an issue include San Diego Association of Governments (1993), Friedman et al (1994), Kulkami et al (1995), Douglas and Evans (1997), Ross and Dunning (1997), Buch and Hickman (1999) and Criterion Planners Engineers (2000), none of which include measures of, or proxies for, income in their models.

Problem 4 – Study Design

Many of the studies listed are comparative studies of the behaviour of neighbourhoods that are "matched" in terms of the socio-demographic make up but differ in their urban form, or matched in terms of locations or connectivity but differing in built forms. Such studies include Cervero and Gorham (1995), Handy (1995), Cervero and Radisch (1996), Handy (1996), Moudon et al (1997), Kitamura et al (1997) and Khattak and Rodriguez (2005). It is unlikely that any two neighbourhoods can really be so alike that the remaining variations in travel behaviour can solely be attributed to the differences in urban form. By matching these areas on a limited set of socio-demographic variables and not including these variables in any subsequent analysis, these studies risk making incorrect conclusions regarding the role of urban form and socio-demographics in the travel behaviour of residents. The matching is not precise and the limited number of variables used to match neighbourhoods means that other significant socio-demographic variables may have been ignored. Moreover, by using only neighbourhood wide measures of socio-demographics, subsequent analysis will, in part, be aggregate in nature with the associated problems already discussed. An alternative study design would be to have case study areas that reflect a range of urban forms and socio-demographics and travel behaviours and to explain differences between these factors through regression analyses.

Problem 5 – Measures of urban form

A number of studies have relied on subjective measures of urban form. Most commonly, urban forms have been assigned to either a compact, or suburban typology. Street network patterns have been categorised as loop, grid etcetera also on personal inspection. Studies that categorise urban form in such a way include Sasaki Associates (1993), San Diego Association of Governments (1993), Friedman et al (1994), Cervero and Gorham (1995), Handy (1995), Kulkarni et al (1995), Rutherford et al (1996), Cervero and Radisch (1996), Handy (1996), Moudon et al (1997), Criterion Planners Engineers (2000) and Khattak and Rodriguez (2005). One problem arising from many of these and other studies is that they often define the boundaries of study areas again on subjective inspection, based on the urban form of these areas. Defining boundaries for the study on the independent variables being investigated can lead to skewed or spurious results.

Other studies have asked residents how they perceived urban form, or proxies for urban form, and used these to then explain their behaviour such as Forsyth et al (2008) and Handy et al (1998). The use of these respondent subjective variables may not be useful in terms of giving guidance to policy makers or modellers; moreover they may reflect their preferences and attitudes in addition to the actual built form, making it difficult to make any conclusions about the role of individual urban form metrics.

Also, the vast majority of studies in the literature refer to residential urban form, ignoring the urban form of employment, leisure and retail activities and there remains no consensus as to the scale over which urban form should be measured, be it at the settlement level, neighbourhood, or street.

Problem 6 – Choice of measures of urban form

Some studies have reduced a larger number of measures of urban form into a smaller number of key measures or attributes that describe urban form, often through factor analyses, such as Replogle (1990), Srinivasan and Ferreira (1999) or Greenwald and Boarnet (2001). While there are benefits for reducing large numbers of urban form metrics to a smaller number of combined measures in this way, such as avoiding problems of correlations amongst independent variables, the results again are unlikely to be useful to policy makers as they do not give any guidance as to what it is about urban forms specifically that may influence travel behaviours. The choice of urban form measures is discussed in detail in section 2.3.1.

Problem 7 - Measurement of travel behaviour

The choice of travel behaviour measures varies considerably from study to study. The majority of studies have focussed purely on travel for one particular activity such as work. Other studies have employed measures of travel for all purposes (Kain and Fauth, 1976; Replogle, 1990; Parson Brinkerhoff Quade Douglas, 1993; Ewing et al , 1994; Holtzclaw, 1994; Parson Brinkerhoff Quade Douglas, 1994; Kulkarni et al, 1995; Rutherford et al, 1996; Schimek, 1996; Kitamura et al, 1997; Cervero and Kockelman, 1997, Kockelman, 1997; Ross and Dunning, 1997; Douglas et al , 1997; Kastri et al , 1998; Frank et al, 2000). Other studies have generalised travel or converted travel into energy consumption or other measures. Examples include Holden and Norland (2005), Newman and Kenworthy (1989), Banister et al (1997) and Perkins (2003). Issues surrounding the definition and measurement of travel behaviour are explored in more detail in section 3.3.1. While concentrating on travel for one particular activity may have most benefit in understanding the causal mechanisms by which urban form and travel behaviour relate, and may have served the different aims of these studies well, the results may not be of use to decision makers seeking to reduce car use and the associated environmental impacts of car use, as any benefits associated with urban form in terms of travel to work for example, may be may be cancelled out by increases in travel for other purposes.

Problem 8 - Study population

Some studies have focussed on a particular study population such as those who have recently moved home (Cao et al, 2007; 2009; Handy et al, 2005; Naess, 2005) or those living in supposedly sustainable developments (Criterion Planners Engineers, 2000; Khattak and Rodriguez, 2005). By focussing on these populations, it is possible that any conclusions drawn on the wider population may be spurious. For example, if those people moving home were found to make fewer trips if they moved to more dense neighbourhoods, it does not mean to say that increasing density will mean that the non-moving populations will react in the same way. Alternatively, studies focussing on those who live in supposedly sustainable developments, may produce spurious conclusions for the wider population if these residents were more environmentally conscious and hence had chosen to live in that area for this reason. This issue is explored in detail under section 2.5.

In summary of the problems listed here, it should be noted that while the results of some studies, as discussed, cannot be doubted, they are in effect answering slightly different questions to the first question being considered in this thesis; does urban form influence travel behaviour? It is also worthwhile noting that this study is interested specifically if urban form influences travel behaviour in the context of Scotland, UK, whereas the studies mentioned so far have been based in a North American context.

Given what has been said about the studies listed, it seems clear that while there is a growing body of evidence suggesting some association between urban form and travel behaviour in the US context, there is no such body evidence demonstrating that urban form causes particular travel behaviours. This conclusion is echoed by other reviews of literature. Crane (1999) concludes that not very much can be said in terms of advice to policy makers regarding the use of urban design and land use planning to reduce car traffic in new developments or retrofitted neighbourhoods.

Similarly, Susan Handy's review, which forms part of a wider report, reviewing the effects of the built environment on physical activity (Committee on Physical Activity, Health, Transportation, and Land Use, 2005) surmises that there is sparse evidence, from the few studies have been carried out, that a causal relationship between the built environment and physical activity exists.

It is clear that the US literature supports this statement. While many studies show some significant associations between urban form and travel behaviour as listed in Appendix A, a large number show no association. Moreover, those that do show an association fail to demonstrate cause and effect.

Three criteria are commonly considered necessary to demonstrate cause and effect in social sciences (Cook and Campbell, 1979). In the context of this study, these criteria can be described as:

1. A statistical association between urban form and travel behaviour
2. The urban form preceded the travel behaviour
3. No un-measured third factors such as self selection causing spurious results

It is clear that many of the eight problems listed previously in this chapter relate either directly or indirectly to the criteria necessary to demonstrate cause and effect between urban form and travel behaviour or between urban form and car ownership.

2.3.2. European Research

It is important to consider the notable work carried out in Europe and the UK, both in terms of the overall picture of urban form travel behaviour research but also because any such relationships may vary based on the wider/national political, cultural and economic context and also because urban forms, transport systems and travel behaviours in the UK and Europe may differ substantively to those studied and cited in the US. For example, some of the US empirical studies cited have included sidewalk provision as an important urban form metric, whereas in European urban areas, the provision of a pedestrian sidewalk or footway is fairly ubiquitous.

This issue of national or regional context is discussed in Macario and Marques (2008) who undertook a large study into whether sustainable urban mobility measures developed in one European city can be applied to other European cities. The study gave an assessment of risk to gauge whether the mobility measure could be transferred to a different urban area to the same effect. The study found measures such as multimodal interchanges, car sharing, car pooling and road pricing were of high risk, in that their outcome may be considerably different when applied in the context of different cities. The study highlights the need to consider the context of each city when developing and applying measures to influence travel behaviour including the urban form of the city, other transport policies in place, political issues, planning, regulation, technology, public funds, and culture and lifestyles etcetera. The building stock of most European cities is considerably older than US cities developed prior to mass car ownership. In parts of Europe newer development continues to be developed around public transport, walking and cycling such as the finger plan for Copenhagen developed in 1947 which sought to direct development along five radial railway lines.

Much of the European research into urban form travel behaviour relationships has been carried out in the Netherlands where land use planning has been used for a long period of time with the expressed aim of reducing travel by car (Schwanen et al, 2004). As in the US however, Snellen (2000) points out, "…this relationship has hardly been validated empirically." Also, the ability of policy to produce compact monocentric towns is questioned, given the continuing trend towards suburban sprawl (Maat and Harts, 2001).

A comprehensive review of spatial planning and travel behaviour research in the Netherlands can be found in the doctoral thesis of Snellen (2002) and in a review undertaken by van Wee (2002). van Wee (2002) concludes that, "..land use can influence travel behaviour. This does not mean that policy makers should choose land-use alternatives having the lowest level of car use. Possible future land use and transport plans should be evaluated on the basis of a broad range of indicators, including impacts on accessibility, congestion, road safety, environmental impacts, residential preferences of households, preferences of firms, financial aspects and the robustness of the land use transport system." Hence, it is worthwhile bearing in mind that in creating sustainable urban forms in terms of reducing the level of travel by private car, or minimising carbon dioxide levels from transport, this may not create the most sustainable travel behaviours in other terms such as safety and equitable access to goods and services. Moreover, if such urban forms are to be successful in producing more sustainable travel behaviours, it is clear that such urban forms will also have to be economically sustainable in the long term.

While urban forms, transport systems and lifestyles may vary considerably between European and US cities, the issues faced by researchers are often the same. Naess (2005) provides a good example of a recent, state of the art study into urban form travel behaviour interactions from a European perspective, addressing issues such as residential self selection, compensation, time order criterion etcetera using multivariate regression analyses in much the same way as some of the more recent US studies such as Handy et al (2005). Naess (2005) found that, "On average for all our respondents, 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."

As is the case for the American based research, measures of urban form and scales over which they are measured vary considerably in the European literature and tend to have a different focus to the American based studies such as the inclusion of polycentricity or regional function measures in many of the Dutch studies and no mention of sidewalk provision reflecting the different urban typologies found in Holland and USA. Again it is hard to see a pattern of research findings providing a substantial body of evidence into the effect, if any, of urban form on travel behaviour.

Many of the issues being addressed in these European studies, while considering different urban forms are remarkably similar to those being explored in the more recent American studies.

Again, while it could be said that there is a growing body of evidence that European urban forms are associated with particular travel behaviours, the same cannot be said for studies showing that urban form influences travel behaviour. As with US based research, cause and effect has been difficult to demonstrate. Moreover, significant relationships between urban forms and travel behaviour in the context of mainland Europe may not be applicable to urban forms and travel behaviours in the context of the UK.

2.3.3. United Kingdom Research

In terms of UK based research, very little disaggregate empirical work has been carried out similar to the studies reviewed so far based primarily in North America or mainland Europe. Much of the UK based work in the field has tended to be descriptive or based on aggregate data or comparative studies with other parts of the world (Banister, 1997). Also many studies, as already mentioned, focussed on whether intensification policies can be implemented (Stead and Hoppenbrouwer, 2004; Breheny, 1997; Hull, 2007; Senior et al, 2004). Land Use Transport Interaction (LUTI) modelling is increasingly being developed and applied in the UK and there are a small number of studies such as that by Cooper et al (2001, 2001a), which have used outputs from travel demand models to test various land use scenarios, however the causal paths specified in such models are not entirely founded on a substantial body of research (Adhvaryu, 2010). Land use transport interaction modelling is discussed further in the following section 2.1.2.

Banister et al (1997) produced a relatively rare piece of urban form – travel behaviour research based on five UK urban areas, plus one area in the Netherlands, looking at travel in terms of energy consumption. The study drew on previous household surveys and roadside interviews that had been undertaken separately for each of the six cities. These data along with those from the census were used to form aggregate measures of transport energy consumption for each city, an average for each household for each city and an average for each person per city. Five urban form metrics were developed for the cities: Density, Open Space, Size, Compactness and Population. Four economic measures developed were Employment, Car Ownership, Unemployment and Jobs/Population ratio. Seven social metrics were also calculated for each city: Socio-economic Group, Housing Tenure Type, Household Size, Young, Elderly Household Composition and Housing Type. These data were also compiled at a ward level within each city. Simple correlations were tested amongst these variables at a ward level for each city with mixed results. Density was correlated with energy use, although dependent on the specification of the density metric, the amount of open space was significantly correlated in the cases of Oxford and Banbury; similarly with the size of urban area in the cases of Leicester and Banbury. Land use mix was found to be correlated with energy use for transport in some circumstances and employment status, car ownership and socio-demographic group were the most important social and economic variables.

Cooper et al (2001) carried out an investigation into links between urban form and energy consumption for housing and transport in Belfast, UK. Energy demand for transport was calculated using survey responses and an urban travel model. Using the urban transport and energy models, different future scenarios were assessed. In this sense the investigation was not in itself used to demonstrate or shed light on any relationships between urban form and travel behaviour, but tested the effects of future scenarios based on a number of assumptions, some of which are developed as part of the study. The results of the study suggest that land use policies, in particular densification can effect very significant reductions in energy consumption from transport.

While not in the UK, a recent study by Vega and Reynolds-Feighan (2008) carried out in the Republic of Ireland where urban forms, lifestyles and travel behaviours are thought to be similar to those in the UK, should be considered. In this study 187,684 valid journey to work records in the Dublin area taken from the Irish census were used to determine utility based mode choice models for the journey to work. It should be noted that disaggregate census information similar to this is not released in the UK, although alternative disaggregate surveys of a sample of the population exist in the UK and Scotland in particular, such as the Scottish Household Survey and the National Travel Survey. Employment subcentres were then defined, partly based on the travel behaviours from the census as those that attract the largest number of commuters from other districts. The model included socio-demographic variables, car ownership, and employment density and results suggest that demand for car and public transport varies according to the spatial distribution of employment. However, the spatial distribution of employment is in turn the result of lower car travel costs, which motivated the development of new employment sub-centres in the first place (Vega and Reynolds-Feighan, 2008). The use of travel behaviour measures to define the study areas and employment subcentres complicates the interpretation of any findings. The study's conclusions are, in any case, unable to shed light on whether employment density as a measure of urban form influenced the mode choice of those travelling to these employment subcentres, or if the employment densities were influenced by the transport system and travel behaviours. A further study by Vega and Reynolds-Feighan (2009) produced a simultaneous discrete choice model of residential location and mode choice for the journey to work using the same datasets. The results were then used to simulate responses to various spatial employment patterns and how sensitive these are to car travel to work attributes. The study found very low levels of potential mode switching in suburban areas due to changes in travel variables. It did find however that residential location decisions were likely to be affected by transport policies aimed at reducing congestion and increasing driving costs particularly for those who were employed in a suburban location.

Giuliano and Narayan (2003) carried out a comparative study of the travel patterns and urban form between the US and Great Britain using regression analysis using the national travel diary data sets; the 1995/97 National Transport Survey in Great Britain and US 1995 Nationwide Personal Travel Survey. Settlement size was found to be significantly associated with trip frequency with those living in smaller settlements having higher trip rates. Density was found to be negatively related to daily travel distance for both countries but the relationship was far more pronounced in the US. Significant differences were found in the behaviour of the study populations between the US and Great Britain due to the unobserved characteristics such as the prices and measures of transport supply. No attitudinal characteristics or consideration of the housing markets in the US and Great Britain were made.

Similar findings are presented for the Great Britain part of the study in Dargay and Hanly (2003). A following study (Giuliano and Dargay, 2006) found comparable results using a structural model of daily travelled distance and of car ownership to test the effects of urban form on these two measures and how these relationships differ between the US and Great Britain. This cross-sectional, disaggregate study included socio-demographic controls of age, employment, household structure, and household income. The urban form measures tested were size of metropolitan area, population density and housing type. The results suggest that residential density was significantly negatively associated with distance travelled, although the effect was smaller in Great Britain than in the US. The association with metropolitan size was less clear with the largest urban areas in the US being associated with higher distances travelled whereas the largest urban area in the UK being associated (not significantly) with lower distances travelled. In terms of car ownership, higher residential density was associated with lower car ownership as was living in a row/terraced house and being closer to public transport although the effect is not as pronounced in Great Britain as it is in the US. The intercepts of the car ownership and distance travelled models differed for between the US and GB suggesting significant characteristics of each nation that had not been observed.

The differing results between the US and Great Britain using comparable analysis and data emphasises the need for UK-based empirical studies into urban form travel behaviour relationships.

Stead (2001) presents the finding of cross sectional regression analyses carried out on the National Travel Survey and two English local authorities' travel surveys (Kent and Leicestershire) at the individual and Ward level. The study concluded that only Density measured at the Ward level had any consistent and discernable effect on distance travelled and that car ownership determined much of the variation.

Currently, the best evidence for the presence and nature of changes in urban form causing changes in travel behaviour in the context of Britain could be considered that described by Aditjandra et al (2011). The paper describes the results of a Structural Equations Model (SEM) developed to analyse the relationships between neighbourhood design and travel behaviour in the Tyne and Weir area of North East England. Current and retrospective recall survey data were gathered for 219 households in 10 neighbourhoods that were defined by street pattern typology. The study found that changes in socio-demographic characteristics explained much of the changes in car ownership. Changes in urban form influence changes in travel behaviour directly but also indirectly through changes in car ownership. Access to shopping facilities and measures of transport safety were especially important.

While this paper goes some way to help guide policy makers in Scotland it should be born in mind that Scotland has a different urban planning system to the rest of the UK and different urban forms. It is also questionable whether measures of accessibility should be included in the study or whether they are by definition, a function of urban form and travel behaviours. This issue is considered further in Chapter 3. The choice of SEM allows for more complex causal paths to be "tested" but has drawbacks in terms of what conclusions can be drawn. The outputs from SEM should essentially be used to gauge the relative explanatory power of different causal path specifications and do not in themselves confirm any one of the causal paths within the model. A fuller explanation of some of the issues regarding SEM is presented in Chapter 5. Selecting case study areas based on inspection of the urban form of these areas can introduce bias to the data. However, despite these problems, this study by Aditjandra et al (2001) represents the current state of knowledge with regard to urban form travel behaviour relationships in the UK.

The role and significance of urban form on travel behaviour has yet to be determined, or indeed whether any apparent association between urban form and travel behaviour can be interpreted as urban form having an influence on travel behaviour at all. The fundamental question of whether urban form influences travel behaviour in Scotland has not been addressed. Mixed results from international studies are confusing in their sometimes opposing conclusions and their applicability to urban forms, lifestyles, transport systems and behaviours in the UK is dubious.

The descriptions of US, European and finally UK based research highlight a number of shortcomings or problems which mean that cause and effect between urban form and travel behaviours has yet to be proven. Currently, little empirical evidence exists that can usefully inform policy makers that changing urban form will result in changes to travel behaviour in urban Scotland. The remainder of this review discusses the key issues of direction of relationship, the role of residential choice, time order of changes urban form and travel behaviour, the role of car ownership, dimensions of urban form and finally accessibility, referring to key studies in the literature that have sought to address these issues.

2.4. Direction of Relationships

As discussed in the previous three sections, many of the problems associated with studies into urban form and travel behaviour are that they are unable to prove the direction of any relationship and demonstrate causality between changes in urban form and changes in travel behaviour. It may be that changes in travel behaviours, perhaps driven by changes in transport technology promoted different types of urban form to develop that better integrated with such travel behaviours. Or at the household level, it may be that changes in travel behaviour due to the purchase of a car and work place relocation prompted a relocation to a different urban form that better facilitated this travel. If the direction of causality were from travel behaviour to urban form then it would call into question the use of urban planning as a policy tool to reduce travel by car. This section explores this issue in detail including those few studies from all parts of the world that have tried to account for this in the research.

A number of studies and techniques have been developed that assume causality in the opposite and both directions and predict land-use/urban-form changes resulting from changes to the transport system (Echenique et al, 1990; Echenique, 1992; Simmonds, 1999; Feng et al, 2008; Pagliara and Papa, 2010). Indeed land use transport interaction models inherently allow for urban form to influence travel behaviour and vice versa. Badoe and Miller (2000) argue that such interaction modelling is required in order to reflect this more complex two-way relationship but unless each path of such a relationship is understood and informed through empirical analysis the results of the overall system or technique are questionable. While some of the individual relationships included in such models are based on sensible theories and principles such as Echenique’s use of a Lowry (1964) and general equilibrium model to develop an activity location sub-model, empirical data supporting land use-transport interaction modelling generally is less clear. This relationship between changes to the transport system and then changes to urban form and travel behaviour has a long history and indeed has been used for many years to assess the impacts of various transport schemes or plans. See Still et al (1999) for a review of the methods most often used in the UK by planners to assess transport's impacts on land-use. Such techniques and research however, suppose that a change in the transport system will influence travel behaviour (trip rates, distributions and mode and route choices) and will also influence connectivity. Changes in travel behaviour and changes in connectivity then, in turn, influence land value, land-use and urban-form, hence travel behaviours are merely an intermediary step by which the transport system influences land use.

Studies such as Lefevre (2009) have used such land use transport models to test the "effects" of different spatial forms on energy consumption and, in this case, emissions. Empirical research into any such direct influence is less well advanced, although there are number of studies in the field that have tried to assess the urban form or land-use impacts of transport as opposed to the prevailing assumption in the field, and implicit in existing policy, that land use and urban form affects transport.

From a historical point of view, there are trends that perhaps suggest that indeed the stronger relationship might be from travel behaviour to land use. New transport technologies such as the train and then the car enabled cities to sprawl and arguably caused cities to sprawl. It is certainly the case that cities did not suburbanise in the expectation that trains or cars would be invented, so it would seem intuitive that change in the transport system and then travel behaviour preceded change in urban form in this context. Conversely, it could be argued that suburbanisation would not have occurred if there had not been a desire to travel in a different way or to reside in different locations. It seems highly plausible that the relationship is more complex and acts in both directions and through a number of intervening factors. For an exploration of this historical approach to the transport urban form debate and an attempt to model such a relationship see Woudsma and Jensen (2003). Such interest on how technologies can shape urban forms through travel behaviours continues. For example, Rhee (2009) discusses how telecommunication technology may theoretically encourage centralisation or decentralisations of cities.

This need to consider the direction of causation in the relationship between urban form and travel behaviour is not a new idea. Research Results Digest (1995) states, "While transit and urban form influence each other simultaneously, almost all empirical investigations to date have focussed on only one direction of the relationship: either how transit investments affect urban form and land use, or how densities, walking environments, and other characteristics of cities affect transit demand and travel behaviour."

It is clear that further research into any possible relationships between urban form and travel behaviour and the nature and direction of such relationships would be of benefit to transport planning as well as informing the sustainability agenda and policy makers, however many practical problems exist in trying to capture such complex relationships as explored in the remainder of this review.

2.5. Self-Selection and Residential Choice

As discussed in sections 2.3.1 and 2.3.2, many of the problems associated with the studies referred to relate to spuriousness of the results. If households are influenced in their choice of residential location by travel preferences, and these preferences are not subsequently controlled for in the analysis of the effect of residential urban form on travel behaviour, then any relationship could be spurious. The unmeasured preference for urban form could cause correlation between urban form and travel behaviour, or it may be that both preference and urban form combined relate to the travel behaviour, rather than urban form alone.

As has been previously mentioned, the role of residential location choice in any interactions between urban form and travel behaviour is accepted as being important if one is to understand the nature and causal mechanisms by which urban form influences travel behaviour, if indeed it does at all. This section explores this widely discussed issue in detail with reference to some of the more recent studies that have tried, successfully or otherwise, to account for this.

While the studies previously referred to have been carried out by those working in the urban form-travel behaviour field, residential location modelling has a history of research in its own right, with diverse motivations such as predicting house prices or housing market impacts of changes to the transport system (Pagliara and Preston, 2003). It is only more recently that those carrying out empirical research have begun to investigate how this impacts on the urban form–travel behaviour debate, although it should be noted the theory of residential location markets and travel behaviour has a long history; see Anas (1982) for a detailed exploration of economic theory regarding the interactions between the two.

The majority of more recent urban form, travel behaviour studies have created attitudinal or preference variables to describe preferences towards more car-oriented neighbourhoods or otherwise; while some studies have attempted to incorporate a residential location choice model into a travel behaviour model. By incorporating a residential location choice element to the modelling of urban-form travel-behaviour interactions, researchers may be better able to answer whether or not households select areas to live that facilitate their existing travel behaviour/ preferred travel behaviour (self selection). Similarly, including a residential choice element that encompasses some measure of travel preference to the work may help to shed light on whether such urban forms are attainable in the light of prevailing residential preferences, normally thought of as being towards less dense, suburban living.

Some studies, such as that by Bagley and Mokhtarian (2002), have accounted for travel preferences in their studies and found that these explain most of the apparent relationship between urban form and travel behaviour. For example, those who want to travel in a “sustainable” way, move to locations where they can most easily do so.

Similarly, some studies, primarily focussed on areas in North America, have looked at the travel behaviour of residents in supposedly sustainable developments or communities (Southworth 1997, Shay and Khattak 2005), often referred to as New Urbanist Communities or Neo-Traditional Neighbourhoods in the US. Such studies suggest that residents in these communities tend to have more sustainable travel behaviours. However, subsequent research suggested that residents in some supposedly sustainable developments, were more environmentally conscious individuals who may have already been travelling in a more sustainable way before moving to the development and had only moved to the area in order to facilitate their existing behaviour and lifestyle, so in fact, the urban form had not had the desired effect of reducing anyone's travel but merely supporting existing travel or travel preferences (Cervero and Duncan, 2002).

This issue of self-selection has understandably been treated as something that needs to be accounted for in recent studies of urban-form travel-behaviour interactions to avoid spurious results (Handy et al, 2005). Little attention has been given in the literature however, as to how householders' travel behaviour or travel preferences have been formed. These travel preferences may be purely aspirational or they may be based on previous life-experience. In other words, a household's travel preferences may have been shaped by the urban form in which the householders have previously lived or currently live. If this second hypothesis were true, it would give added weight to the argument that urban form influences travel behaviour. That is, while current thinking is that travel preference must be accounted for to avoid spurious results, it is possible that travel preference is an intervening variable by which urban form influences travel behaviour.

It is important to recognise that other studies have showed that travel preferences or travel costs are less important considerations when selecting where to live compared to other neighbourhood and housing attributes (Hunt, 2001).

Mokhtarian and Cao (2007) give a detailed overview of possible strategies to address the problem of self-selection in the design of a study. The following categories are adapted from Mokhtarian and Cao (2007).

Direct questioning through a personal interview to assess whether or not people selected their residence based on predetermined travel preferences. However, this technique, the paper reports, suffers from bias in terms of the ability of the respondent to remember what their attitudes were and can also be costly to conduct interviews on a large enough scale to develop a useful data source for multivariate analysis.

Statistical control of attitudes through an often extensive set of attitudinal questions included in a self completion survey. This technique has the benefits of being able to gather a large enough dataset for multivariate analysis to be undertaken. However, attitudes are not easy to measure through such surveys and the time order of attitudes and behaviour is not known.

Instrumental variables models, which is an econometric technique to, in effect, account for attitudes/preferences in the built environment variables used in the model by adjusting the built environment measures until they no longer have any correlation with the error term. Some of the assumptions that the technique is based on however, can be hard to satisfy and great care needs to be taken of the sampling variances in built environment variables.

Sample selection models, which account for residential self selection by modelling travel behaviour of respondents, given their previous residential location choice, into discrete types of urban form such as suburban or urban. This method relies on a simplification of the range of urban form typologies available to the respondent and cannot explore the time order of behaviour and preferences.

Joint discrete choice models of travel behaviour and residential choice where the joint probability of any combination of discrete travel behaviour and residential location choice is modelled. Examples of this and similar techniques are discussed later in this section. Time order can be explicitly reflected by the use of a nested choice model where the residential location choice precedes the travel behaviour choice but that is not to say the model can test whether or not this assumption is true.

Structural equations models are also types of joint models, have been used to model the multi-directional (or iterative) associations between attitudes, urban form and travel behaviour and can be applied to cross-sectional or longitudinal experimental/observational designs. Again this technique can specify a time order, it cannot test to see if that assumed time order is true. Also the technique is not well suited to multinomial endogenous variables such as mode choice, destination choice or route choice.

Longitudinal designs test the effect of changing urban form on the respondents over a specified time period. In the context of urban-form travel-behaviour research this normally refers to tests of those who have moved home and what the influence of the change in urban form on their travel behaviour has been. The focus on those who have moved home however, makes it hard to generalise any results to the wider population. Longitudinal and quasi-longitudinal designs are discussed in more detail in the following sub-chapter.

The approach taken to account for residential preferences may well influence the results and indeed the approach used may answer slightly different questions in terms of the roles of residential choice, urban form and travel behaviour. Mokhtarian and Cao (2007) suggest that methods which explicitly include attitudes can perform well in terms of non-spuriousness, while those that involve measurements at multiple points in time can excel in terms of the time order criterion. However, longitudinal studies have been less common due to their cost and time needed to carry out such a study.

It is useful to consider more recent studies that have used one or more of these approaches to reflect residential self selection in studies of urban form and travel behaviour relationships. Sermons and Seredich (2001) attempt to jointly model residential location choice, vehicle availability and trip making using disaggregate data from a household travel survey of residents in San Francisco in 1990. The study was cross sectional and used data on socio-economics and attributes of the built form to develop a residential location model and a car ownership model. Similar joint modelling of interactions between infrastructure, household location and trip generation were presented by Eliasson and Mattison (2000). The cross sectional nature of both studies supposes that residents were residing in their optimum location for travel. It may be the case that people do not live in their optimum locations. Given that the decision on where to reside may have been made many years previously, residents are perhaps unlikely to be in their optimum location in terms of their travel preferences. It is highly plausible that it is only when the disparity between the household's travel (or other preferences) becomes large enough to outweigh the costs of moving home that a relocation occurs. No attitudinal or travel preference data appears to have been used, so no conclusions can be drawn regarding how these might impact on residential self selection and the associated issues of spuriousness.

Similarly Salon (2008) presents the results of a joint choice model of residential location, car ownership and commute mode in New York. Based on utility maximisation theory the study created a discrete choice model for the combined choice of location, car ownership and mode choice using a cross sectional dataset. As with the study by Sermons and Seredich (2001), the use of utility maximisation models in this way could lead to ambiguous results or questionable interpretations of results as it assumes that households are located in their optimum residential location, have their optimum car ownership levels and are choosing their optimum modes of transport, which, as already suggested, is likely to be an incorrect assumption.

Cervero and Duncan (2002) go one step further and develop a nested logit model of residential location choice and travel behaviour, albeit for a rather limited set of choices and measures of behaviour. Residential location choice is modelled as a binary response; within half a mile of a rail station or not within half a mile of a rail station. Commute mode choice is expressed as a binary choice of rail or non-rail. The data source used for the study was the 2000 Bay Area Travel Survey (California, USA). The San Francisco area was not included in the study as, in such cities where public transport is fairly ubiquitous, residential self selection based on travel preferences becomes less relevant. The study suggests that outside of the San Francisco area, around 40% of those living close to a rail station and commuting by rail could be regarded as doing so due to self selection. The means by which the influence of the transport system can be accounted for when investigating urban form, travel behaviour interactions are discussed in more detail in chapters 4 and 5. It considers that the provision of such enables those who wish to reside in such locations to do so. It is notable that in a UK or European cities, normally less consideration of public transport services needs to be given in deciding where to live due to more extensive coverage. In this sense, European cities might be considered more akin to San Francisco where residential self selection could be considered less relevant as almost all areas have public transport accessibility (Cervero and Duncan, 2002). However, Rouwendal and Meijer (2001) present the results of a logit/mixed logit analysis of stated preference data regarding housing, jobs and commuting in the Netherlands, a densely populated country relatively well served by public transport. The study found that the housing being constructed, as per policy in high density, easily accessible areas close to large cities did not match residential preferences which are towards detached housing. The study suggested that such preferences would mean that the most likely response to improvements in accessibility of employment centres would be that people would commute a longer distance as many live in denser areas due to a lack of lower density alternatives in their price range and within a commutable distance. However, the previous residential location of the households seemed to influence these preferences with those who previously resided in older, denser areas being more attracted to this new high density and easily accessible development.

Scheiner (2010) carried out a study of residents in 10 areas in and around the city of Cologne. The study was cross sectional in nature and analysed the effect on trip distances (for three purposes) of built forms, attitudes, lifestyles and location preferences, along with the usual socio-demographic factors through structural equations modelling of a hypothesised casual model. The findings suggested that neither lifestyle nor location preference had strong associations with trip distances with the exception of leisure activities. However, car ownership was associated with far longer distances travelled for shopping and leisure travel. Car ownership was also higher in more suburban areas. The cross sectional nature of the study makes it difficult to draw too many conclusions about the likely role of car ownership, residential location preference and distances travelled in this study.

It is possible that any influence residential and transport preferences have on travel behaviour for any particular household is dependent on the time the household has lived at the address. Moving home may allow the household to align their location/environment with their travel preferences. Those who have not moved house for some time, but whose work place, income and other factors have changed, may be living in areas and travelling in a way which does not best meet their preferences and resources. Indeed it could be considered that these disparities, when at a certain level, trigger a relocation. If this hypothesis were true, then a mismatch between travel preferences and travel behaviour may develop over time. Schwanen and Mokhtarian (2005) describe a study which starts to explore some of these issues. The study introduces the notion of neighbourhood dissonance, defined as, "the mismatch between a commuter's current neighbourhood type and her preferences regarding the physical attributes of the residential neighbourhood." The study was carried out through a fourteen page questionnaire sent in 1998 to neighbourhoods in the San Francisco Bay area. Personality, lifestyle and attitude/preference dimensions were developed through factor analysis of the data. Neighbourhood dissonance was measured in terms of the respondents score on a standardised pro-high density factor contrasted against their actual neighbourhood type measured as a binary; urban or suburban. One quarter of respondents were considered to be mismatched. The study found that as residential dissonance increased for urban dwellers, the probability of commuting by private vehicle increases but "suburban minded urban residents will not exhibit the same propensity of commuting by private vehicle as true suburbanites." This suggests that aspects of urban form still have a significant association with travel behaviour after preferences have been accounted for.

Consideration of housing markets and residential location choice may also have other benefits to researchers in the field. If certain urban forms, such as dense, compact forms, are accepted as being related to more sustainable travel behaviours, this may not mean that building ever increasingly dense developments will necessarily lead to ever increasingly sustainable travel. It is possible that only a certain proportion of the population wishes to, or is willing to accept, living in high density areas such as these. In areas where demand for housing is outstripping supply, such as the South East of England, development of such housing is likely to be fully occupied due to the high demand for housing, or in a city such a Hong Kong, where the only option for most may be to live in a high density area, new developments of this sort are also likely to be fully occupied. In an area with lower housing demand and a wide variety urban forms available to residents, such as Glasgow, with its high levels of vacant, high density housing, construction of more high density housing will not lead to more sustainable travel behaviours if the housing market means that people in lower density areas are not going to move to these developments. See Filion et al (1999) for a qualitative exploration of how residential preferences may act as a barrier against increasing urban compactness and any resulting change in travel behaviour. On the question of the proportion of residents who were amenable to move to more compact urban forms, Krizek and Waddell (2002) considered the joint decisions of travel behaviour, activity participation, vehicle ownership and residential location. These four dimensions are then combined to categorise households into one of nine lifestyle categories. Two lifestyle categories appeared to behave in accordance with the ethos of the New Urbanist movement while five lifestyle categories showed a positive attraction to highly accessible neighbourhoods, although the authors note this does not mean to say the respondents in these categories travelled in a more sustainable fashion. It appears, at least from this US study that there is a section of society who are willing to adopt lifestyles and could, given the option of a particular urban form, travel in a more sustainable way. By grouping the four measures of travel behaviour, activity participation, vehicle ownership and residential location together in this way, it is not however possible to explore the nature of the interactions between them.

As already mentioned here, a growing number of urban form travel behaviour studies have attempted to control for residential self selection. Interestingly, some such studies have concluded that self-selection appears to negate any influence of urban form on travel behaviour while others have found significant associations even after self selection has been accounted for (Khattak and Rodriguez, 2005). It is obvious that there is no consensus on the role of residential self selection in urban form travel behaviour interactions. It is also clear that any such role is likely to be highly place specific, depending on the levels of housing supply and demand in an area, public transport coverage, and other barriers to residential relocations.

2.6. Longitudinal Research

The previous two sections discussed some of the major issues in urban form travel behaviour research; the direction of any relationships between the two and the issues surrounding residential self-selection. A possible solution to addressing both of these issues is the use of a longitudinal study as briefly discussed in the previous two sections. It is worthwhile however exploring in more detail the ways in which such a study design has been used to address these problems in previous studies.

Despite many studies demonstrating a statistically significant association between urban form and travel behaviour, this is not to say that such evidence is proof that urban form influences travel behaviour in itself (Handy, 2005). In order for this to be proven the chronology of these various factors needs to be investigated. Which came first the change in urban form or the change in travel behaviour?

By adding a longitudinal element to the study, it may be possible to satisfy the second criteria listed in Handy (2005) as being necessary to prove cause and effect; that urban form preceded travel behaviour.

Some studies have tried to introduce such a longitudinal or quasi-longitudinal element to their research by various means; some of which have already been discussed. A relatively small number of studies have attempted to measure organic changes in urban form and how these relate to changes in travel behaviour. A good example of such research is presented by Vandermissen et al (2003) who utilised repeated cross sectional travel behaviour data from 1977 and 2006 Quebec Metropolitan Area travel surveys. The data contained a number of socio-economic control factors, although importantly, and unfortunately, did not include measures of income. Urban form was measured by computing the network distance to a central axis of the city in 1977 and 2006 for residential locations and work place locations as well as a number of mode specific accessibility measures. The study found that commuting duration over the years had been increasingly influenced by the distance of workers' residences from their work place and between both their home and work place to the central axis. The decentralisation of both home and work places related to increased journey time to work, although this affect diminished over time as the freeway system replaced the radial network. The findings however, do not tell us what aspects of urban form such as density, land use mix and so on, relate to these changes in travel to work distances and journey times. Moreover, although there is a longitudinal element to the study, it is still not possible to say whether the change in urban form preceded travel behaviour or change in travel preferences preceded urban form change. A similar study design was adopted by Su (2009) who utilised a dynamic panel dataset collected over 20 years to analyse the associations between vehicle miles travelled and measures of urban form in 85 urban areas in the US. The aggregate analysis found that road density and urban spatial size had positive significant associations with travel demand whereas population density and urban congestion had negative significant associations with travel demand. Such aggregate or disaggregate repeated cross sectional studies are problematic in that changes in urban form of a city normally occur over long periods of time. Capturing urban form metrics over such long periods can be difficult. Also, the large number of other determinants of travel behaviour (both observed and unobserved) are substantial in number and vary greatly over such long time periods.

Recent work by Handy et al (2005) has sought to shed light on this question of chronology and understand the causal mechanisms by which urban form and travel behaviour may interact. In order to account for time order and to have a measurable change in residential urban form, the study group consisted of a number of people who had moved home from one neighbourhood to another and also people who had not moved home to act as a reference. The socio-economics, attitudes and preferences were measured in addition to the respondents' current travel behaviour and how they felt this behaviour had changed compared to one year ago. The characteristics of the neighbourhoods (both current and previous) were also recorded. The findings show no significant relationships from the cross sectional analysis of urban form and travel behaviour but a significant relationship was found from the longitudinal analysis with change in urban form and change in travel behaviour, even after socio-economics and preferences are accounted for, suggesting that policies to shape urban form may indeed be useful tools for shaping travel behaviour, notwithstanding the many issues with residential location choice already discussed. This form of study design is referred to as a current and retrospective recall survey. Similar study designs can be found in use in other disciplines and have also been used by Cervero and Day (2008) and Cao et al (2009) who also focussed on movers and non-movers in selected traditional or suburban residential locations. However, Cao et al (2009) only describes the cross sectional analyses.

A truly longitudinal or cohort, observational study is presented by Krizek (2003) who analysed data from the Central Puget Sounds panel survey focussing on the 430 households who had relocated between two waves of the annual survey. Regression analysis was used to explore the relationships between base measures of urban form, socio-economics, travel behaviour and other variables along with the change in these variables over the short time period. The study found that increased neighbourhood accessibility was significantly associated with reduced vehicle miles travelled, reduced personal miles travelled and reduced number of trips per tour, but an increase in the number of tours. It is not clear from the paper exactly how households were defined and how those individuals joining or leaving study households were dealt with. The study gives added weight to the notion that urban form may influence travel behaviour. Similarly designed European studies include that carried out by Meurs and Haaijer (2001). However, the focus on the relatively small part of the population that has recently relocated does not mean that the wider population will necessarily react to a gradual or organic change in urban form in the same way.

2.7. Research into the relationship between urban form and car ownership

Investigations into the interactions between urban form and travel behaviour have not treated car ownership in any consistent way. On one hand some studies have treated car ownership as an attribute of the household or individual that needs to be controlled for when investigating the role of urban form on behaviour; alternatively, many studies have ignored the role of car ownership completely as previously discussed in this review, while some have investigated the role of car ownership on travel behaviour explicitly and other studies have focussed on interactions between car ownership as the dependent variable and measures of urban form as explanatory variables. It is this latter group of car ownership – urban form research that is reviewed here and is of most relevance to this thesis.

Studies into the interactions between urban form and car ownership are less numerous and perhaps less well developed than those studies that have focussed on urban form travel behaviour research, which may or may not have included car ownership as a socio-demographic control variable such as Boarnet and Sarmiento (1998). Having said this, the interactions between urban form and car ownership have been the subject of academic research from at least as far back as 1964 (Beesley and Kain, 1964; 2000).

Many of the research issues and problems associated with urban form car ownership research are understandably the same as those associated with urban form-travel behaviour research. This thesis does not therefore discuss these issues at length again but gives examples of how these issues relate to car ownership studies. It also describes key studies into urban form and car ownership relationships. Some studies have tried to investigate urban form car ownership interactions through direct comparisons between supposedly more sustainable urban forms and more suburban or dispersed urban forms such as that presented by Shay and Khattak (2005). Their study found significant differences in terms of car ownership between the two areas after accounting for socio-economic and other attributes as expected. However, by focussing the study on areas which were deemed to be sustainable developments, the issue of self-selection becomes particularly prominent, which does not appear to have been addressed. Other studies have looked at variations in urban form throughout a particular city or region rather than comparisons between supposedly sustainable and unsustainable urban forms per se. A recent and rare example of such a disaggregate study is presented by Potoglou and Kanaroglou (2008). One objective of their study was to explore the relationship between urban form and car ownership in the Canadian urban context, while controlling for household characteristics. This was carried out by means of a multinomial logit analysis of data collected through the internet for the Hamilton area of Ontario, Canada. The results suggest that type of dwelling was statistically significant, with those living in a single family home (house) more likely to own a car than those living in any other type of dwelling. The number of working adults and the number of persons with a driving licence were positive and significantly related to car ownership. Household structure was also found to be significant with couples, couples with children and extended families or unattached individuals having significantly higher car ownership levels than single person households. As expected, income was positive and significant. The measures of land use mix used were negatively associated with car ownership, also as expected. Density was found to be closely correlated with the mix variables and hence not used. Distance to work was significant and positively associated with car ownership also.

Similar results were found by Hess and Ong (2002), who used an ordered logit model to predict car ownership levels for various neighbourhoods in the Portland, Oregon area with land use mix being associated positively with no-car households. The paper argues that by allowing more compact development, the latent demand for such residential locations will be realised, thus reducing car dependence. Chu (2002) also found land use mix to have the greatest affect on vehicle ownership in a study of 3,397 households in the New York City area using an ordered probit model.

However, as Bhat and Guo (2007) state, “[t]he ‘true’ causal impact of the built environment on travel behaviour can be assessed only if the spurious association due to residential sorting based on demographics and other characteristics is controlled for.” This issue of self-selection appears to be as an important consideration in urban form car ownership research as has previously been mentioned in this thesis in terms of travel behaviour generally and urban form. Bhat and Guo (2007) go on to describe a study where a joint residential location and car ownership model is fitted to 2,954 respondents from the San Francisco Bay area. The analysis was carried out by developing a joint utility model of car ownership and residential location (joint mixed multinomial ordered logit) and found that built environment attributes affect residential location choice and car ownership levels. Household demographics have more influence on car ownership than built form measures such as household density and employment density. Interestingly, the results did not support the notion of residential sorting (self-selection) in car ownership propensity terms. The self-selection appeared to be along socio/demographic lines and hence, individual models of the influence of urban form on car ownership may be valid once these socio-demographic affects have been accounted for.

Cao et al (2007) on the other hand carried out an analysis of 1682 (24% response rate) self administered survey respondents from eight neighbourhoods in Northern California. 688 of these respondents were recent movers. The data were analysed both in cross section, using an ordinal probit model, and longitudinally by using static score model based on previous work by Finkel (1995). In addition to the significant socio-economic variables, housing tenure was also found to be significant with those renting having lower car ownership levels than owner-occupiers, even after other socio-economics had been accounted for. Proxies for outdoor spaciousness were found to be positively associated with car ownership and proxies for land use mix negatively associated with car ownership, although these associations were marginal compared to socio-demographics. However, once attitudinal and residential preferences are accounted for, outdoor spaciousness and housing tenure were no longer significant. The quasi-longitudinal analysis showed change in outdoor spaciousness and land use mix to be significant even after attitudes were accounted for although, again, these associations were marginal compared with socio-demographics.

While the majority of the research in the field has focussed on car ownership levels and how urban form may influence these, some studies such as that by Cao et al (2006) have focussed on the choice of vehicle type and how attributes of the built environment may affect this choice. In their study, Cao et al (2006) used a nested logit model to investigate type of vehicle choice from a self completion survey sent to 6,746 residences from eight neighbourhoods in Northern California with a 25% response rate. The results showed a statistically significant association between the vehicle type and urban form, with suburban neighbourhoods being associated with higher sports utility vehicles, pick-up trucks and minivans and more traditional, compact urban forms being associated with higher preferences for normal passenger cars. Socio-economic and attitudinal factors were also found to be significant and the higher propensity for larger SUV, minivans and pick-up trucks in suburban areas was, to an extent, the result of disproportionate representation of these social and attitudinal groups in these areas.

Similarly Bhat et al (2009) created a nested model (multiple discrete-continuous extreme value and multinomial logit model) to analyse households' decisions on the number of cars to own, type of vehicles and mileage of these vehicles. The study did not consider households with no cars given its US context. The data used were gathered from the 2000 San Francisco Bay Area Travel Survey (8,107 households), Census and other sources. Explanatory variables tested included household demographics, individual characteristics, vehicle attributes, fuel cost, built environment characteristics (population density, employment density, urban - rural setting, measures of land use and dwelling type, bikeway density and highway density). The model analysed the simultaneous decision choice of multiple vehicle types/vintages and usage. Results suggest that a 25% increase in bike lane density would be associated with a small decrease in the ownership as well as usage of all motorized vehicle types, a 25% increase in street block density would be associated with an increase in the ownership of compact cars, a decrease in pickup trucks and a decrease in the use of non-motorized modes of transport. While the study is encouraging in that it suggests some measures of urban form may be associated with (albeit marginal) changes in vehicle ownership and use, it does not answer the question of whether urban form influences car ownership and use as it does not demonstrate the time order of these issues. The modelling assumes a simultaneous decision on car ownership and use based on a given urban form. That is the decision of the urban form in which to reside is not considered. While the association can therefore be demonstrated, cause and effect between urban form, car ownership and use cannot. Also, it is worthwhile cautioning that the analysis does not consider the situation of no-car households given that 92% of American households owned at least one car (Bhat et al, 2009). See also Fang et al (2008) for similar results using slightly different modelling frameworks.

Roorda et al (2009) introduce a joint modelling framework for activity participation and household decision making with regards to vehicle transactions, which includes a limited number of urban form measures. The paper presents a means by which individuals within a household lead to an overall household decision on whether to buy or sell a particular car and the various factors that might influence such a decision. To be more precise, simulations were run according to a conceptual framework developed regarding householders' activity participation and activity scheduling. Measures of "stress" defined by Miller (2005) are developed from the simulations, which seek to measure the deviation of the current state from the optimal state in terms of activity scheduling, residential location and vehicle ownership. These stress measures are then used in a dynamic simulation model of vehicle transactions and the results compared to empirical data taken from the survey. A nested logit model is developed to represent vehicle transactions with various explanatory variables such as income. The measures of stress are then included in the model with the effect of improving the overall model performance. The main emphasis of the paper is regarding the development of the individuals-within-the-household's joint decision regarding activity participation and vehicle transactions which is not within the scope of the study presented in this thesis. The study presented in this thesis does not presuppose any such decision making mechanism within the household as the analysis is purely explanatory in terms of analysing those factors which might affect the choice of how many vehicles to own with a particular emphasis on those urban form metrics which may be related. However, it is worthwhile noting some key findings from the empirical part of the analysis that suggests that, in economic terms, the elasticity of the utility compared with car ownership were asymmetrical. That is, households moving from no cars to one or more cars gained less utility than was lost by households moving from one or more cars to no cars.

Similar results were found by Dargay (2001) using data from the UK family expenditure survey in terms of hysteresis between income and car ownership, whereby increasing income is associated with a greater increase in car ownership than the magnitude of the reduction in car ownership associated with an equal reduction in income. It is highly plausible that the difference in the elasticity of car ownership levels with respect to income occur as the individual or household becomes accustomed to the car and adapts their lifestyle or other circumstances around the use of the car, such as changes in residential location, job location, activity participation etcetera. As Dargay (2001) was based on different households who either increased or decreased their level of car ownership, it is not possible to say whether the elasticity in one direction is different from the other. For example, if a household were to gain a car one day and then dispose of it the next, their gain in utility from having the car would be expected to equal their loss in utility from losing the car.

A recent longitudinal study in the Republic of Ireland, which may well be a more comparable context than those already cited, is presented in Nolan (2010), which used disaggregate data from 1995 to 2001 to analyse the determinants of car ownership. Household composition, lifecycle, income and previous car ownership were found to be significant predictors of car ownership. Higher levels of elasticity between income and car ownership were found for households who did not own or have access to a car in the initial period. This perhaps suggests a degree of hysteresis.

The links between car ownership and travel behaviour are widely accepted. See Kitamura and Kostyniuk (1986) for a review of such relationships. It is likely that the relationships between urban form, car ownership, residential location choice and travel behaviour are far more complicated than simple one directional causes and effects. A very small number of studies such as that by Bagley and Mokhtarian (2002) have tried to address this by utilising structural equations analysis in their investigations. Golob (1989) presents one of the first uses of structural equations modelling in the transport research field to analyse panel data from the Dutch National Mobility Panel. By using structural equations modelling it is possible to test various causal models including feedbacks and time lags in order to ascertain which of the causal paths being tested is the more likely or better reflects the observed data.

As can be seen by the review of literature into specific car ownership - urban form research, that there is not a substantial body of evidence regarding the relationship or causal mechanism by which the two interact. There does appear to be some evidence that land use mix might be the more important urban form metric though when considering associations with car ownership. However, there are very few studies that have accounted for self selection in their design or considered the time order, both of which are necessary in order to say that urban form influences car ownership. There is a distinct lack of such research focussed outside of the North America and in the UK in particular.

2.8. Dimensions of Urban Form

In this section the urban form metrics tested in previous studies are discussed and summarised. The data sources available in order to measure these metrics are then explored. Those metrics selected for use in this study are then presented in Chapter 3.

This review of metrics summarises the key measures of urban form used in previous studies into the influence of urban form on travel behaviour, on other factors such as community cohesion and also a substantial body of work which is purely interested in how to quantify and measure spatial form. The review also considers the limits of information and time available to the study and suggests those measures of urban form that would be of interest and would also be feasible to gather in order to investigate how urban form might relate to travel behaviour.

When developing the measures of urban form the following need to be considered:

- The metrics of interest in terms of Urban Form Travel Behaviour/Car-ownership research,
- The scale at which these metrics are to be measured,
- The means of measuring them,
- The limits of the data and resources available.

There has been a considerable amount of work carried out in the area of urban form measurement and categorisation, which can be drawn upon in determining those most suitable for this study. The literature, although extensive, is not in consensus as to the best ways to measure urban form. This is partly due to differing motivations of the individual studies in each particular field i.e. studies of community cohesion and urban form may be interested in different measures of urban form at different scales to studies in urban form and travel behaviour. There are also considerable differences in how to measure urban form within the field of how urban form affects travel behaviour itself as previously reviewed in this thesis.

2.8.1. Summary of Previously Used Urban Form Dimensions

A list of the most frequently used measures which have been used to test the influence of urban form on travel behaviour and other measures is shown in Appendix D. An extensive review of each of these measures is also presented in Appendix C.

It is suggested that different measures of urban form need to be made at different scales in order to accurately describe the built/ urban form of any study areas and their setting. It is unclear whether, for example, the residential density of the abode, street, neighbourhood or settlement have any effect on travel behaviour and, if so, whether each has the same effect.

One other consideration as to which urban form metrics to use is the degree of correlation between individual metrics. In any statistical modelling of urban form travel behaviour or urban form car ownership, the measures of urban form should be independent of each other. The lack of independence of the urban form metrics is a recognised problem in urban form travel behaviour research and can lead to misleading conclusions being drawn about the role of each of the independent variables being considered. Most of the urban form metrics noted in this review are unlikely to be truly independent of each other. For example, measures of residential density may well be related to the size of the city, the mix of land uses, the proportion of flats to houses etcetera. While many studies have sought to overcome this problem through developing composite measures of urban form or by categorising urban form into typologies such as traditional neighbourhoods or suburban, or compact urban form by either subjective inspection of the area or through statistical techniques, this reduces the potential for simple policy recommendations to be made in terms of densities, land use mixes or whether development should be close to existing urban centres.

2.9. Accessibility

The review presented so far focuses on studies into travel behaviour, their findings, weaknesses and methods. The majority of the urban form – travel behaviour studies already referred to in this literature review, or listed in Appendices A & B, consider travel behaviour in terms of distance travelled by private car or other modes of transport or the number of trips made for different activities. The choice of travel behaviour measure has implications on the interpretation of results and their use or meaning for policy makers and modellers. On the whole, the studies reviewed do not discuss how these dimensions of travel relate to the overall sustainability of the travel behaviour with notable exceptions such as Holden and Norland (2005). In many studies it is perhaps implied that reducing car use in itself would be beneficial although it should be recognised that often the aims of the study were different to that of this study as already discussed. Some studies however, have converted the dimensions of travel into a measure of energy consumption or emissions (Hankey and Marshall, 2009).

Many studies, instead of investigating interactions between urban form and travel behaviour or urban form and car ownership, have investigated how urban form influences accessibility or connectivity. An even greater body of work has been concerned with the relationships between accessibility and travel behaviour (see Levinson 1998 for an example). Geurs and van Wee (2004) review different accessibility measures and their usefulness in evaluating land-use and transport changes. The paper states that, “the plausibility of an accessibility measure not only depends on how it is operationalised and measured but also on the theoretical basis and practical limitations of the transport and land use models used.” This implies that accessibility measures should be considered as one step in the causal path between urban form and travel behaviour. If accessibility were to be used in this way then the land use – accessibility relationship needs to be clearly researched as does the accessibility - urban form relationship. Given the complexities, conceptually, computationally and in terms of data requirements, many researchers such as those cited previously in this thesis have continued to focus their efforts on investigating the relationship between urban form and travel behaviour without an intervening accessibility measure.

Dill (2003) considered data from a travel diary survey of employees in the San Francisco Bay Area and found a negative correlation between distance from the workplace to a rail station and rail transit use. The paper does note however that the design or layout of the employment site often created significantly longer walking distances than the straight line distance used in the analysis. This simple example illustrates some of the problems of mixing accessibility and urban form metrics in travel behaviour research. Measures of urban form including street pattern configuration, density and land use mix are likely to be highly correlated with measures of connectivity or accessibility.

This point is illustrated by Handy (1992) when she states, "For the purpose of testing the relationship between spatial structure and travel patterns, accessibility is a more effective measure of spatial structure than either population density or jobs/housing ratios because it reflects both these characteristics and because it is based on assumptions about how individuals make travel decisions." While the statement about accessibility being a more effective measure of spatial structure may be true in terms of getting the best model fit from any empirical analysis, using accessibility as a proxy for urban form is also problematic. Firstly, accessibility is a multi-faceted notion, itself a product of many variables including urban form measures. In order therefore, to use accessibility as a proxy for urban form in any model, the numerous non urban-form variables would also have to be taken into account including, issues as diverse as public transport subsidy, political and cultural attitudes, socio-demographics etcetera at both a wider and localised scale. Secondly, unless the causal path between urban form and accessibility is also investigated and specified, urban planners, policy makers and others will find it difficult to set guidance on, or implement, urban forms that are likely to create the kinds of travel behaviours they are seeking. It is perhaps unsurprising therefore that a considerable amount of research into urban form and travel behaviour directly is increasingly being carried out as opposed to using accessibility as a proxy for urban form in this way.

If accessibility and urban form metrics are both included in a simple regression analysis, it becomes hard to ascertain what effect if any, urban form has on travel behaviour or car ownership. A path type model such as structural equations modelling or a hierarchical model may be able to represent this more complex relationship between urban form, accessibility and travel behaviour better. This study will focus on measures of urban form, travel behaviour and car ownership rather than accessibility as a proxy for either travel behaviour or urban form as detailed in Chapter 3.

2.10. Summary of Literature

The extensive review of literature explored in this chapter and in Appendices A and B shows the breadth and depth of research into the relationship between urban form and travel behaviour. While some studies have found no significant associations between urban form and travel behaviour such as that carried out by Boarnet and Sarmiento (1998), it is clear from this review that there is a weight of evidence supporting the notion that a statistically significant association between urban form and travel behaviour does exist. However, there is no consensus as to those metrics of urban form that are associated with particular measures of travel behaviour and indeed even if the associations are positive or negative. As already reviewed, some studies have found that, for example, the more mixed and compact urban forms may in fact be associated with more trips (Crane and Crepeau, 1998) although this does not necessarily mean greater distance travelled. Not only is there a lack of consensus on the nature, direction and strength of these associations but, often due to the modelling frameworks used, it is not possible to say where on the scale of any urban form metric, the biggest gains can be made in terms of changing behaviour. For example, Cervero (1997) comments that by simply plotting trip rates against density, the biggest drop off in trip rates occurs when going from low (4 to 5 dwellings per acre) to moderate (12 to 15 dwellings per acre) densities; however such simple plots of density and travel behaviour, as already discussed are problematic in their lack of statistical controls, nor do they demonstrate causality. Once other factors such as income are accounted for, the nonlinearity of the association may no longer be apparent. This linearity or otherwise of any association between urban form and travel behaviour is discussed in further detail in Chapter 5, Analysis.

Even though there may be a substantial number of studies showing a significant association between urban form and travel behaviour, there is no substantial body of evidence that suggests that urban form influences travel behaviour. There is no consensus on whether urban form affects travel behaviour, vice versa or if a more complex causal relationship or no relationship at all exists. Moreover, many studies have different objectives and methods and are based in various national contexts, making generalisation of findings difficult.

The multitude of urban form metrics used in studies and the mixed results from these studies gives little help or guidance to policy makers when deciding what urban forms they may wish to promote.

The statistical frameworks and research methodologies used to analyse any relationships between urban form and travel behaviour, although recently advancing, lags behind those techniques applicable and used in other fields of research.

Given the large number of unobservable variables that may influence travel behaviour it may not be sensible for decision makers in any particular country, region or urban area to develop spatial plans and urban form policies based on research findings from other countries, cities and urban areas. It is obvious that such research findings in the UK and Scotland in particular are rare, if not non-existent. Stead (2001) and Aditjandra eta al (2011) suggest that in England, population density might have a limited direct effect on travel behaviour and in the latter case, an additional effect through car ownership.

In this study it is considered that a measure of overall travel should be made. That is, the travel associated with all activities. This is because focussing on a limited number of activities such as the journey to work may give misleading advice to policy makers interested in minimising the impact of overall travel, emissions or car use, bearing in mind the substitution issues already discussed. In keeping with other studies already mentioned, travel is considered with a view that the private car use is the key measure of travel that is of most concern to those decision makers involved in urban planning. While it is noted that other forms of transport such as flights may be more energy intensive forms of travel and may have higher emissions per passenger kilometre, this travel is not considered normal day to day travel for work, shopping, education, leisure etcetera that this study is interested in. The activities associated with longer distance air trips and the motivations for them may be quite different from more frequently undertaken activities and as such should be given separate consideration.

The remit of this study is to try to determine what it is about different urban typologies that influences travel behaviour or car ownership, if at all. As such, the study will rely on disaggregate measures of urban form, accepting the limitations of these measures in terms of their lack of independence to one and other. The final set of urban form dimensions to be included in the analyses is presented in Chapter 5.

3. Research Hypotheses and Methods

3.1. Development of Hypotheses

At this point, it is useful to introduce the conceptual urban form travel behaviour causal mechanism as hypothesised by this study. It is through the development of such a conceptual model that the final hypotheses to be tested are developed. This chapter will therefore describe the conceptual model developed as part of this study, given the findings discussed in the literature and isolate the hypotheses to be investigated as part of this research project.

It is interesting that the majority of studies reviewed in this thesis do not explicitly present the conceptual relationship that they are testing. Handy (2005) presents a good exploration of conceptual models in urban form travel behaviour research and suggests that researchers should consider a more comprehensive conceptual model accounting for bi-directional relationships between choices about residential location, auto ownership, the built environment and travel behaviour. Echenique (1968) also states that, "[i]t is widely recognised that without a theoretical framework of reference factual information does not have any relevance." There are notable exceptions of observational studies which have sought to test a number of links within a supposed causal path. Travisi et al (2010) propose a causal mechanism by which measures of urban sprawl in Italy were related to a mobility index incorporating generalised costs of transport including environmental costs. Analyses of causal path networks give an indication of how well the network specified represents the observed data. Theoretical causal mechanisms are presented in a number of similar studies that utilise some form of structural equations modelling to give an indication of the significance, effect and direction of each link (Scheider, 2010). Simulation studies, such as that presented by Lefevre (2009), often specify conceptual models but fail to provide empirical evidence supporting the links within the given model. That is, they use a set of assumed causal links to construct a conceptual model to test scenarios and analyse results, sometimes comparing the results with empirical data. Unless the model perfectly represents the observed data, it is possible that the causal path network specified could be improved upon.

While discussing the issue of wider conceptual models and reviewing previous work, Boarnet and Crane (2001) suggest that the body of research lacks a strong conceptual framework in which to frame statistical results or to make the case for causality outside the data. Such conceptual models are often based on existing theories such as micro-economics/rational choice theory/utility maximisation, sociological and psychological theories or, more rarely, have been hypothesised by the researcher.

In keeping with these comments, this study introduces a wider conceptual model and, although it is beyond the scope of this research exercise to investigate and confirm each link in such a wide conceptual model, it helps shape the hypotheses, study design, data collection and aids the interpretation of results, which may or may not support links within the conceptual framework. Figure 3.1 outlines the conceptual model of the relationships between urban form and travel behaviour that are hypothesised as part of this study. Definitions are given in the subsequent text. The open titles included in the diagram are intentional. Some of the links presented are relevant at different levels of aggregation with some affecting individuals, others households and some whole systems. It should be noted that the decision maker in each of the links below may differ from individuals to households. It is accepted that even this large conceptual model does not capture all factors that might influence any term in the model such as those external factors that might influence socio-economic and preferences which relate to the individual and their life history. These might relate for example to the socio-economic status of an individual's parents, the school that they attended and so on. However the conceptual model shown does give an overview of how the factors most often considered in the literature are hypothesised to interact.

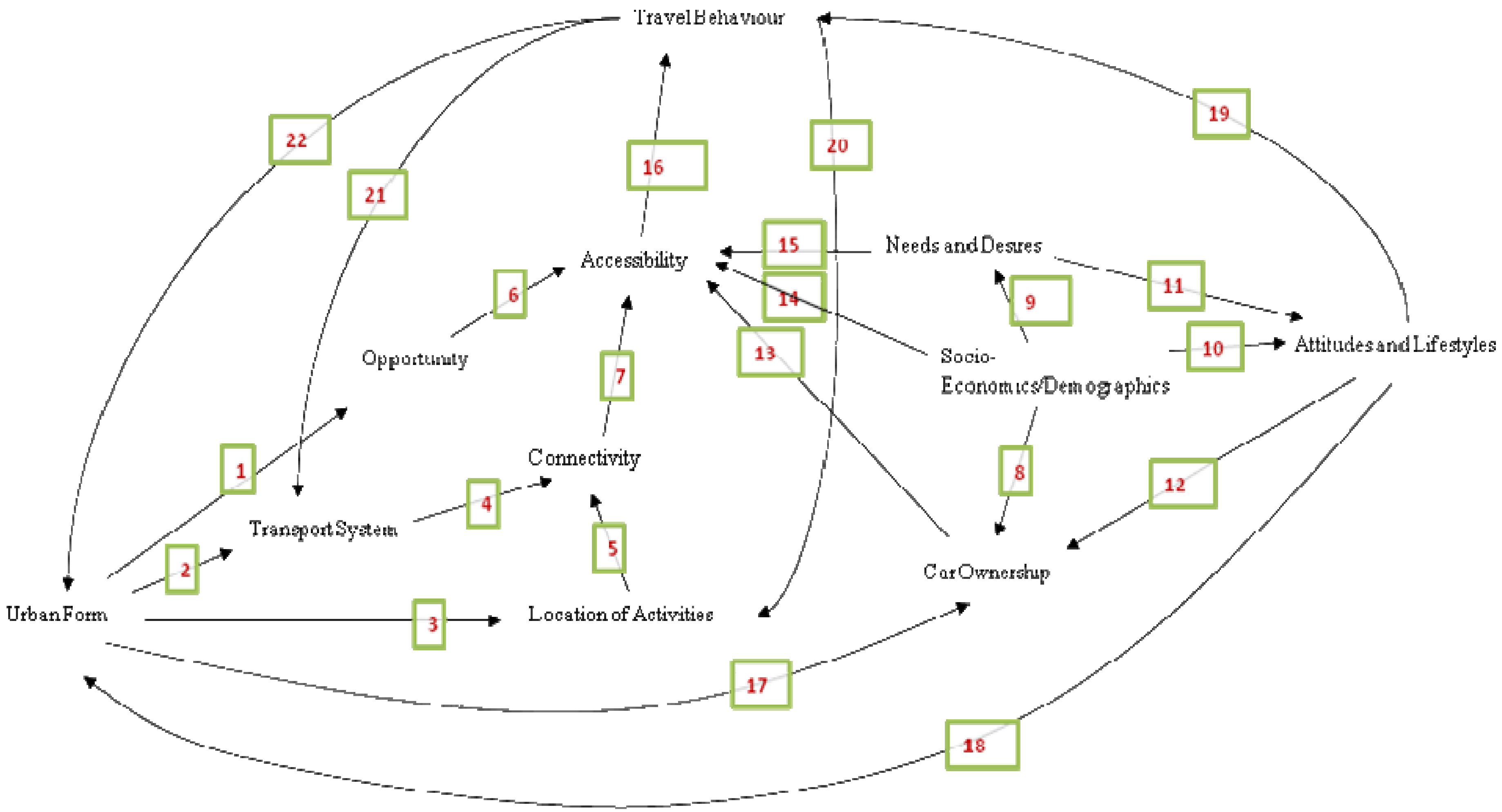

Figure 3.1 Conceptual Urban Form Travel Behaviour Relationships.

Travel Behaviour can be defined in a number of ways as discussed later in section 3.3.1 such as the number of trips, trip length, mode choice etc.

Accessibility is a measure of the ability of an individual or group of individuals with a given set of characteristics to undertake necessary or desired activities that are spatially and temporally separate.

Needs and Desires relate to what activities the individual or household needs or wishes to carry out.

Attitudes and Lifestyles refers to the individual's or group of individuals' attitudes towards transport and travel, the environment, residential choice location etc. For example, whether the individual has a preference for a car dependent suburban lifestyle or for a mixed use city centre lifestyle dependent on walking and public transport.

Socio-Economics/Demographics in this instance includes household structure, employment type and status, age, gender, income etcetera.

Transport System is the impedance or deterrence to travelling between any two locations.

Connectivity is the impedance or deterrence associated with travelling to any location where a particular activity can be undertaken. For example connectivity to employment would be influenced by the transport system and the location of employment activities.

Location of Activities relates to the spatial distribution of locations classified by the activities which can be undertaken there; for example the location of supermarkets.

Opportunity relates to qualities of the locations i.e. the attraction. For example, the floor area of supermarkets, the number of jobs at a location etc.

Urban Form, such as residential population density, land use mix and size of settlement, highlighted in the literature review as being associated with travel behaviour. The list of final urban form measures used in this study is developed further in section 3.3.2.

The categories to the right hand side of the diagram (needs and desires, socio-demographics, household resources and attitudes and lifestyles) can all be considered attributes of individuals within the household. The conceptual model shown suggests that these household attributes may influence the travel behaviour of householders directly and indirectly and may also have an impact on the urban form that the household resides in.

While the conceptual model may be complex, it is believed that, based on discussions in the literature, the relationship may well be extremely complex. Indeed, conceptual models produced by simulation studies also tend to be complex as they try to predict land use transport interactions (eg. Echenique 1969, Hankey and Marshall, 2009; Adhvaryu, 2010)

Each of the arrows highlights a hypothesised link in the conceptual model as follows:

1 – From the definitions given, it seems highly plausible that the urban form of an area (density, mix etc) affects the quality of locations such as the floor space of retail units. For example, less dense and less mixed areas may relate to large format supermarket shopping.
2 – The urban form of an area may have a direct influence on the transport system of the area. Particular urban forms may physically constrain the transport system and the construction of large highways for example.
3 – Similarly to Link Number 1, it seems highly plausible that measures of urban form influence the location of activities, such as work places, residences and places of education for example.
4 – In this conceptual model, connectivity is defined as the impedance of travelling to a particular destination. As such it is defined partly by the transport system.
5 – Similarly to link 4 the connectivity is also partly defined by the location of activities.
6 - Accessibility is defined as the ability of an individual or group of individuals to travel to and from the locations where they wish to carry out activities and, as such, the opportunity or attraction of activities influences accessibility.
7 – As with link 6, accessibility is also influenced by the connectivity or impedance of travelling to these various activities.

8 – It is hypothesised that household car ownership is highly influenced by the socio-demographics of the household such as age, household structure, employment status and most importantly income.

9 – The needs and desires of the household, that is the activities that the household has to, or wishes to carry out, are, in this hypothesised model, related to the socio-economics/demographics of the household as defined.

10 – The households' attitudes or preferred lifestyles are hypothesised to be influenced by the socio-demographics of the household such as number of young children in the household, age, income etcetera.

11 – Similarly to link 10 these attitudes and preferred lifestyles towards residential typology, travel behaviours etcetera are influenced by the activities that the household needs or wishes to undertake. That is, the needs and desires are hypothesised to influence the attitudes and lifestyles of the household.

12 – Car ownership is expected to be highly influenced by the attitudes and preferences of the household in terms of preferred travel behaviours and residential typologies.

13 – Accessibility is partly defined in this hypothesised model by car ownership

14 – Accessibility as a measure of the ability of the household to carry out the activities it needs or wishes to undertake is expected to be, in part, the result of socio-economics/demographics of the household; particularly the income.

15 – Similarly to link 14, accessibility is expected to be, in part, a function of the needs and desires of the individual or household.

16 – Travel behaviour is hypothesised to be dependent on accessibility based on the definitions given.

17 – Direct influences of urban form on car ownership are of key interest to this study and it hypothesised that urban form, in part, determines levels of car ownership based on the findings of the literature reviewed.

18 – It is hypothesised based on the findings of the literature reviewed in this thesis that urban form will be influenced by attitudes and lifestyles. This maybe more immediately through the household choosing a residential location choice or over longer periods with new developments reflecting urban forms that are in demand.

19 – It is hypothesised that there is a direct influence from attitudes and preferences to travel behaviour as well as the indirect influences indicated.

20 – It is expected that over longer periods of time travel behaviours may influence the location of activities with businesses and other activities locating and relocating to areas which can be accessed by evolving travel behaviours. For example, large employers may relocate to out of town areas which can be served by car, as car use increases over time.
21 – Similarly to link 20 it is hypothesised that as travel behaviours evolve, transport systems evolve also to meet demand. That is over longer periods, travel behaviour influences the transport system.
22 – As with link 20 and 21 it is hypothesised that over longer periods of time urban forms will evolve to reflect changing travel behaviours. For example more suburban car orientated developments will be developed as car use increases.

This conceptual model, while detailed, is far from exhaustive and other links may exist or may have been hypothesised by others. The conceptual model presented here is that which is hypothesised by this study based on the literature. It is not intended to be an exhaustive summary of all relationships reported in other studies.

Links 20, 21, 22 and to a lesser degree link 18 are expected to act over longer periods of time, while the other links in the system can be expected to act more immediately. Carrying out empirical investigations to support such a causal model would be extremely difficult given the long time lags over which some paths are expected to act and the large number of different variables being considered. This would make data collection very time consuming and difficult. Suitable analytical frameworks for such a complex model would be difficult to specify and computationally difficult to implement. Also, even if such data were available and a suitable modelling framework could be specified and used, the results may only give a relative measure of likelihood or fit compared to any other conceptual model being tested. While some notable exceptions exist (Vandermissen et al, 2003; Woudsma and Jensen, 2003) the majority of the literature has not tried to model or analyse such long term links and it is not proposed to do so in this study. Such changes to transport systems, urban forms etcetera over time merely help to define the choice set for any particular household in terms of the options the household has when deciding where to reside, what modes of transport to use etcetera. It is those links that constitute these **choices** rather than the links that define the **choice sets** that are to be investigated as part of this study. It is however, important for a hypothesised conceptual model to be introduced in order to specify the paths of interest, to help frame any discussions on self selection or other issues of spuriousness, and to give an indication of how any results are believed to fit into an overall causal mechanism. Links 18, 20, 21 and 22 have therefore been excluded from the scope of this study.

It is suggested that urban form, car ownership and travel behaviour are of critical importance in researching this or similar conceptual models. Households can decide in what kind of urban form they wish to reside, how many cars to own and how they intend on travelling. Households have much less choice or direct influence on other factors such as the transport system, their socio-demographic status or the location of activities and could be thought of as constraints.

The transport system, location of activities, opportunity, needs and desires and attitudes and lifestyles will be influenced by other factors not shown in the conceptual causal model such as government regulation and fiscal policy, life history etcetera and, along with connectivity and accessibility, could be considered intermediaries in the relationship between urban form and travel behaviour and socio-demographics and travel behaviour. As discussed in section 3.3.1, there are many problems associated with using accessibility as a proxy for urban form or travel behaviour. These problems are more obvious when accessibility is presented as part of a wider conceptual model. For the reasons previously stated, measures of urban form will be tested in this study as opposed to proxies for urban form. While including all the links and stages in the conceptual model might be attractive in helping to shed light on the causal mechanism by which urban form might influence travel behaviour, this is problematic and, as already mentioned, the results more difficult to interpret.

Socio-economics/demographics in this model can be considered as given and not influenced by other factors in the system. Travel behaviour in this simplified model can be considered as a function of urban form, car ownership and socio-economics. Urban form on the other hand is slightly more difficult as it cannot be considered to be completely independent of socio-demographics; the hypothesised link between the two referring to residential location choice. At this point it is useful to clarify the unit of consideration in the conceptual model. The units of consideration in the wider expanded conceptual model were purposely vague as some relationships reflected changes at the macro level. For example changes in the travel behaviour of the general population might lead to changes in the transport system and urban form, whereas the changes in the behaviour of an individual or household are unlikely to do so. Similarly, this hypothesised link between socio-economics to urban form via residential preferences. Over a longer period of time the collective preferences of the population will shape urban forms. Again, these longer term processes relating to the general populations are outside the scope of this study, which is focussed on the individual and household level and short to medium term relationships. In this instance the link between socio-demographics and urban form relates to the choice the household has, of which urban form to reside as opposed to defining the choice set of urban forms available.

Both urban form and socio-economics/demographics are hypothesised to influence travel behaviour directly through accessibility and indirectly through car ownership and accessibility. Key decisions in the design of any investigation into the role of urban form on travel behaviour and car ownership relate to how residential location choice is dealt with and what modelling framework should be applied to, what is still, a complex relationship incorporating the issues of time order and non-spuriousness.

Socio-economics/demographics help determine the residential location choice through attitudes and preferences, which may also be influenced by many other issues, including perhaps the previous experiences of the household. For example, if householders are used to walking cycling and using public transport they may be more prepared to so in their new residence.

Regardless of whether households may choose to reside in areas which best meet their predetermined travel behaviours or preferences (self selection), by shaping the choice set of where households can reside, it may be possible that urban form still influences travel behaviour. That is, it could be considered that by limiting the choice set of urban forms to a particular type, it may be possible to “force” households to reside in urban forms which influence their travel behaviour. Investigating whether particular urban forms cause more sustainable travel behaviours is of key importance to decision makers and planners, be that by limiting the choice set available to households or more directly. It is also important to consider that in previous studies such as Scheiner (2010), self selection was not considered relevant or found to be significant in large cities with fairly ubiquitous public transport such as Glasgow or Edinburgh where this study is focussed. It is therefore far from clear whether controlling for residential preferences would ignore a possible causal path by which urban form influences travel behaviour leading to an underestimate of the effect, if relevant at all. It is possible that within Glasgow and Edinburgh people may "self select" into new developments that were specifically marketed as being "sustainable" or less environmentally damaging. The focus of this study however, is not on such developments and people selecting where to live in Glasgow or Edinburgh might be assumed to have a range of urban forms available to them with good public transport and personal transport connectivity. It is for these reasons that in this study the link between socio-demographics, or attitudes and preferences to urban form (residential location choice) is removed from the causal model. The simplified conceptual model can therefore be refined to five paths as shown in Figure 3.2.

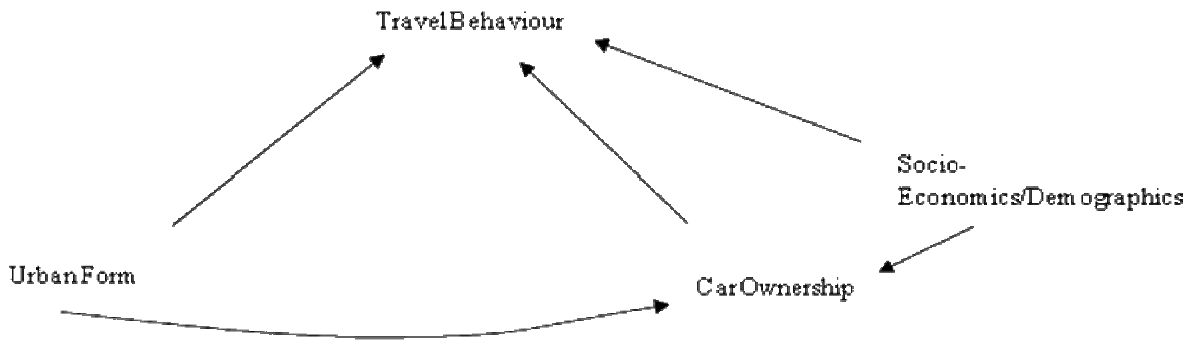

Figure 3.2 Conceptual Model

The model however, is still problematic in terms of fitting any analytical framework with travel behaviour being both directly influenced by urban form and socio-economics/demographics and indirectly through car ownership. The interest of this study is in the effects of urban form. Therefore, the study will focus on the hypothesised links from urban form and car ownership to travel behaviour while controlling for socio-economics/demographics and the link from urban form to car ownership while controlling for socio-demographics. In seeking to explain the travel behaviour in such a way, this study could be considered as having a rational choice conceptual framework.

3.1.1. Summary of Research Hypotheses

Through the careful consideration of a conceptual model outlined in this chapter, it has been possible to form the hypotheses to be analysed in this study that urban form influences travel behaviour and that urban form influences car ownership in the context of Scottish urban areas.

The hypotheses to be tested are as follows:
H1: Urban Form and Car Ownership have direct effects on Travel Behaviour
H2: Urban Form has direct effects on Car Ownership

3.2. Research Methods

Given what has been said in the previous review and discussion of hypotheses, the following questions need to be considered and addressed in the design of this study in order to address the hypotheses.

- What are the effects of urban form on travel behaviour?
- What are the effects of changes in urban form on travel behaviour?
- What is the effect of urban form on car ownership?
- What are the effects of changes in urban form on travel behaviour?

The study must be designed in such a way that these questions can be answered. The development of a method to address these points is described in this chapter. The ways in which urban form and travel behaviour have been defined in other studies and a description of the urban form and travel behaviour measures to be addressed in this study are then presented. Reference is made to the various means by which such data has been collected in other studies in order to inform the data collection described in the following chapters.

In order to address the objectives of this study and to test the hypotheses, the study must have a temporal element. If changes in urban form and travel behaviour are to be analysed, it is necessary for some kind of study through time to be undertaken. The various means by which this can be addressed in the method of research are discussed at length in the literature review. These range from analyses of how travel behaviours have changed in a particular geographical area over a number of years, studies into the travel behaviours of a particular cohort over time, repeated cross sectional studies or current and retrospective recall studies.

There have been no truly experimental designed studies whereby a number of existing areas have had their built form changed by the study authors and the travel behaviours emanating from such urban forms measured. This is due to the obvious costs, timescales, ethics and other practical considerations required for such an experimentally designed study. In keeping with the majority of studies cited in this thesis, this study was observational in nature. That is, travel behaviours and urban forms, not altered as part of this study were observed in order to research relationships between the two.

The literature review highlighted the weaknesses associated with studies of aggregated groups of people or households. The main criticism of aggregate studies is that by masking some of the variation between individuals or households, less robust statistical analyses can only be undertaken. Sources of data for aggregate studies tend to be censuses or other data sources collected not for the purposes of investigating urban form and travel behaviour interactions; hence they often have a limited number of variables useful to researchers in the field, leading to criticisms of possible spuriousness in any associations found. As such this study will be disaggregate in nature based on data collected on individuals and households.

Trying to measure organic changes in urban form is time consuming as such changes are only likely to be significant over longer time periods. Controlling for other variables over such time periods is also problematic as is the retention of any cohort. Repeated cross sectional studies showing changes in behaviour over long periods of time with respect to organic changes in the built environment suffer from many of the same problems and also, by not having a cohort on which repeated measures are made, it is not possible to control for the unobserved variables affecting travel behaviour specific to the individual or household as discussed in Yee and Niemeier (1996); the assumption that the unobserved attributes of the household remain constant over time is questioned by Hess and Rose (2009).

It was therefore decided that the observational study would be in the form of a current and retrospective recall survey of households who have recently moved home in line with that undertaken by Cervero and Day (2008) and Handy et al (2005).

This type of data collection is often referred to as being quasi-longitudinal. A longitudinal study is defined as "…one which is based upon repeated measurements of the same individuals over time." (Wall and Williams, 1970), whereas a retrospective recall tries to gather the same information from the cohort using only one round of the survey. Wall and Williams (1970) point out that retrospective studies may arguably fulfil the same role as a longitudinal study and be cheaper to carry out but warn that human memory is fallible, and events which subsequently prove to be critical in their effects may appear trivial at the time and hence be easily forgotten. People may unconsciously fabricate or exaggerate something to explain the present state of affairs. However, retrospective recall may be suitable when events are recent and have little emotional significance.

It is therefore important to keep any questions asked retrospectively as factual as possible rather than asking for motivations behind behaviours or choices; a problem often overlooked in studies using retrospective or revealed preference data to develop residential location, urban form and travel behaviour research. Similarly, the timescales over which the data is to be recalled should be kept to a minimum.

Such a current and recall study can be considered quasi-experimental. In this case with the pre-test data collected through the recall and the post-test from the current reporting.

Given what has been said about the slow pace at which urban forms change, the study considered those households who had relocated between the recalled date and the current date and how their change in residential location related to a change in travel behaviour or car ownership. The recalled data was for a specific point in time, three years prior to the date the questionnaire was received by the respondent. Data on households who did not relocate were also collected in order to carry out cross sectional analyses at the two points in time and to gauge if the general population of interest had shown a change in travel behaviour. The treatment could then be considered as a change in residential location between the two waves (recalled and current). Whether or not the household is subjected to the treatment cannot be determined by the study author; neither can the form of this treatment (the change in urban forms experiences by the household). Households self select their treatment.

It should be noted that by having households self select into non-equivalent groups, could raise questions over internal validity. Non-equivalent group problems occur if the two groups, “treated and non-treated” were in fact different in some way before the study started and that that difference was either a difference in the dependent variable or a difference in a significant variable not described by the data collected (Trochim, 2010). In the case of this study that would mean they differed at the time of recall in some significant way which is not described by the data collected through the survey or alternatively that either movers had a different car ownership level at the recall time or travel behaviour compared to the non-movers. If this were the case, then having higher or lower car ownerships for the treated group compared to the untreated in the current period of time could make any conclusions unsound. It should be noted that the point of the study is not to analyse different levels of car ownership for movers or non-movers but to compare how movers differ from non movers in terms of increases or decreases in car ownership. No problems of internal validity threat of selection that can be associated with non-equivalent groups are expected, despite the self selection into one of the two groups for the reasons stated.

Logically there could be associated questions over possible regression towards the mean. If all of the movers started (at the recall) with a very low car ownership it might be expected that they will have increased car ownership by the current. These issues are returned to in more detail in the analysis contained in Chapter 5, but it should be noted that non-equivalent group designs are possibly the most commonly used sampling methods in social research (Trochim, 2010).

3.3. Description of Research Procedures

Section 3.3 describes the dimensions of travel behaviour and urban form to be collected and tested as part of this study. The selection of case study areas along with a description of each case study area is then presented. The household questionnaire and its development are then discussed followed by a discussion of sample size considerations, sampling method and finally the data collection undertaken is described.

3.3.1. Selected Travel Behaviour Dimensions.

As discussed in the literature review, many studies have used measures of connectivity or accessibility as proxies for measures of either urban form or travel behaviour. This study will utilise measures of overall travel behaviour with a particular emphasis on car use. Distance driven by car per household for all purposes will be collected and analysed as part of this study.

The survey therefore required questions on annual distance driven for the cars available to the household and also an activity diary collecting data for the respondent over a number of days. The survey and activity diary are discussed further in section 3.3.6 and are shown in Appendix F. The survey also asked how, compared to three years previous, their car use had changed, expressed on a five-point likert scale from a lot less to a lot more.

It is also worthwhile noting that there are different ways of measuring car ownership. The most commonly used dimension of analysis in the literature is the number of vehicles owned, then some measure of the type of vehicle such as make or model or fuel type (Bhat et al, 2009). In this study the number of cars available to the household currently and previously will be recorded along with the type of vehicle. It is believed that the number of cars available to the household, currently and previously, is something that the respondent will be able to easily recall addressing the potential difficulty with retrospective recall surveys.

3.3.2. Urban Form Data Sources

This study is based in Scotland. For cities in Scotland there are a number of different sources of data that could be useful in developing urban form metrics that may be of use to this study. For example, various layers of information from the Ordnance Survey (2008) are available. This gives the location of all addresses as points, shows an indication of land uses and also gives the building footprints, edges of footways, roads etcetera.

Aggregate information on built form is also available from the census at various geographies for all of the study areas indicating populations, housing types etcetera. Data can also be collected by means of a visual survey as well as collecting some built form measures by means of a postal survey. A detailed discussion of the data sources available to this study is presented in Appendix E.

3.3.3. Selected Urban Form Dimensions

While it would be advantageous to test as many dimensions of urban form as possible, there are many constraints, such as the level of data available for the study areas and the time/budget constraints of the project. This section aims to show those dimensions that are considered useful in terms of their possible ability to relate to travel behaviour or car ownership, based on previous research, while being practicable to derive in terms of the constraints of the project and available sources of data, and being of use to planners and decision makers.

It should be noted that measures of the same dimension at different scales may not be independent of each other, thus the same dimension measured at different scales will not be entered into any model at the same time. This is discussed in more detail in Chapter 5.

The dimensions of urban form used were not only for the current address of the respondents, but also for their previous residential location in the cases where the respondent had recently moved house, which forms another constraint as to the dimensions of urban form suitable.

Density

Residential population density is the most frequently used dimension of urban form in the literature and has been found to be significantly associated with various travel behaviour in some of these studies as described in the literature review. It is hypothesised that, based on the findings of the literature discussed, that density influences car ownership and travel behaviour in a number of ways as presented in the causal path diagram represented in Figure 3.1. Density is hypothesised to affect the transport system. Higher density areas are believed to be easier served by public transport than more sparsely populated areas. Higher density areas are also hypothesised to suffer from more road traffic congestion. Density is hypothesised to affect the location of activities although this is also related to land use mix. Higher residential densities could make other activities more viable. Measures of density will therefore be made at two different geographies; Census Output Area and Census Area Statistic Ward level. Ward refers to a Census Area Statistic Ward for Scotland. This is a geography based around electoral wards but made up from a number of output areas with a total residential population of approximately 7,000. Output Area refers to the smallest census geography available, with a resident population of approximately 100 people. Residential population densities were obtained from the UK census undertaken in 2001.

Land Use Mix

The ways of defining land use and mix vary greatly from study to study as can be seen in the detailed descriptions in Appendices C and D. Often the area of land designated for two groups of different uses are compared with each other or with measures of population in the area (Song, 2002). Others use balances of jobs and populations within an area (Ewing, 2003; Cevero, 2002; Zhao, 2009; Peng, 1997). The categorisation of land to any particular use also varies greatly. Hess et al (2001) reviews measures and categories of land-use-mix used in the literature, and suggests that land uses should be categorised into complementary groups such as retail and services. It seems likely that the mixture of heavy industry to agriculture in an area is unlikely to have a substantial direct impact on travel behaviour, whereas the balance between the population (or proxies for it) and measures of land uses to which residents are likely to travel to regularly (employment in particular) is believed to have a larger effect. As such, land use mix is hypothesised to affect travel behaviour and car ownership. Increased land use mix should, by the definitions set out in Chapter 3, be strongly associated with the location of activities. It is also likely that more mixed patterns of land use will relate to the opportunity that the activity locations offer, with more mixed land use relating to higher retail floor space and office units compared to residential land use for example. It was decided that measures of the mix between residential land uses and employment land uses were most important in the analysis of urban form travel behaviour relationships based on the findings of similar studies cited in Appendices A and B, as employment could encompass a range of non residential land uses and employment related travel makes up a large proportion of all travel in the UK. For this reason, the proportion of jobs to resident population will be used as a proxy for the mix between these two land uses. This study is focussed on travel behaviours of people; hence it is felt that the balance between trip generating and trip attracting land uses will relate to travel behaviours. Land uses that are not likely to be trip generators or attractors such as agricultural land are unlikely to relate to travel behaviours of resident of a particular area. Given the problems discussed in the literature review of defining suitable land use mix metrics which contain more than two categories of land use, the ratio of jobs to population was felt to be a good proxy for the mixture of trip generating land uses (residential) and trip attracting land uses (office, retail, leisure, education etcetera). This measure will be taken from census obtained in 2001 again at an Output Area and CAS Ward level. While it is accepted that such a proxy for land use mix may not be the most applicable for policy makers, it is not easy for a small (or single) measure of land use mix directly to be developed that reflects the balance between employment land uses and residential land uses. Also, data on land use itself are less readily available and considerably more onerous, expensive and time consuming to collate compared to using data from the census in this way. Census data is also fairly standard across the whole of the UK and while the case study areas in this study are all based in Scotland, urban form metrics including any measures of mix have to be collected for the previous residential locations of those who have recently moved house. It was expected that a proportion of those who have moved to the Glasgow and Edinburgh will have done so from the other parts of the UK. Land use categorisations are not standard across the UK which is another reason why census data used as a proxy for land use mix is preferable in this instance to actual land use mix measures.

Housing Type

As mentioned in Appendix C, housing type has not often been tested in the literature, possibly because information has not been gathered at a household level. Data were collected on housing type through a household survey as part of this study. The housing typology the respondent currently and previously lived in was collected as opposed to measures of the proportions of different housing types in these areas. The questions used to gather this information are discussed later in section 3.8.8. It is possible that the type of housing relates to travel behaviours through a number of mechanisms such as a lack of cycle storage and car parking facilities in tenements or flats causing lower levels of car and bike ownership and use and greater use of walking and public transport.

Distance to Urban Centre

The Euclidean distance from the residential location to the centre of the nearest urban area was collected. The nearest urban centre for the case study areas was either Glasgow City Centre or Edinburgh City Centre; however, the nearest urban area for previous residential locations was defined as being a settlement with more than 10,000 inhabitants as set out by the Scottish Executive (2004). Distance to urban centre could relate to travel behaviours through provision of public transport which tends to be greater closer to urban centres, shorter distances to employment and other land uses or increased congestion deterring car use.

Urban / Rural Classification

Similarly it could be hypothesised that it is not only the distance to the urban centre that helps determine travel behaviours but also the size of the settlement in which the household is located. The Scottish executive classifies the degree of urbanisation of all areas of Scotland (Scottish Executive, 2004). Data was therefore gathered on the classification of the current and previous residential locations of respondents. Given that the study areas are all within large urban areas of Scotland the previous urban rural classification is of most interest in the longitudinal analysis of change in urban form and change in travel-behaviour/car-ownership. While the data set applies only to Scotland, the previous residential location of those respondents who had recently moved from other parts of the UK were assigned to one of the urban/rural categories using the definitions set out by the Scottish Executive (2004). This is because the urban/rural classification system used in England and Wales (Statistics, 2004) differs to the Scottish categorisation. Scottish Executive Urban Rural Classification is made up of the following eight categories.

- Large Urban Areas - Settlements of over 125,000 people.
- Other Urban Areas - Settlements of 10,000 to 125,000 people.
- Accessible Small Towns - Settlements of between 3,000 and 10,000 people and within 30 minutes drive of a settlement of 10,000 or more.
- Remote Small Towns - Settlements of between 3,000 and 10,000 people and with a drive time of between 30 and 60 minutes to a settlement of 10,000 or more.
- Very Remote Small Towns - Settlements of between 3,000 and 10,000 people and with a drive time of over 60 minutes to a settlement of 10,000 or more.
- Accessible Rural - Settlements of less than 3,000 people and within 30 minutes drive of a settlement of 10,000 or more.
- Remote Rural - Settlements of less than 3,000 people and with a drive time of between 30 and 60 minutes to a settlement of 10,000 or more.
- Very Remote Rural - Settlements of less than 3,000 people and with a drive time of over 60 minutes to a settlement of 10,000 or more.

The size of settlement for those respondents who had moved from England or Wales to the case study area was recorded from Communities and Local Government (2001).

Distance from home to place of work was also collected for the respondents and their spouse/partner, along with the availability of parking at the place of work. Drive times were determined using Google Route Planner. Other urban form measures such as access to a private garden were also collected for further analysis not presented in this thesis. See Jenks and Jones (2010) for details on how some of this additional data was used.

It was believed that these urban form dimensions were the most useful in describing the aspects of the built environment most likely to affect travel behaviour or car ownership based on the literature. They are also relatively simple in terms of their definition and are based on readily available data sources and as such simple for planners and policy makers to implement. The use of readily available data sources such as the census or easily computed metrics such as the distance to the nearest urban centre was essential given that the previous residential locations of those who have recently moved home were unknown and as such measures relying on less readily available local data sources or site surveys were not practicable.

The data that were required in order to address the research aims and objectives are summarised on the following pages with the sources of data as discussed in this chapter and elaborated upon in Appendix E.

Urban Form

Current

- Housing Type,
- Residential Population Density (persons per hectare),
- Jobs to Population Ratio (jobs divided by residential population),
- Distance to Urban Centre,
- Distance from home to place of work for respondent,
- Distance from home to place of work for respondent's partner/spouse,

Previous (or change since recalled date)

- Housing Type
- Residential Population Density (persons per hectare),
- Jobs to Population Ratio (jobs divided by residential population),
- Distance to Urban Centre,
- Distance from home to place of work for respondent.

Travel Behaviour/Car Ownership

Current

- Vehicles available to household,
- Annual mileage of vehicles available to household,
- Date vehicle acquired,
- Age, make and model of vehicles available to household,
- Mode of journey to work.

Previous (or change since recalled date)

- Change in car use,
- Change in car ownership,
- Previous distance to work,
- Previous mode of journey to work

Socio-Demographic/Other

Current

- Household Income,
- Age of respondent,
- Household structure,
- Gender or respondent.

Previous (or change since recalled date)

- Change in income,
- Change in household structure,

Changes between previous and current are expressed in current minus previous for scale variables. For those who had changed home or job location an analysis could be made of how changes in these metrics are related to any subsequent reported change in travel behaviour. Section 3.3.8 describes the household survey questions used to gather such information and Chapter 4 provides a detailed description of all variables for which data were collected. Figures 4.2 and 4.3 show all variables collected and used in the analysis presented in this thesis including the units of measurement for scale variables and the groups used for categorical variables.

3.3.4. Selection of Case Study Areas

The case study areas were selected as part of a wider research project undertaken by the CityForm consortium (City Form, 2009). See Jenks and Jones (2010) for details of the overall programme of research.

As was highlighted in the literature review, many studies have been carried out on case study areas such as neighbourhoods that are themselves defined by the researcher based on their urban form. The definition of case study boundaries based on the explanatory variables being tested is statistically questionable and could lead to skewed urban form measures. Defining study boundaries using urban form metrics may overstate differences in urban forms and exaggerate edge effects. Arbitrary boundaries not defined specifically by urban form metrics are preferable such as a grid system or use of electoral or census boundaries.

The study areas were selected to be of a similar population size but represent a range of different urban forms within each case study, rather than representing a single urban form typology each. It was felt that Glasgow and Edinburgh would provide interesting case studies due to the number of different urban and suburban typologies from different time periods reflecting the range of urban typologies that are present in the UK today. For a review of urban and suburban typologies in Glasgow, Edinburgh and other UK cities see Frey et al (2005).

The case study areas selected for this study included an inner urban area, suburban area and intermediate area from both Glasgow and Edinburgh. Each case study area included at least 2000 households, a mixture of land uses, various housing types, and nearby public transport (Jenks and Jones, 2010).

3.3.5. Description of Case Study Areas

The following descriptions give an overview of the built forms, socio-demographics and other characteristics of the case study areas. How the socio-demographics etcetera of the areas compares to the national averages is not discussed in this chapter. This issue is discussed in more detail when considering the responses to the survey in Chapter 4 but it should be noted that this study is explanatory, to help understand whether and in what way urban form influences travel behaviour; it is not a simulation study. Therefore, a range of urban forms and travel behaviours need to be collected, not necessarily reflecting the exact proportions found in the wider population. If inferences about the impact of changing the urban form in a particular area were to be made from the results of this study, weightings would have to be applied to the data to reflect that area. The six case study areas were as follows:

Glasgow Central – Anderson area of Glasgow

Figure 3.3 Photograph of Glasgow Central Case Study Area (Jenks and Jones, 2010).

Figure 3.4 Detailed Map of Area (Jenks and Jones, 2010).

The area as shown in Figure 3.4 lies to the north of the River Clyde including areas to the centre and southeast of the city centre. The area appears large geographically due to the boundaries of some of the output areas in the centre of Glasgow which contain large numbers of commercial properties but little residential population.

The area contains various built forms with higher density newer flats being located closer to the city centre and along the River Clyde, older refurbished tenement areas in the gentrified Merchant City area of the city and 1980s and later family terraced and semi-detached housing to the east of the study area. The study area is served by various public transport routes including the Glasgow subway system, mainline railway stations and terminals and bus services, as would be expected in the city centre.

Glasgow Intermediate – Pollokshields

Figure 3.5 Photograph of Glasgow Intermediate Case Study Area (Jenks and Jones, 2010).

Figure 3.6 Detailed Map of Area (Jenks and Jones, 2010).

The area as shown in Figure 3.6 lies to the South of the Glasgow City Centre. The area is made up of a number of large detached villas, many of which have subsequently been converted into flats to the west of study area. To the east of the study area, the majority of buildings are tenement style buildings many of which include commercial uses on the ground floor with three levels of housing above. The area is culturally diverse and has a high population density.

The study area is served by various public transport routes including the Glasgow subway system to the north of the study area, mainline railway stations around the edge of the study area and bus services. The majority of this public transport provision is radial in nature linking the area to Glasgow city centre. The area is also bordered by the M77 motorway to the West.

Glasgow Outer – Darnley

Figure 3.7 Photograph of Glasgow Outer Case Study Area (Jenks and Jones, 2010).

Figure 3.8 Detailed Map of Area (Jenks and Jones, 2010).

The area as shown in Figure 3.8 lies to the South of Glasgow. The area is bounded by the M77 motorway to the east and the railway line into central Glasgow to the North. In addition to the rail services into central Glasgow, bus services are operated throughout the study area, predominantly also to Glasgow City Centre. The area while suburban in location, includes various urban forms such as newer detached and semi detached family housing, mid to late twentieth century, high density, deck accessed flats and tenements. The area to the West of the study area is in the process of being demolished. The area includes large out of town shopping centres including a large supermarket and other large format shops close to the M77 motorway.

Edinburgh Central - Dalry

Figure 3.9 Photograph of Edinburgh Central Case Study Area (Jenks and Jones, 2010)

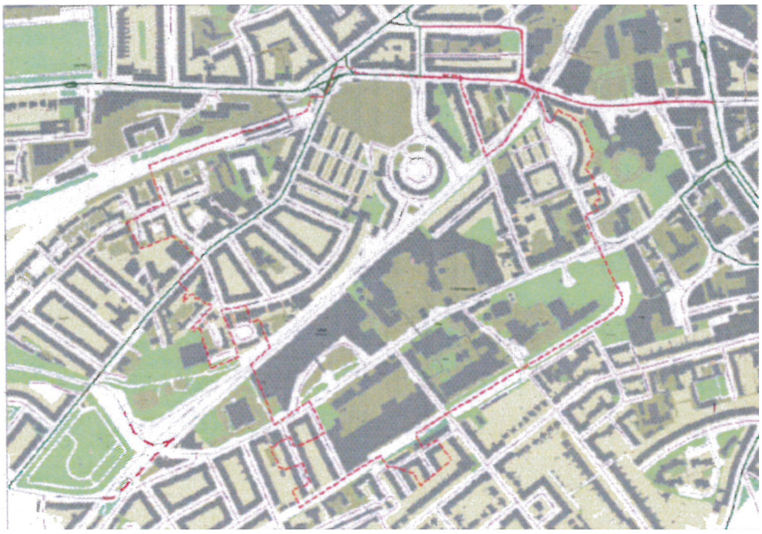

Figure 3.10 Detailed Map of Area (Jenks and Jones, 2010).

The area shown in Figure 3.10 borders Edinburgh city centre and lies immediately to the south west of the main shopping and leisure centre of the city. The study area has good public transport connectivity to the city centre via local bus services and rail services. The area is also well connected to other parts of Scotland via Edinburgh Haymarket rail station. The area is also close to the major financial employment centres of Edinburgh such as the Exchange. The area is made up of a mixture of built forms with older tenements, colonies (terraced houses with each floor having an entrance into the street at one side of the building only) and more modern apartments.

Edinburgh Intermediate – Restalrig

Figure 3.11 Photograph of Edinburgh Intermediate Case Study Area (Jenks and Jones, 2010)

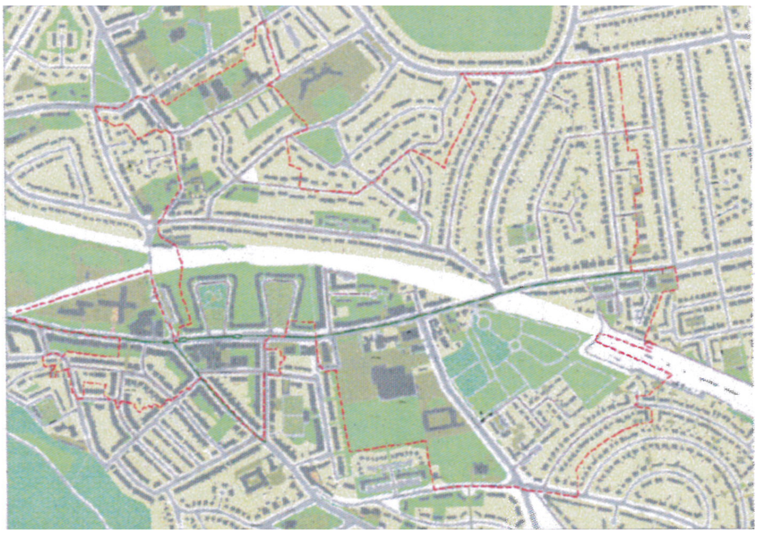

Figure 3.12 Detailed Map of Area (Jenks and Jones, 2010).

The Intermediate study area of Edinburgh lies to the Northeast of Edinburgh City Centre as shown in Figure 3.12. The study area is bisected by the East West mainline railway. Largely post-war housing with approximately half being flats and half made up of semi-detached and detached housing (Jenks and Jones, 2010).

Edinburgh Outer – Corstorphine

Figure 3.13 Photograph of Edinburgh Central Case Study Area (Jenks and Jones, 2010)

Figure 3.14 Detailed Map of Area (Jenks and Jones, 2010).

Study area shown in Figure 3.14 lies to the West of Edinburgh. Compact and largely residential in nature with a large proportion of detached and semi-detached houses with private gardens. A major arterial road runs East-West through the study area along which buses into and out of Edinburgh City centre and other destinations run (Jenks and Jones, 2010).

3.3.6. Household Questionnaire

A postal survey was carried out in the six case study areas in order to gain information on current and previous behaviour, urban form and socio-economics/demographics.

The survey was a mail-out mail-back self completion survey. A copy of the survey is included in Appendix F.

Households were asked questions about their current and previous residential location, socio-economics, car ownership and travel behaviour amongst other questions. This was to enable analyses to be carried out on each of the four questions listed at the start of this chapter and answer the overall research questions of whether urban form influences travel behaviour and car ownership in the UK.

The survey was designed in accordance with good practice guidance (Ampt and Stopher, 2006). A precursor letter was be sent out to each of these addresses explaining that they would shortly receive the questionnaire, informing them of what they needed to do, as well as giving them some background to the research and means by which to contact the research team should they wish their addresses to be removed from the study.

As an incentive to encourage a greater response, 4 gift vouchers for Marks and Spencer (department store) to the value of £50 were offered as a prize draw for those who completed the survey. The four winning respondents were randomly selected from the cleaned list of respondent addresses.

The survey asked a householder to complete a questionnaire about themselves, their household and their partner/spouse if also living at the address. A copy of the questionnaire, precursor and follow-up letters are included in Appendices F and G respectively. A four-day activity diary was also included in order to carry out further analysis not described in this thesis. In order for the respondent to complete the activity diary, a map and list of locations was also included tailored to either Edinburgh or Glasgow as necessary.

The survey asked the respondent how they felt their use of the car had changed since the end of 2002. This date was chosen to coincide with the property sales data, which showed all properties that had been sold since the end of 2002. The survey also asked whether or not the respondent had moved house since the end of 2002, and if so, what their previous address was and what type of building they occupied at that address in order to capture those people who had moved but where no property sale had taken place, such as those people living in rented accommodation. From this response, it was possible to determine if the respondent had moved home and if so where from. It was then possible to compare the urban form of the current and previous address and any change in travel behaviour over the same period. A full list of questions can be seen in the copy of the questionnaire included in Appendix F.

The names of householders were not available from either the property sales or Ordnance Survey data set, so the survey was addressed to “The Householder”. The surveys and letters had a unique code included discreetly, which allowed the response to be linked back to an address. To ensure anonymity, two separate databases were developed and stored separately, one which included the unique reference number and survey response data and one which included the unique reference number along with the address and post code. Urban form data could then be added to the survey response database by using the address database as a lookup table. In order to comply with data protection requirements, an assurance was given to the respondent that the data would only be used for the purposes of research, would not be given to any third parties not involved in the research and data would only be published in aggregate form to ensure anonymity. The survey design was given the approval of the ethics committee of Strathclyde University.

Prior to the data collection exercise, a number of different versions of the questionnaire and activity diary were developed. Each version was a variation in length, format, type of activity diary and form of questioning. Various versions of the questionnaires were tested amongst small groups of individuals involved in the research project to determine the time required to complete the survey, whether the questions were easily intelligible, if there were any errors in the survey and to give some small indication of the range of responses. Minor errors were discovered and amended. The activity diary proved to be the most difficult aspect of the survey in terms of intelligibility and also required a considerable amount of time to complete. The activity diary asked the respondent to record his or her activities and associated travel for a specified four day period to include both a weekday and weekend. The dates for the survey to be sent out were carefully selected to avoid school or other holiday periods so that the travel could be considered usual travel behaviour. The mix of weekday and weekend travel was designed to enable other analyses not reported in this thesis to be undertaken. A decision was taken to keep the more personal questions on income and household structure towards the end of the questionnaire. It was felt that these questions might dissuade some people from responding. However, having already completed the majority of the survey before reaching these questions it was hoped that the respondents would continue to complete the survey. At the very end of the survey was the activity diary. This, being the most onerous part of the survey was felt most likely to dissuade people from responding, so was kept to the end of the survey for the same reason.

The overall method of data collection (mail out, mail back self completion survey with precursor letters) was tested through an earlier round of data collection carried out by the City Form consortium in the case study areas, partial results of which are presented in Jenks and Jones (2010). Those households who had been targeted in this earlier round of data collection were excluded from the list of addresses used in the data collection exercise presented in this thesis. This was done to maximise the response rate as it was felt that having two substantial questionnaires in a fairly short space of time might lead to a certain degree of fatigue. This earlier data collection exercise helped to inform the data collection presented here in term of likely response rates and the logistical problems associated with carrying out a large scale mail out, mail back survey of this kind.

A draft version of the survey was trialled on a mixture of undergraduate and postgraduate students in the Department of Civil Engineering at Strathclyde. This helped fine tune the questionnaire and also provided a larger trial data set to be developed in order to gauge the range of responses and the time taken to input the data into a database. A balance had to be struck between how long and onerous it was complete the survey and the richness of the data gathered. An approximate completion time, determined through the pilot, of 11 minutes for the final version of the survey was considered acceptable.

3.3.7. Sample Size Considerations

Without knowledge of the range of responses, the accuracy of the measures of travel behaviour and other socio-demographics, and detailed knowledge of the specification of any analytical model, it was not possible to determine the size of sample required.

It is worthwhile recalling that the study was designed to be explanatory in nature and not to represent the travel behaviours of the people of Glasgow and Edinburgh. If it were, then there would have been further sample size considerations. If the sample size were not great enough it could lead to the null hypotheses being wrongly accepted, depending on the level of statistical confidence used.

Power analysis is a useful tool in helping to determine the minimum sample size required to test a hypothesis to a particular degree of statistical confidence. Along with the degree of statistical confidence, the power of a statistical test depends on the size of the effect of the independent variable being tested. In the case of this study, it would refer to the expected magnitude of the effect of density and other urban forms on car ownership and vehicle miles driven. Since no *a priori* knowledge exists of the effects of each independent variable, power analysis would be difficult to utilise in this instance.

Tabachnick and Fidell (2007) suggest that as a rule, the sample size should be 104 plus the number of independent variables to be included in any regression analysis.

Garson (2010) suggests another popular rule of thumb is that there must be at least 20 times as many cases as independent variables or, if using stepwise regression, the sample size should be 40 times the number of independent variables.

While the precise number of independent variables was not known nor had the method of entering the variables into any regression model been determined at this stage, these two rules of thumb would suggest a sample size in order of between 114 and 400. With an estimated response rate from similar studies of 18%, approximately 2,200 households would need to be included in the survey to achieve the largest of these sample sizes.

3.3.8. Sampling Method

As previously mentioned six case study areas were selected. Within each case study area it was necessary to have a number of respondents who had and who had not moved home in the preceding three year period.

Property sales data were obtained from the Registers of Scotland for all property sales over a preceding three-year period (late 2002 to early 2006) in the six case study areas. All addresses highlighted as having been sold in the previous three year period were selected for possible inclusion in the data collection exercise. Addresses which appeared commercial in nature were removed, as were incomplete addresses which usually appeared to refer to land being sold or new residential properties that had not yet been allocated a full address leaving 1727 residential addresses where a sale had taken place. Addresses which had previously been contacted by the study team were also removed. Given that approximately double the number of sales had taken place in the Glasgow central case study area compared to any of the other study areas, only half of the available addresses where a sale had taken place were selected for the study.

The final number of addresses selected where a sale had taken place in each of the case study areas was:

Edinburgh Dalry,	351 addresses
Edinburgh Restalrig,	212 addresses
Edinburgh Corstorphine,	182 addresses
Glasgow Central,	363 addresses
Glasgow Pollokshields,	372 addresses
Glasgow Darnley,	208 addresses

To this database, further addresses were added from the Mastermap Address Point Layer from the Ordnance Survey (2008) after those addresses contained within the database of movers, those addresses which appeared commercial in nature and those addresses previously targeted by the study team had been removed. Approximately double the number of non-sales addresses compared to the sales addresses was added to each case study area. A total of 2,495 addresses were selected and had survey questionnaires posted to them, of which one third were addresses where no sale had taken place and two thirds were addresses where a sale had taken place in each case study area as follows:

Edinburgh Dalry	522 (Sales = 351 Non Sales = 171)
Edinburgh Restalrig	346 (Sales = 212 Non Sales = 134)
Edinburgh Corstorphine	264 (Sales = 182 Non Sales = 82)
Glasgow Central	518 (Sales = 372 Non Sales = 146)
Glasgow Pollokshields	514 (Sales = 372 Non Sales = 142)
Glasgow Darnley	332 (Sales = 208 Non Sales = 124)

3.3.9. Data Collection

Precursor letters were sent out to each of the 2,495 addresses explaining that they would shortly receive the survey, informing them of what they needed to do, as well as giving them some background to the research and means by which to contact the research team should they wish their addresses to be removed from the study (Appendix G). A number of these initial letters were returned address unknown or unavailable, and 12 people asked for their addresses to be removed from the survey mailing list. On the 12th June 2006, the surveys were mailed out to all those addresses that had not otherwise asked to be removed from the mailing list or where the precursor letter had been returned address unknown. The travel diary requested that a householder complete the diary from Thursday the 15th of June to Sunday the 18th of June 2006. The mail out date of 12th June was designed to allow up to three days for the surveys to arrive at the households, with most expected to arrive the following day sent by first class post.

On the 29th of June a reminder letter was sent to those addresses that had not otherwise responded and a number of replacement surveys were also mailed out on request. The reminder letter asked the respondent to complete the travel diary from Thursday 6th July to Sunday 9th of July. Details of the response rates can be found in section 4.1.

The survey was coded up manually using SPSS data entry mode. The activity diary was coded up by students of Strathclyde University, using a form created in SPSS data entry mode. The form used to code the activity diary and also the field set-up for the survey data entry allowed for some basic checks to be carried out while entering the data. For example, the alpha numeric format of postcodes was specified to ensure the post code being entered was of the correct format, times of activities could be checked and a small number of logic checks could be made such as checking whether the respondent stated they had previously moved home or not and whether or not they then entered a previous residential address.

In addition to these checks, a certain amount of manual checking and completion of the data was required. The most common of these was in checking the post codes for work place addresses and manually entering these if only the address had been given without a post code and also entering the age of the vehicles if only the registration letter had been given.

Urban form data were collected from the Office of National Statistics along with data on socio-demographics from the census available at output area and ward level as previously described. Urban Rural classifications were obtained from the Scottish Executive for current residential locations or previous locations in Scotland and determined using the method set out in Scottish Executive (2004) for previous residential locations in the rest of the UK. No previous urban form metrics were collected for residences outside of the UK due to a lack of easily accessible and comparable data sources.

3.4. Summary of Research Hypotheses and Methods.

Six case study areas were selected, three in Glasgow and three in Edinburgh to reflect a range of different urban forms found Scottish cities. Within each case study area, residential addresses were selected including a high proportion where a sale had taken place in the previous three year period. By selecting such addresses in the case study areas, data could then be collected that would enable the hypotheses of this study to be tested that Urban Form and Car Ownership have direct effects on Travel Behaviour and that Urban Form has direct effects on Car Ownership. The hypotheses were developed from a wider causal path model developed as a result of the review of findings in the literature. A mail out mail back survey was designed to capture travel behaviours, car ownership levels and socio-demographics at the current time and recalled from three years previously. Dimensions of urban form were specified based on the availability of data, findings from the literature and use to urban planners. Dimensions of travel behaviour and change in travel behaviour were specified in order to capture household travel by car for all journey purposes.

4. Descriptive Statistics

In this chapter the results of the data collection are presented and discussed. The response to the household survey is also shown. It should be borne in mind that the point of the study is not to describe the population of Scotland or the case study areas but to understand motivations behind behaviours of recent movers and non movers with regards to their travel behaviours and car ownership levels. If it were to describe the populations of the case study area or Scotland, then greater consideration would need to be made of the representativeness of the survey sample and weightings applied accordingly. The sample should be considered as representative of movers and home movers in the 6 case study neighbourhoods only. The implications for any conclusions drawn from this study are then discussed. The chapter then presents basic descriptive statistics regarding the urban form, travel behaviour and other data collected for the responding households. Some preliminary cross-tabulations are then presented and discussed which help to identify possible relationships between the data collected which is then tested in the multivariate statistical analyses presented in Chapter 5.

4.1. Survey Response Data

A total of 281 completed surveys were received representing a response rate of 12% after the 211 addresses where at least one of the letters was returned as address unknown were deducted from the total. Table 4.1 overleaf shows the sample population, the number of addresses where the survey or other mail outs were returned address unknown and the number of respondents in each of the 6 case study areas. Those addresses for which one of the mail-outs was returned "address unknown" were removed from the database for the following mail-out.

	Sample Population	Introduction Letter Returned to Sender	Survey Returned to Sender	Reminder Letter Returned to Sender	Respondents	Response Rate %
Glasgow Central	518	39	34	20	49	10.1
Glasgow Intermediate	514	57	52	49	71	15.4
Glasgow Outer	332	1	0	0	25	7.5
Edinburgh Central	264	24	6	13	46	17.8
Edinburgh Intermediate	522	59	53	45	50	11.2
Edinburgh Outer	346	0	0	0	40	11.6
SUM	**2496**	**180**	**145**	**127**	**281**	**12.0**

Table 4.1 Survey Response Data

The response rate varied from 7.5% in the Glasgow Outer case study area to 17.8% in the Edinburgh inner case study area. While the full reasons for the differences in response rates is not know, it is possible that the low response from the Glasgow Outer area could be due to the higher levels of vacant housing found in the area.

Given the burden involved in completing the survey and activity diary the response rate is within the range achieved in similar studies such as the 11% response achieved by Kitamura et al (1997) or 12.6% by Xing et al (2010), although admittedly towards the bottom of the range. The 280 responses is less, but still within the same order of magnitude as the 900 households that Cervero and Day (2008) based their current and retrospective recall study on, and greater than the 80 respondents used for a longitudinal travel study by Kenyon (2009). It should be noted that the various "rules of thumb" previously discussed that are used to help determine appropriate sample sizes for regression analyses of this kind suggest sample sizes of between 114 and 400 as a minimum. However, that the sample size is smaller than 400 does not necessarily mean that there is a lack of data as previously discussed. High unit and item non-response rates can be associated with two problems; representativeness and statistical power. The problem arises if there is an underlying reason for the lack of response which correlates with the answers that would be given. For example, the low response rate in this example might not be an issue if the reason for the non-response were that the respondents were too busy to respond as this would probably not be related to how the respondent's travel behaviour and car ownership are influenced by built form. Similarly, if fewer working age people responded compared to retired people, this would not cause a problem as this data is collected in the survey and hence accounted for. However, if the respondents did not wish to respond because they felt that there travel behaviours were excessive, given that they have many alternatives, the non-response would introduce bias into the data collected. To account for the item non-response it is possible that an explanatory model developed through regression analyses, could be used to predict the output for the item that was not responded to if a subsequent simulation of the total population were required, although this is not within the scope of this study. It should be noted that the questions in the survey were written to be as factual as possible and not emotive, to try to reduce the possibility of item non-response due to unobserved factors. The small response rate does however present the problem of larger standard errors in the regression modelling, which makes it more difficult for explanatory variables to be found to be significantly different from zero. Statistical methods are described in Chapter 5 which are suited to dealing with relatively small datasets of this kind with a 10% level of significance set as a threshold to reflect this smaller sample size.

While it is obvious that the characteristics of the respondents differ in some respects from those of the general population of Scotland the purpose of this research is not to try to simulate or explain the behaviour or car ownership of the population of Scotland. The purpose of this study is to investigate relationships between measures of urban form and travel behaviour or car ownership in the context of Scotland, with a focus on people who have moved home, which is a subtle but important difference. This aim is to understand the determinants of vehicle miles driven and car ownership and changes in both as a response to urban relocation. As such, it is important that a range of urban forms, travel behaviours and control factors are gathered. For example, it is important to have a good number of respondents living in a detached house if any analysis is to be undertaken of how living in a detached house relates to vehicle miles driven, regardless of whether or not a high proportion of residents of urban Scotland live in a detached house. These are then modelled as described in Chapter 5 to ascertain whether there is a statistically significant association between such measures, not in order to describe the overall behaviour of the Scottish population.

The following two tables (4.2 and 4.3) present descriptive statistics on variables collected in the household survey or, where shaded, have been imputed from other data sources as described. This gives an indication of the range, spread, frequencies and counts for those variables relevant to this study, data collected for other analyses not presented here are omitted.

Variable Name (question)	Response Categories	Count	%
Current Accommodation (Q. A1)	Detached	29	10.7%
	Semi-detached	35	12.9%
	Terraced	21	7.7%
	In a tenement	94	34.7%
	In a purpose built block of flats	70	25.8%
	Part of a converted or shared house	15	5.5%
	In a commercial building	7	2.6%
Previous accommodation (Q. A8)	Detached house	44	16.9%
	Semi-detached house	34	13.0%
	Terraced house	30	11.5%
	Flat, maisonette or apartment	153	58.6%
Previous Urban Rural Class (Q.A8)	Large Urban Areas Pop> 125,000	212	84.8%
	Other Urban Areas Pop 10,000 to 125,000	19	7.6%
	Accessible Small Town Pop 3,000 to 10,000	4	1.6%
	Remote Small Town Pop 3,000 to 10,000	0	.0%
	Accessible Rural	6	2.4%
	Remote Rural	3	1.2%
	Greater London	6	2.4%
Movers (Q. A8)	Non-movers	95	35.6%
	Movers	172	64.4%
Current Car Ownership (Q. C1)	None	67	24.9%
	One	145	53.9%
	Two	51	19.0%
	Three or more	6	2.2%
Previous car ownership (Q. C3)	None	69	25.9%
	One	132	49.6%
	Two	54	20.3%
	Three or more	11	4.1%
Gender (Q. F1)	Male	109	40.7%
	Female	159	59.3%
Current Employment Status (Q. D1)	Employed, full time	150	56.4%
	Employed, part time	31	11.7%
	Self employed/freelance	12	4.5%
	Unemployed/seeking work	9	3.4%
	Retired	47	17.7%
	Looking after family/home	4	1.5%
	Full time student at college or university	5	1.9%
	Long term sick or disabled	7	2.6%
	Other	1	0.4%

Variable Name (question)	Response Categories	Count	%
Previous Employment Status (Q. D9)	Employed, full time	146	55.9%
	Employed, part time	27	10.3%
	Self employed/freelance	13	5.0%
	Unemployed/seeking work	6	2.3%
	Retired	34	13.0%
	Looking after family/home	7	2.7%
	Full time student at college or university	24	9.2%
	Long term sick or disabled	4	1.5%
Household Composition (Q. F4)	Married/ cohabiting couple with children <16	47	17.7%
	Married/ cohabiting couple with children >16	13	4.9%
	Lone parent with children <16	8	3.0%
	Lone parent with children >16	6	2.3%
	Two or more adults living together unrelated	14	5.3%
	Other	3	1.1%
Household Income (Q. F7)	Nil	6	2.4%
	Up to £10,399	23	9.4%
	£10,400 to £15,599	23	9.4%
	£15,600 to £20,799	25	10.2%
	£20,800 to £25,999	21	8.6%
	£26,000 to £31,199	22	9.0%
	£31,200 to £51,999	68	27.8%
	£52,000 or more	57	23.3%
Age of Respondent (Q. F2)	16 – 24	21	7.8%
	25 - 34	75	28.0%
	35 – 44	61	22.8%
	45 – 54	45	16.8%
	55 – 64	29	10.8%
	65 +	37	13.8%
Current Car Ownership (Q. C1)	None	67	24.9%
	1	145	53.9%
	2	51	19.0%
	3 or more	6	2.2%
Previous Car Ownership (Q. C3)	None	69	25.9%
	1	132	49.6%
	2	54	20.3%
	3 or more	11	4.1%
Change in Distance Driven (Q. C10)	A lot less	66	25.4%
	A little less	34	13.1%
	About the same	100	38.5%
	A little more	25	9.6%
	A lot more	35	13.5%

Table 4.2 Frequency Table of Categorical Data

All variables shown in Table 4.2 are taken directly from the survey except the Previous Urban Rural Classification (shaded grey), which was computed from any previous address stated in the survey and the Urban Rural classifications already described in Section 3.3.3. The questions in the survey to which the variable relate are shown in parentheses. A copy of the questionnaire used can be seen in Appendix F. For most categorical variables there is a good range of responses, which is required in order to carry out analyses that uncover the determinants or a change in distance driven and car ownership; however, there are some categories of responses to which there are few responses. Only 7 respondents reported living in part of a commercial building, 6 respondents reported paying part rent and part mortgage, 3 respondents lived rent free and 6 respondents had access to three or more cars. In terms of the current employment status there were few people who reported being unemployed, looking after family, being a full time student, being long term sick or disabled or "other". In terms of household composition, few respondents reported being a lone parent with children either less than or greater than 16 years of age and only 3 respondents described their household composition as "other". Previous urban rural classifications were primarily large urban areas and other urban areas. Having few respondents to each of the categories mentioned makes it difficult to determine associations between these variables and vehicle miles driven and car ownership. Solutions to such problems include re-categorising variables or exclusion of some instances from the analysis.

Similarly, not only is there little variability in the response to a small number of questions, it can be seen that the number of people responding to each question differs. The issue of missing data is important. There were only 83 respondents for whom a full set of data as described in Tables 4.2 and 4.3 was available due to non-response to one or more question in the survey. The descriptive statistics included in Appendix H, give more detail as to those questions less frequently answered. It is important to consider whether there were underlying reasons behind groups of questions not being answered that might affect any subsequent analysis. In this instance, there appears to have been a certain level of fatigue in answering questions, with those included later in the survey having slightly lower response rates. Also, questions which required some degree of recall, or information perhaps not directly to hand, such as post codes of former workplaces, also appear to have slightly lower response rates. It was therefore felt that there were no underlying reasons why groups of answers would not be given that might relate to the travel behaviour or urban form of the respondent. In this case, the missing data are omitted. These issues are discussed in more detail in Chapter 5, Analysis.

Variable	Mean	Maximum	Median	Minimum	Standard Deviation	Count
Current Output Area density (no. of resident per hectare)	104.85	801.84	61.37	2.57	104.67	281
Previous Output Area density (no. of residents per hectare)	108.80	801.84	64.86	.01	119.11	281
Change in Output Area Density (current minus previous)	-3.81	772.9	0.00	-705.7	129.86	250
Current Ward density (no. of residents per hectare)	48.43	143.47	40.62	16.96	25.87	281
Previous Ward density (no. of residents per hectare)	48.36	143.47	40.62	.06	31.96	281
Change in Ward density (current minus previous)	0.6392	128.60	0.00	-97.53	29.09	250
Distance to current centre (m)	3133	8742	2591	0	2258	281
Distance to previous centre (m)	3865	110115	2859	0	7341	281
Change in distance to centre (current minus previous)	-712.65	8729	0.00	-107275	7304	250
Current jobs:pop ratio	1.1044	11.8729	.3065	.1553	2.3435	281
Previous jobs:pop ratio	.6542	11.8729	.3065	.1049	1.3489	281
Change in jobs:pop ratio (current minus previous)	0.350	11.74	0.00	-11.65	2.33	250
Network distance from current address to current work place (km) (Q D3)	8.17	170.59	2.90	.00	16.90	281
Network distance from previous address to previous work place (km) (Q D10)	11.17	170.59	4.02	.00	21.80	281
Change in dist to work (current minus previous); (Q D3, D10)	-2.46	92.22	0.00	-79.66	16.46	209
How many people normally live at this address? (Q F5)	2	16	2	1	1	281
Total household distance driven (miles per anum) (Q C2)	9043	150000	6000	0	16179	281

Table 4.3 Frequency Table of Continuous & Count Data

Table 4.3 describes the spread of continuous and count data collected either directly from the survey or computed from the response to the survey and other data sources. Those variables shaded grey have been computed from the survey response and other data sources. The urban form variables were computed using the unique survey ID that was printed on each questionnaire. The survey ID enabled the postcode of the respondent's current address to be linked to the response. Using the postcode, census data for the respondent was then computed. Output Area and Ward density were taken from the census Output Area or Ward in which the post code of the residential address was situated, similarly for the previous residential location. Jobs to population ratios were taken from the census data for the ward in which the residential location was situated and was calculated as the number of jobs divided by the residential population. Network distance from current address to current work place was computed from the post code of both locations and Google Maps, similarly for previous residential locations and work places and distances to current and previous urban centres. Total annual distance driven by the household is calculated by summing the self reported annual mileage of all vehicles owned by the household from the survey. For each of the variables there is a large range as required for the analysis. It is important to present this information as no conclusions can be sensibly drawn about circumstances outside of these ranges of data. For example, the maximum distance to current urban centre included in the dataset is 8,742m. It would therefore not be sensible to draw any conclusions about the likely effect of residing more than 8,742m from an urban centre. Outliers are considered in Chapter 5, Analysis.

Appendix H contains more detailed descriptive statistics of the responses to each individual question from the household survey however, it is useful to consider the two variables being described by this study in more detail; car ownership, household distance driven, and change in both.

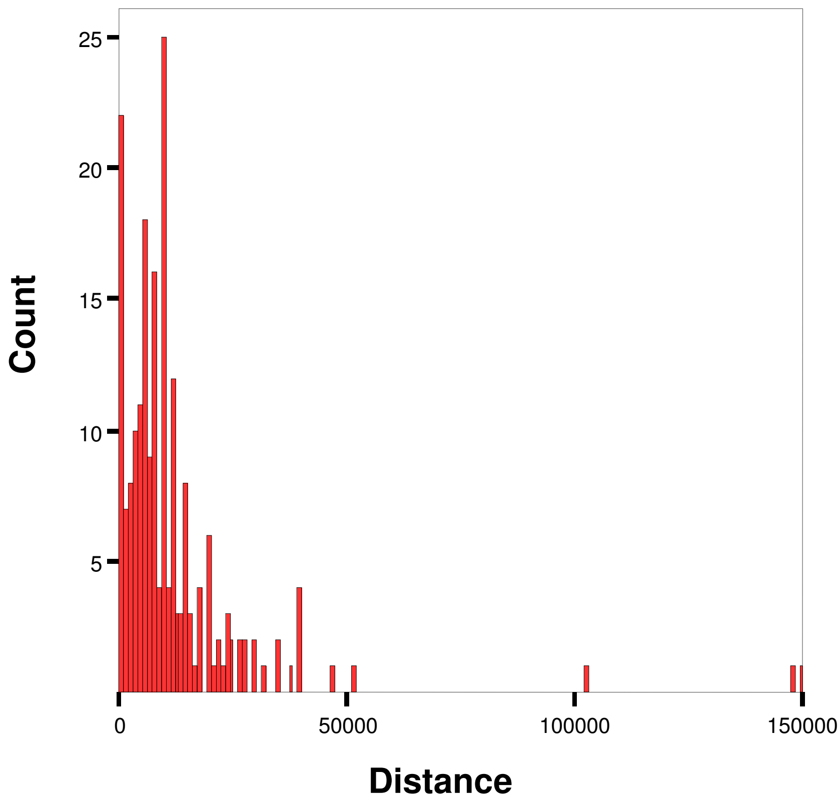

Figure 4.1 Distribution of Total Household Distance Driven (miles per annum)

Figure 4.1 shows the distribution of annual distance driven at the household level and includes households who owned no cars and hence drove zero miles. Of those households that owned or had access to a car the annual distance driven followed a positively skewed bell shape with a long tail to the positive end of the range. While the shape of the distribution is similar for movers and non-movers, the annual household distance driven for those who had relocated within the previous three years (movers) was higher than those who had not relocated (non-movers). The median for the movers was 7,000 miles per anum (mean of 9,993 miles per anum) compared to a median of 5,000 miles per anum for non-movers (mean of 8,431). The inter-quartile range for movers was higher than that of non movers (12,000 compared to 10,000 miles per anum). However, these differences were largely due to the higher car ownership levels of the movers subsample. Considering only those households who owned or had access to a car and hence reported any distance driven, the median for the movers was 9,000 miles per anum (mean of 13,575 miles per anum) compared to a median of 10,000 miles per anum for non-movers (mean of 13,974). The inter-quartile range for both movers and non movers 9,000 miles per anum.

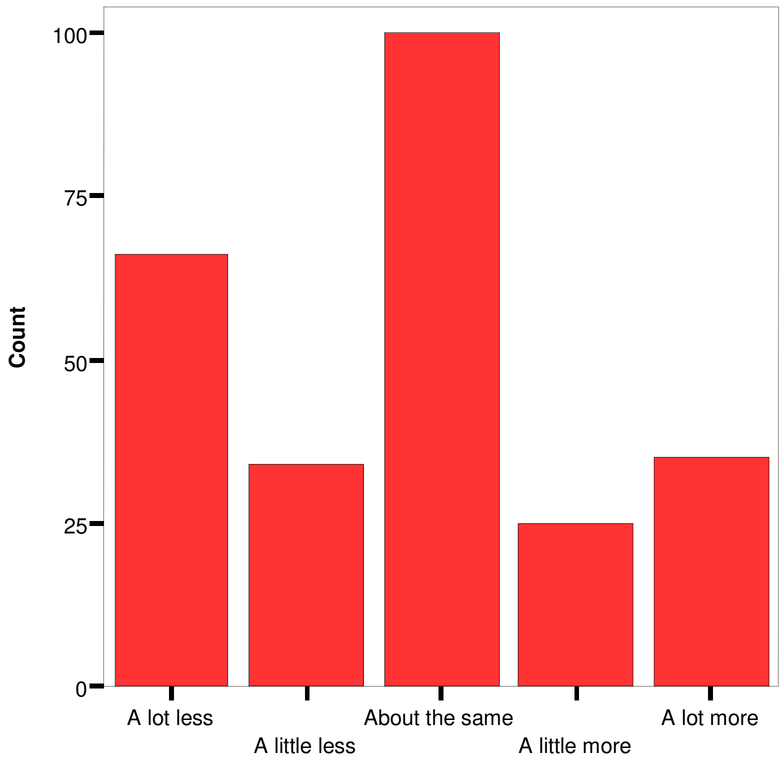

Figure 4.2 Distribution of reported change in distance driven by the respondent.

The reported change in distance driven relates to the respondent only and not to the household. The question that the respondent answered was, "Compared to the end of 2002, how much do you use a car as the driver or passenger at the moment? (Exclude taxis)". The phrasing of the question raises issues as to how the respondent may have comprehended the question. The intention was to gain information on how distance driven had changed over time, but it is possible that the respondent could have interpreted the question to mean how frequently they drive. Also, the ability of the respondent to recall or judge how their distance driven had changed is likely to be imperfect. The current distance driven asks for annual mileage to be specified for all cars owned or available to the household, which is felt to be relatively easy to recall or judge, however the ability of the respondent to recall these figures or judge a change in distance driven is less reliable. It should therefore be borne in mind that the subsequent longitudinal analyses presented in Chapter 5 relate to the perceived change in car use for the respondent.

As can be seen from Figure 4.2 there is no strong pattern of distribution of the reported change in distance driven. A large number of respondents reported no change in the distance driven and more respondents reported a reduction in distance driven than an increase. A higher proportion of non-movers reported to have reduced their car use either a little or a less (43%) than movers (35%). Conversely, fewer non-movers reported an increase in car use, either a little or a lot, (14%) compared to movers (29%). The most common response for both non-movers and movers was that their car use had remained about the same (43% and 36% respectively).

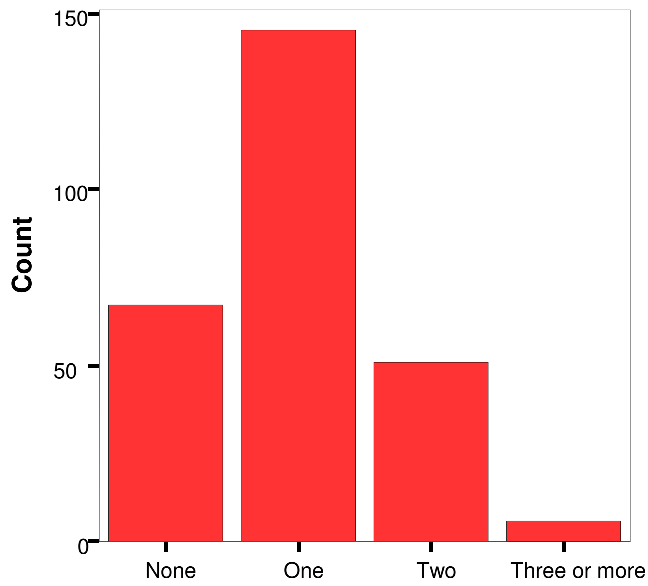

Figure 4.3 Distribution of Household Car Ownership.

As can be seen in Figure 4.3 the current household car ownership followed a Poisson shaped distribution with the most common level of car ownership being one car per household (54%). The mean household car ownership was slightly lower for non-movers (1.96) compared to movers (2.02) as a higher proportion of non-movers had no cars available to them (28%) compared to movers (22%).

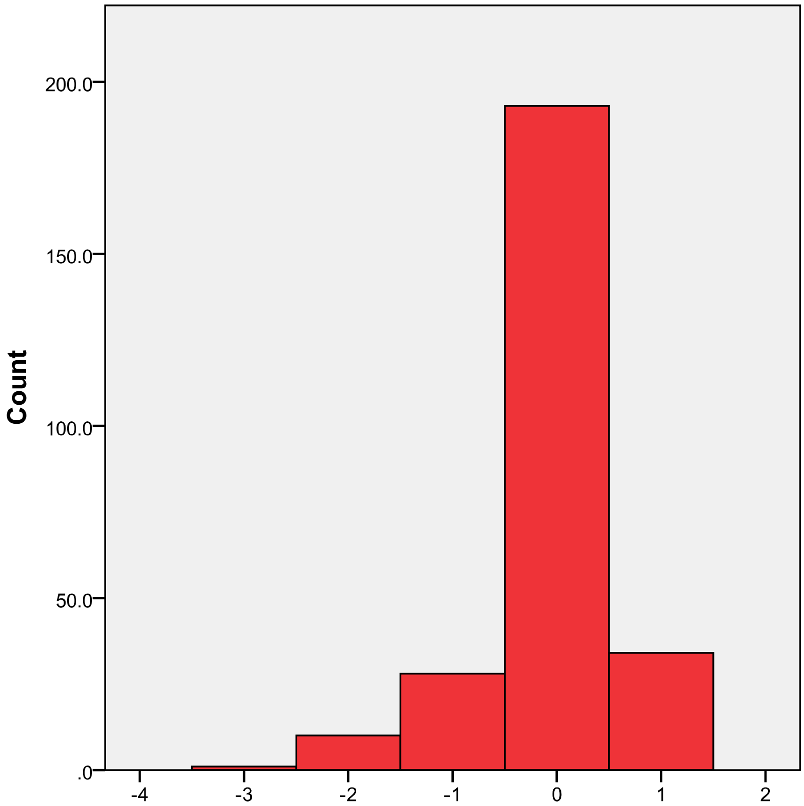

Figure 4.4 Distribution of Change in Car Ownership.

The distribution of change in household car ownership showed that the majority of household (73%) had the same number of cars available to them as they had three years previously (Figure 4.4). A similar number had either increased or decreased their car ownership level over the same time period. Ten households had reduced their car ownership by two and one household had three fewer cars than three years previously. A difference emerges between movers and non movers. Although movers had a slightly higher level of car ownership than non movers, on average they had reduced their car ownership level by 0.11 cars, whereas non movers on average had increased their car ownership by 0.02 cars. 18% of movers had reduced their level of car ownership, compared to 8% of non-movers.

4.2. Correlation Matrices

The descriptive statistics presented in the previous section and in Appendix H do not give any indications of possible associations between any variables. Accordingly this section examines correlations between responses to some key urban form and travel behavioural variables in order to gauge which explanatory factors might best describe travel behaviours, car ownership levels and changes in both. It also helps to give some indication of the best geographies over which urban form might be defined in the subsequent analysis.

Tables 4.4 to 4.7 following, give an indication of the associations between various pairs of variables. Through producing such correlation matrices it is possible to highlight likely associations that can be tested through the subsequent analyses presented in Chapter 5. It should be noted that the Pearson Correlation statistic assumes a linear relationship between two normally distributed variables, which may not be the case for each pair of variables presented. If the two variables are not normally distributed, the Pearson Correlation statistic is likely to exaggerate any correlation. The correlations are described in four tables to firstly demonstrate correlations between pairs of urban form variables, secondly to show correlations between pairs of socio-demographic variables, thirdly to show correlations between dependent variables and lastly to show correlations between key variables from all three groups. It should be noted that all correlations shown are pairwise correlations (with pairwise removal of missing data) and as such do not control for any other variables; thus any correlations may be spurious or indeed associations may exist between pairs of variables if other variables are controlled for. The matrices are presented to give an indication of the correlation and to help inform the subsequent analysis only.

Variable	Statistic	Current accom type	Distance to work	Output area density	Ward density	Distance to urban centre	Jobs:population ratio
Current accom type	Pearson Correlation	1	-.072	.158**	.251**	-.563**	.244**
	Sig. (2-tailed)		.266	.009	.000	.000	.000
	N	271	243	271	271	271	271
Distance to work	Pearson Correlation	-.072	1	-.057	-.080	-.024	-.080
	Sig. (2-tailed)	.266		.376	.214	.711	.212
	N	243	243	243	243	243	243
Output area density	Pearson Correlation	.158**	-.057	1	.470**	-.308**	-.079
	Sig. (2-tailed)	.009	.376		.000	.000	.189
	N	271	243	281	281	281	281
Ward density	Pearson Correlation	.251**	-.080	.470**	1	-.383**	-.200**
	Sig. (2-tailed)	.000	.214	.000		.000	.001
	N	271	243	281	281	281	281
Distance to urban centre	Pearson Correlation	-.563**	-.024	-.308**	-.383**	1	-.387**
	Sig. (2-tailed)	.000	.711	.000	.000		.000
	N	271	243	281	281	281	281
Jobs:population ratio	Pearson Correlation	.244**	-.080	-.079	-.200**	-.387**	1
	Sig. (2-tailed)	.000	.212	.189	.001	.000	
	N	271	243	281	281	281	281

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4.4 Correlation Matrix for Current Urban Form Variables.

Table 4.4 is useful in the detection of colinearity amongst explanatory urban form variables at residents' current addresses. Distance to work is included here for completeness although is not, as such, a direct measure of urban form. Those correlations significant at the 1% level are highlighted by means of a double asterisk. There were no correlations significant at the 5% level that were not also significant at the 1% level. As can be seen on in Table 4.4, there is a high degree of correlation between each pair of urban form variables except for urban form variables paired with distance to work. The only other pairing of urban form variables that are not correlated are the jobs to population ratio and output area density. The high degree of correlation is not unexpected given the discussion of urban form measures presented in section 2.5.

Variable	Statistic	Current Employment Status	Gender	Age	Household Structure	N° in household	Household income	Change in household income
Current employment status	Pearson Correlation	1	-.053	.495**	-.037	-.088	-.555**	-.372**
	Sig. (2-tailed)		.396	.000	.555	.160	.000	.000
	N	266	263	263	262	259	242	251
Gender	Pearson Correlation	-.053	1	-.098	.083	.010	-.055	.112
	Sig. (2-tailed)	.396		.110	.178	.873	.394	.075
	N	263	268	268	266	264	245	255
Age	Pearson Correlation	.495**	-.098	1	-.132*	-.002	-.244**	-.240**
	Sig. (2-tailed)	.000	.110		.031	.972	.000	.000
	N	263	268	268	266	264	245	255
Household structure	Pearson Correlation	-.037	.083	-.132*	1	.536**	.100	-.031
	Sig. (2-tailed)	.555	.178	.031		.000	.118	.628
	N	262	266	266	266	262	244	253
N° in household	Pearson Correlation	-.088	.010	-.002	.536**	1	.143*	-.069
	Sig. (2-tailed)	.160	.873	.972	.000		.027	.275
	N	259	264	264	262	264	241	252
Household income	Pearson Correlation	-.555**	-.055	-.244**	.100	.143*	1	.318**
	Sig. (2-tailed)	.000	.394	.000	.118	.027		.000
	N	242	245	245	244	241	245	241
Change in household income	Pearson Correlation	-.372**	.112	-.240**	-.031	-.069	.318**	1
	Sig. (2-tailed)	.000	.075	.000	.628	.275	.000	
	N	251	255	255	253	252	241	255

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4.5 Correlation Matrix for Current Socio-Demographics.

Table 4.5 shows that there was correlation between some of the socio-demographic variables. Gender of the respondent was not correlated with any other socio-demographic variable. Current employment status had a correlation of large magnitude with age, household income and change in household income. Age was negatively associated with household structure, household income and change in household income. Household structure was highly correlated with the number of people within the household by definition. The number of people within the household was correlated with household income and the current reported household income was correlated with change in income as expected.

Variable	Statistic	Current household car ownership	Previous household car ownership	Total Household Distance Driven	Respondent change in car use
Current household car ownership	Pearson Correlation	1	.644**	.405**	.186**
	Sig. (2-tailed)		.000	.000	.003
	N	269	266	269	258
Previous household car ownership	Pearson Correlation	.644**	1	.308**	-.082
	Sig. (2-tailed)	.000		.000	.193
	N	266	266	266	256
Total household distance driven	Pearson Correlation	.405**	.308**	1	.107
	Sig. (2-tailed)	.000	.000		.084
	N	269	266	281	260
Reported change in car use	Pearson Correlation	.186**	-.082	.107	1
	Sig. (2-tailed)	.003	.193	.084	
	N	258	256	260	260

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4.6 Correlation Matrix for Travel Behaviour & Car Ownership.

As can be seen in Table 4.6, a large number of the car ownership and travel behaviour measures were correlated. Current and previous household car ownership and total distance driven by the household are all positively correlated to one another as expected. However, the reported change in car use measured from one being “a lot less” to five being “a lot more” is only correlated with current household car ownership as expected, with households having a higher level of car ownership more likely to have reported an increase in driving. This is perhaps expected as the first three variables relate to the household, whereas change in car use is related to the respondent only.

Variable	Statistic	Current Household Car Ownership	Total household distance driven	Current jobs:pop ratio	Distance to current urban centre	Current Output Area density	Current Ward density	Household income	Current accommodation type
Current Household Car Ownership	Pearson Correlation	1	.405**	-.205**	.215**	-.249**	-.199**	.494**	-.248**
	Sig. (2-tailed)		.000	.001	.000	.000	.001	.000	.000
	N	269	269	269	269	269	269	243	268
Total household distance driven	Pearson Correlation	.405**	1	-.087	.012	-.050	-.034	.267**	-.045
	Sig. (2-tailed)	.000		.148	.845	.402	.574	.000	.463
	N	269	281	281	281	281	281	245	271
Current jobs:pop ratio	Pearson Correlation	-.205**	-.087	1	-.387**	-.079	-.200**	-.018	.244**
	Sig. (2-tailed)	.001	.148		.000	.189	.001	.784	.000
	N	269	281	281	281	281	281	245	271
Distance to current urban centre	Pearson Correlation	.215**	.012	-.387**	1	-.308**	-.383**	-.045	-.563**
	Sig. (2-tailed)	.000	.845	.000		.000	.000	.483	.000
	N	269	281	281	281	281	281	245	271
Current Output Area density	Pearson Correlation	-.249**	-.050	-.079	-.308**	1	.470**	-.202**	.158**
	Sig. (2-tailed)	.000	.402	.189	.000		.000	.001	.009
	N	269	281	281	281	281	281	245	271
Current Ward density	Pearson Correlation	-.199**	-.034	-.200**	-.383**	.470**	1	-.113	.251**
	Sig. (2-tailed)	.001	.574	.001	.000	.000		.078	.000
	N	269	281	281	281	281	281	245	271
Household income	Pearson Correlation	.494**	.267**	-.018	-.045	-.202**	-.113	1	-.093
	Sig. (2-tailed)	.000	.000	.784	.483	.001	.078		.145
	N	243	245	245	245	245	245	245	245
Current accommodation type	Pearson Correlation	-.248**	-.045	.244**	-.563**	.158**	.251**	-.093	1
	Sig. (2-tailed)	.000	.463	.000	.000	.009	.000	.145	
	N	268	271	271	271	271	271	245	271

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4.7 Correlation Matrix of Key Variables.

Table 4.7 shows the correlation of the urban form variables that have most frequently been shown to be important in the literature with car ownership and distance driven, for the current household location. As can be seen in Table 4.7, household car ownership is correlated with distance driven, household income and all urban form variables presented in the expected directions. Household distance driven however only appears correlated to household car ownership and household income. No urban form variables appear correlated to household distance driven. This may indicate that urban form influences distance driven through the intermediary of car ownership decisions.

A full matrix of correlations between all variables is included in Appendix I. The correlations presented, although based on assumptions of normality and linear relationships, help inform the specification of models included in the following chapter. However, in order to examine the pairwise correlations further it is useful to present bi-variate plots in order to explore the nature of the apparent correlation between the variables. The following sections compare firstly, urban form metrics with current travel behaviour and car ownership levels and also change in urban form metrics with change in travel behaviours and car ownership levels. Only population density as previously described is used as a measure of urban form in this instance being the measure of urban form most commonly associated with travel behaviour in the literature. While these cross tabulations do not prove any associations, they give a useful indication as to whether or not associations might be found and at what geography. They also help to demonstrate the spread of data between two variables useful in the interpretation of any results. Depending on the type of data (categorical, scale and the number of categories) some cross tabulations are presented in graphical form.

In order to determine whether or not the associations are linear, the following cross tabulations are then considered.

4.2.1. Density and Vehicle Distance Driven

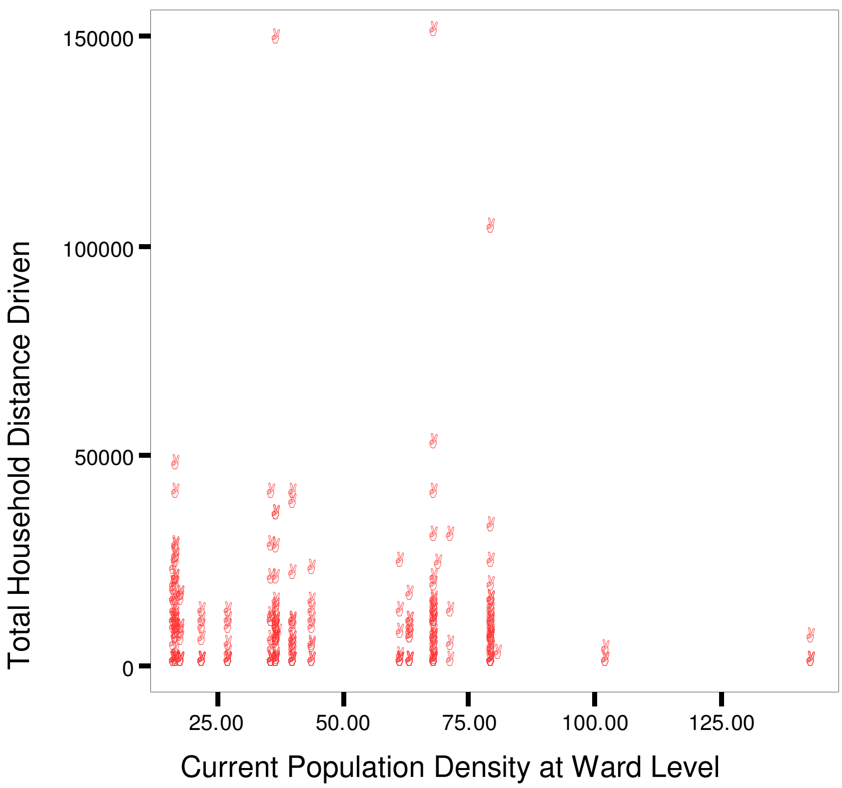

Figure 4.5 Ward Density (people per hectare) – Distance Driven (Household annual kms) for all survey respondents.

From Figure 4.5 it is difficult to identify any strong relationships, however it does appear that there may be a trend for higher density areas to have lower vehicle miles driven. By using the ward level data, it does limit the data to a few categories of density due to the sampling framework being constrained to case study areas.

Three households who reported travelling more than 100,000 miles per anum were identified. The way in which outliers are dealt with is discussed further in Chapter 5 however it should be recognised that outliers are important as they can have a large affect on any regression analyses undertaken. Fitting any sort of best fit line to the data when there are few extreme values can cause the best fit line to poorly reflect the bulk of data that is not extreme. When these extreme values refer to only a few cases, it is important to consider how confident one is in the accuracy of those values. In this instance the density is taken from the census and is hence highly reliable. Distance driven is self reported and hence less reliable and as such it should be considered whether these respondents should be excluded from the analyses presented in Chapter 5.

Figure 4.6 shows the same comparison but measured at the output area level. The data appears less clustered at particular levels of density due to the smaller size of the output area compared to the ward. This evidence lends support to the hypothesis that there is a negative relationship between population density and total household distance driven.

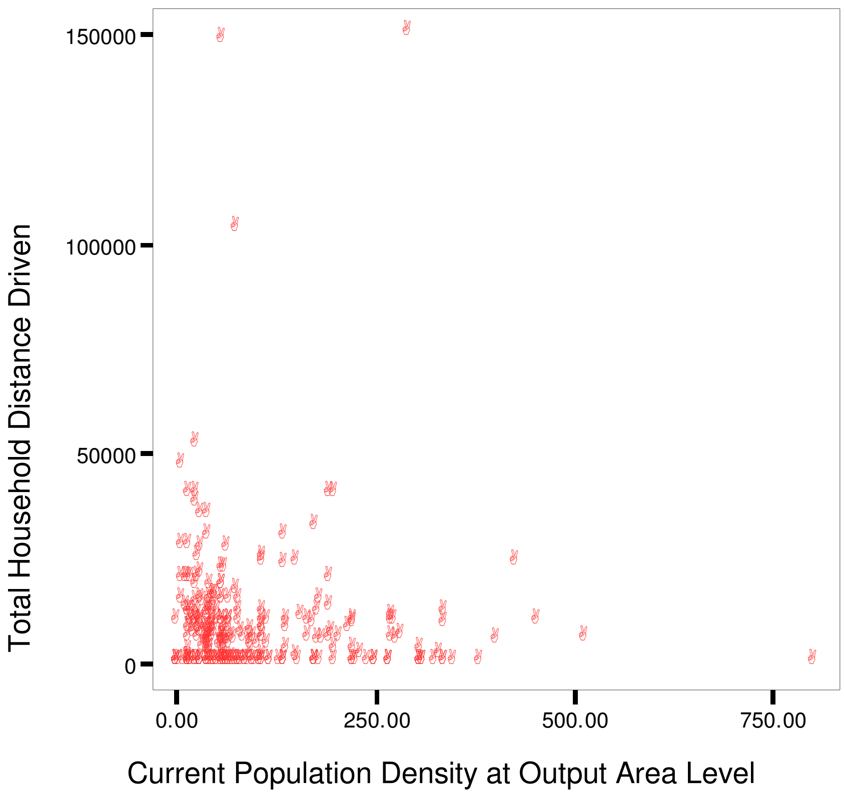

Figure 4.6 Output Area (people per hectare) – Distance Driven (Household annual kms) for all survey respondents.

4.2.2. Change in Density and Change in Vehicle Miles Driven

Initial inspection of the respondents' reported change in driving was undertaken for those people who had moved home. The Figures 4.7 to 4.16 show the previous and current residential density of these "movers" broken down by their reported change in car use. Those points above the y=x line represent respondents who have moved to a higher density area, those on the y=x line represent those who have moved to an area of equal density and those below the y=x line represent those who have moved to a lower density area. Initially, density measured at the Output Area level is presented followed by graphs with density presented at the Ward level. The numbers shown in boxes at the top left and bottom right of each chart summarise the numbers above and below the y=x line. By presenting the data in this way, it is not only possible to begin to explore how change in residential density varies with reported change in vehicle miles driven but also whether it is a move from a very low density to medium density or from a medium density to very high density that might be the most useful move in terms of reducing vehicle miles driven.

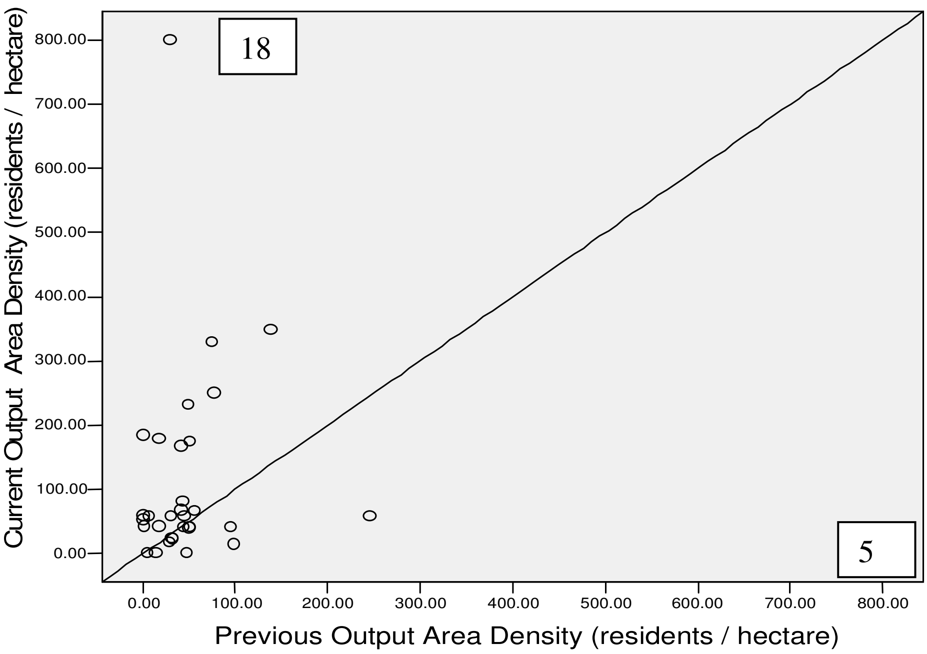

Figure 4.7 Plot of current population density against previous population density at Output Area level for respondents reporting that they "Drive a lot less".

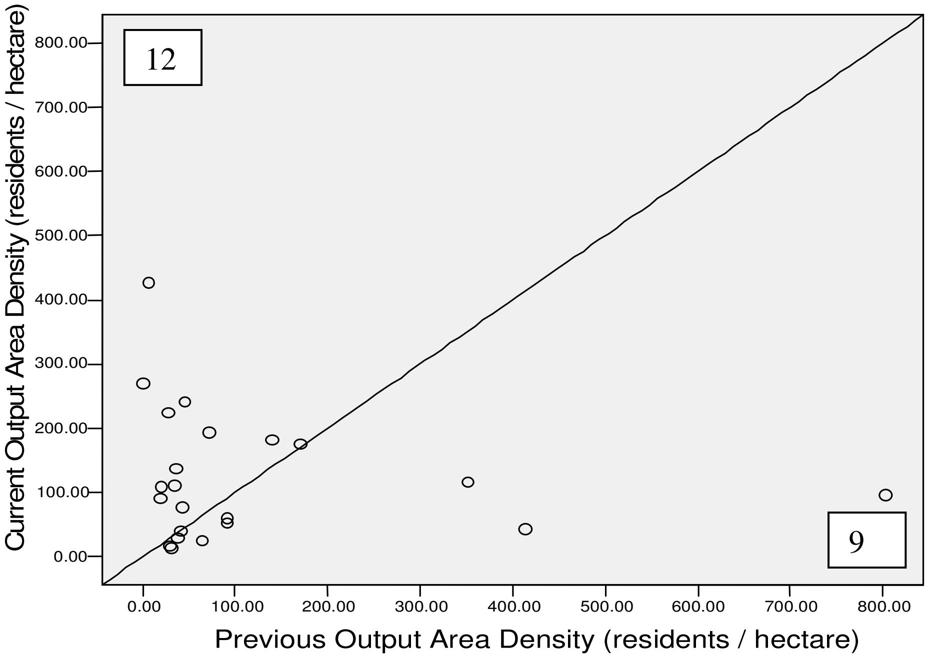

Figure 4.8 Plot of current population density against previous population density at Output Area level for respondents reporting that they “Drive a little less”.

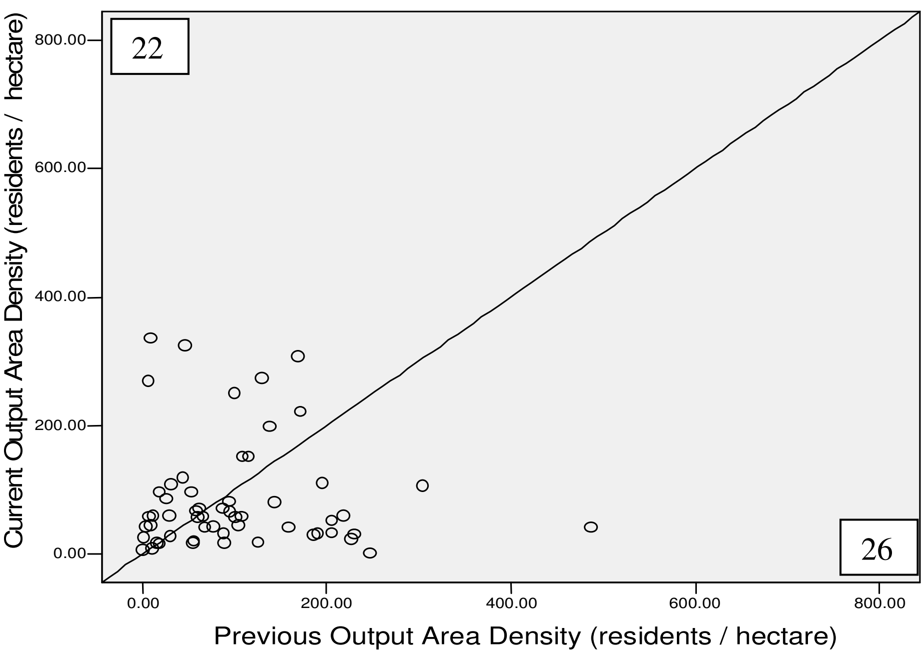

Figure 4.9 Plot of current population density against previous population density at Output Area level for respondents reporting that they “Drive about the same”.

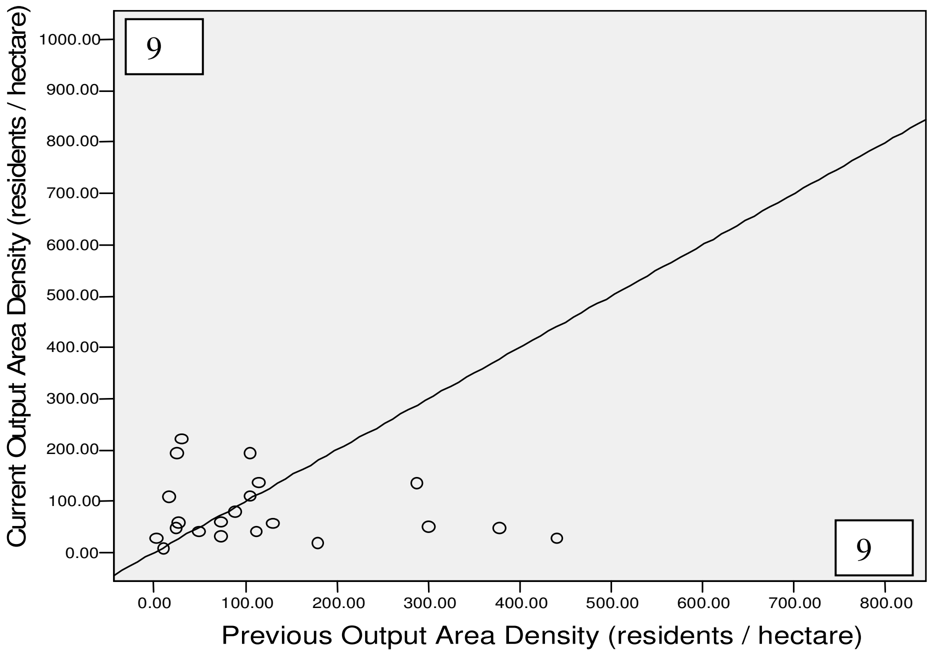

Figure 4.10 Plot of current population density against previous population density at Output Area level for respondents reporting that they “Drive a little more”.

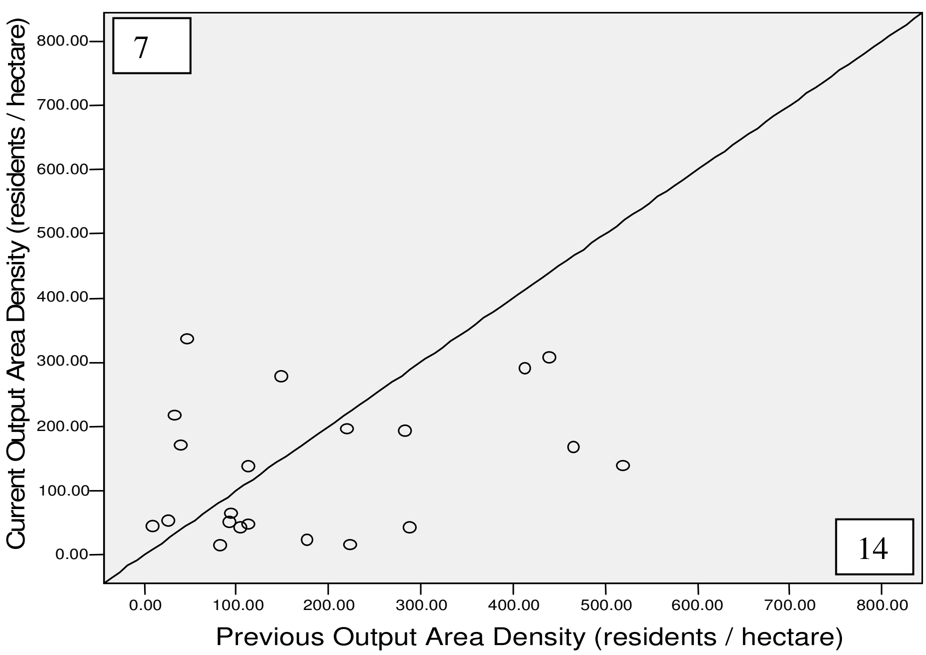

Figure 4.11 Plot of current population density against previous population density at Output Area level for respondents reporting they “Drive a lot more”

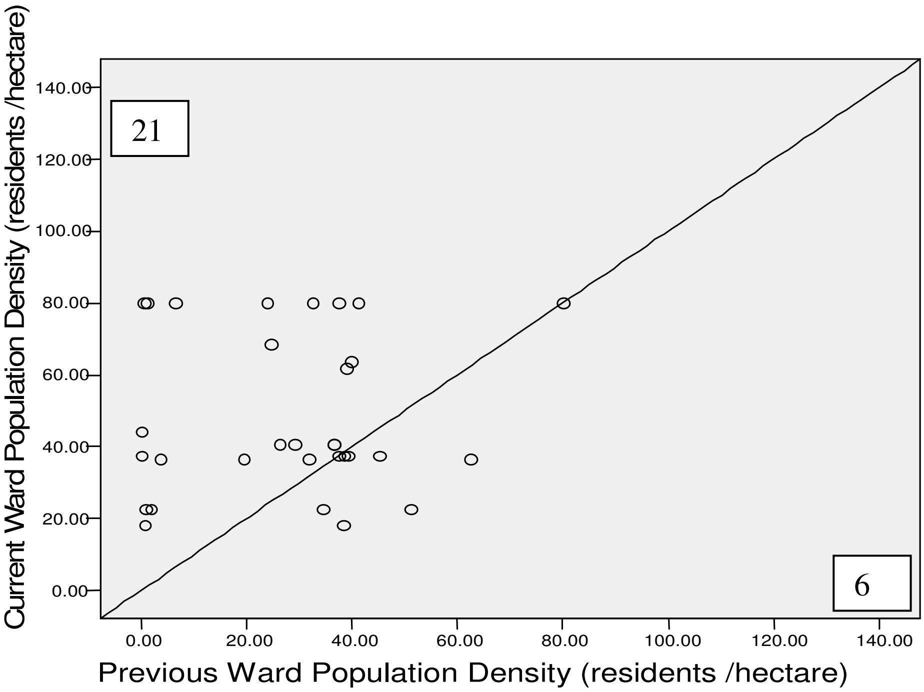

Figure 4.12 Plot of current population density against previous population density at Ward level for respondents reporting that they "Drive a lot less".

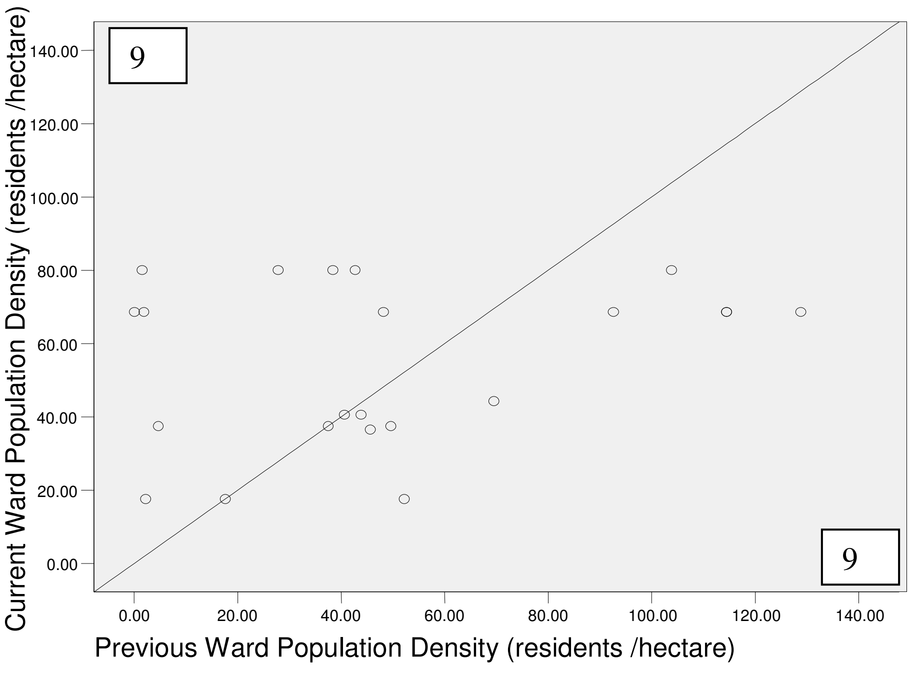

Figure 4.13 Plot of current population density against previous population density at Ward level for respondents reporting that they "Drive a little less".

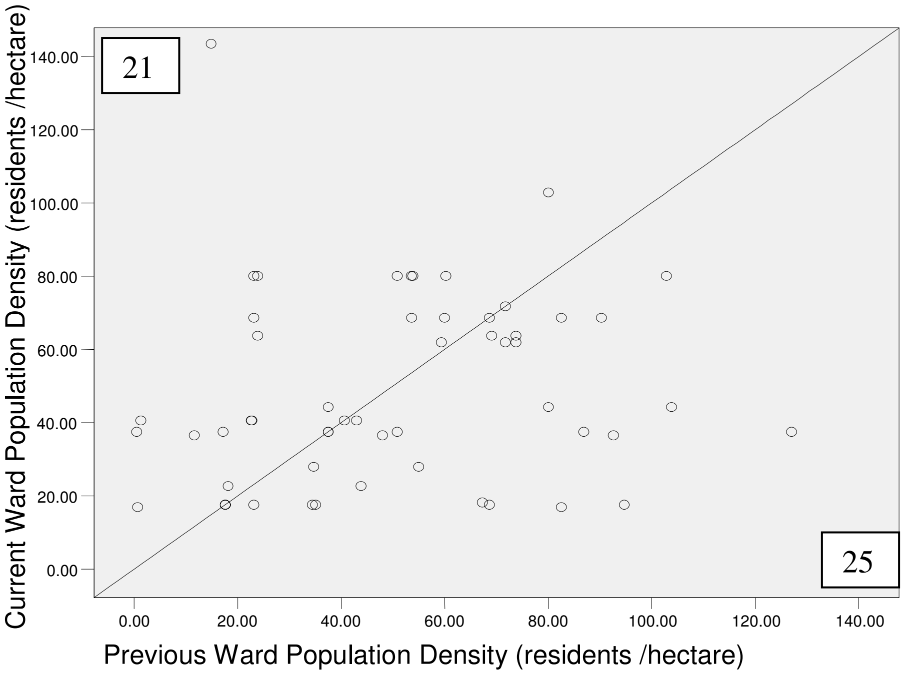

Figure 4.14 Plot of current population density against previous population density at Ward level for respondents reporting that they “Drive about the same”.

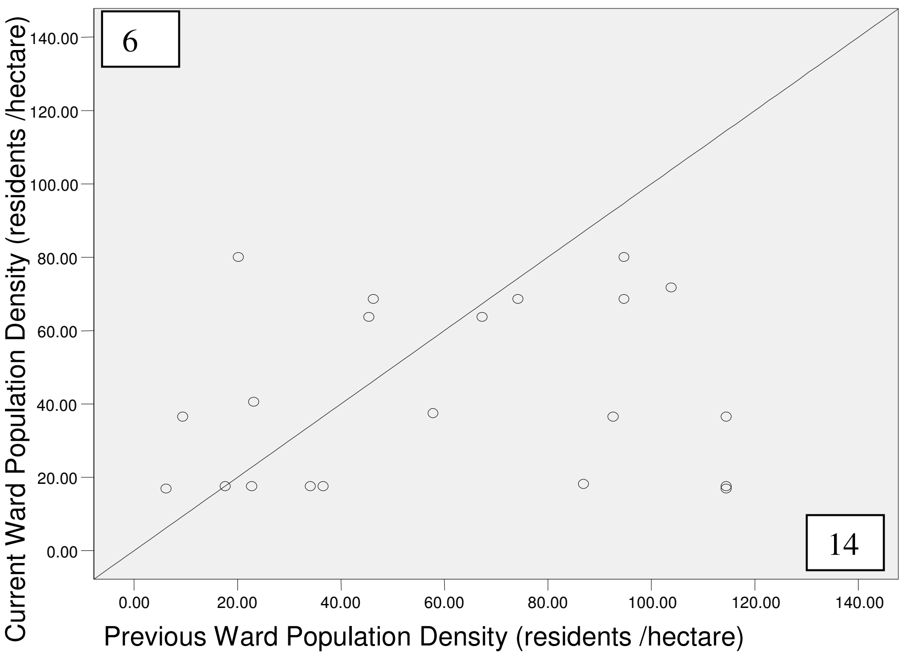

Figure 4.15 Plot of current population density against previous population density at Ward level for respondents reporting that they “Drive a little more”.

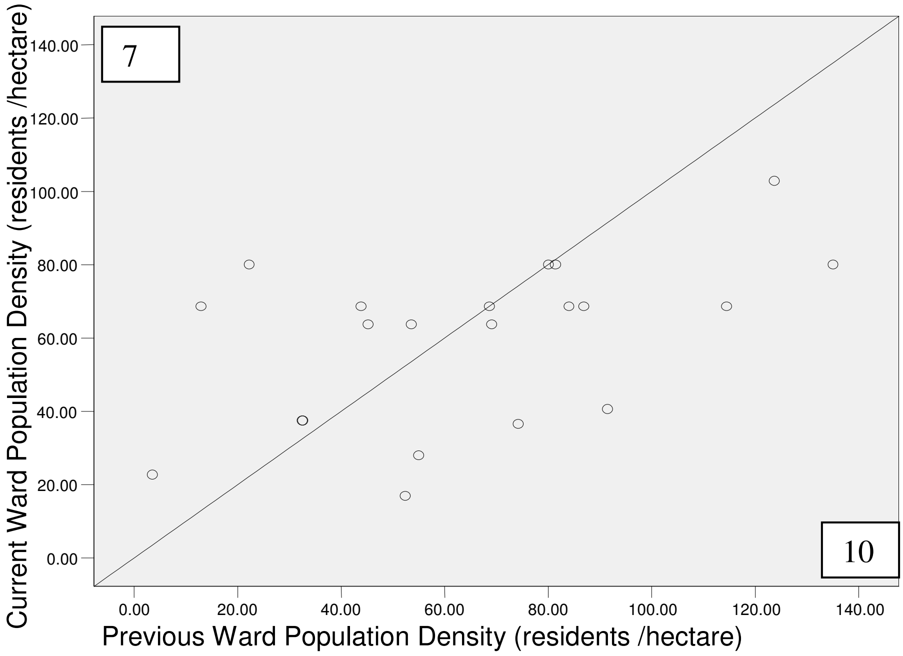

Figure 4.16 Plot of current population density against previous population density at Ward level for respondents reporting that they "Drive a lot more".

As can be seen from Figures 4.4 to 4.16, it does appear that those respondents who reported that they drove a little or a lot less in 2006 compared to the end of 2002 were more likely to have moved to a higher density area (above the y = x line). In contrast, those who reported that they drove a little or lot more tended to have moved to a lower density area (below the y = x line). This result appears to hold true at both the Ward level and the Output Area level.

Of those who stated that they now drove a lot less:

- At an output area level 61% had moved to a higher density output area, 3% had no change in output area density and 36% had moved to a lower density output area.

- At a ward level 71% had moved to a higher density ward, 6% had no change in ward density and 23% had moved to a lower density area.

This suggests that an increase in residential density, particularly when measured at the ward level is associated with a reduction in the use of the car, which is explored in more detail in the multivariate analysis presented in Chapter 5.

4.2.3. Density and Car Ownership

The following graphs plot the current car ownership levels with the current population densities at ward and output area levels.

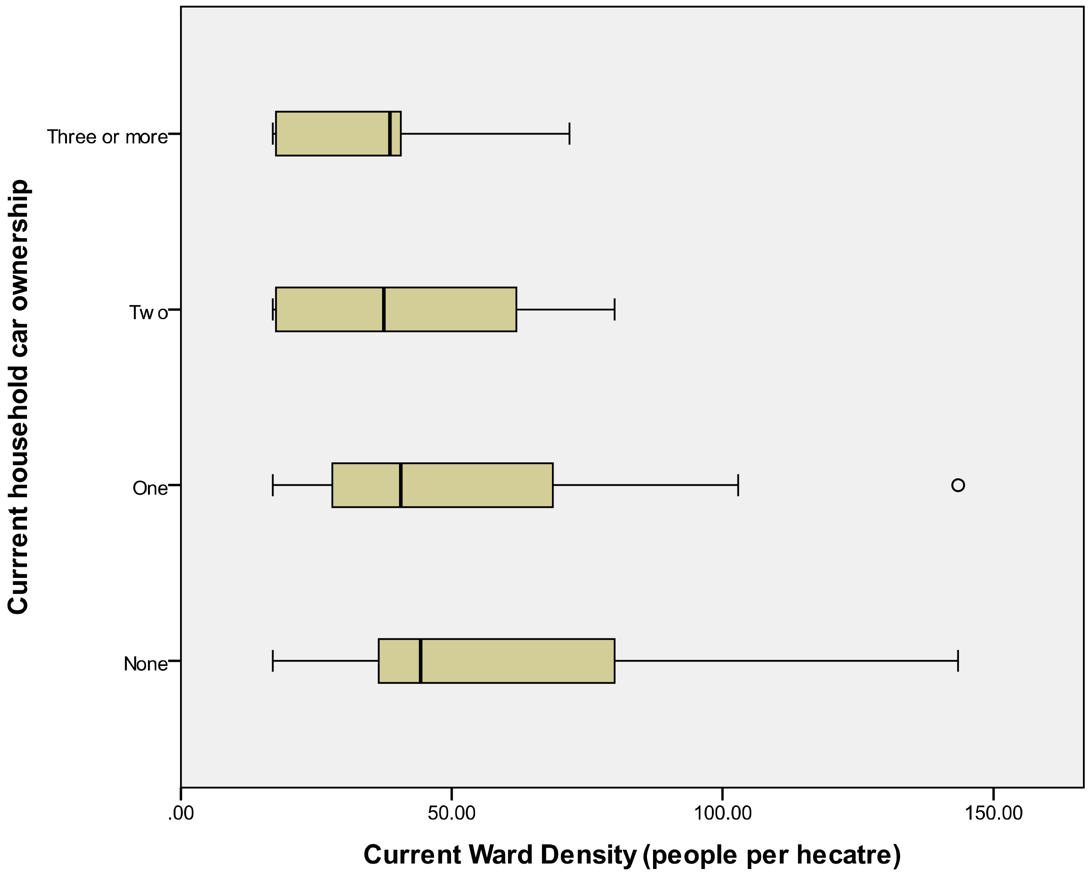

Figure 4.17 Boxplot of Current household car ownership against current population density at Ward level.

With reference to Figure 4.17, again, having density measured at the ward level limits the variation of density measures somewhat and makes graphical interpretation more difficult compared to data presented at the output area level. The boxplots show the range, inter-quartile range and median values of density for different levels of car ownership. It does appear that a negative correlation existed between the two variables. It is also worthwhile noting that the range of densities was smaller with higher levels of car ownership. No car households had a median population density of 44.3 residents per hectare, one car households 40.6, two car households 37.5 and households with three or more cars had a median population density of 38.6 residents per hectare.

Two possible outliers were identified. The issue of outliers is discussed in more detail in Chapter 5.

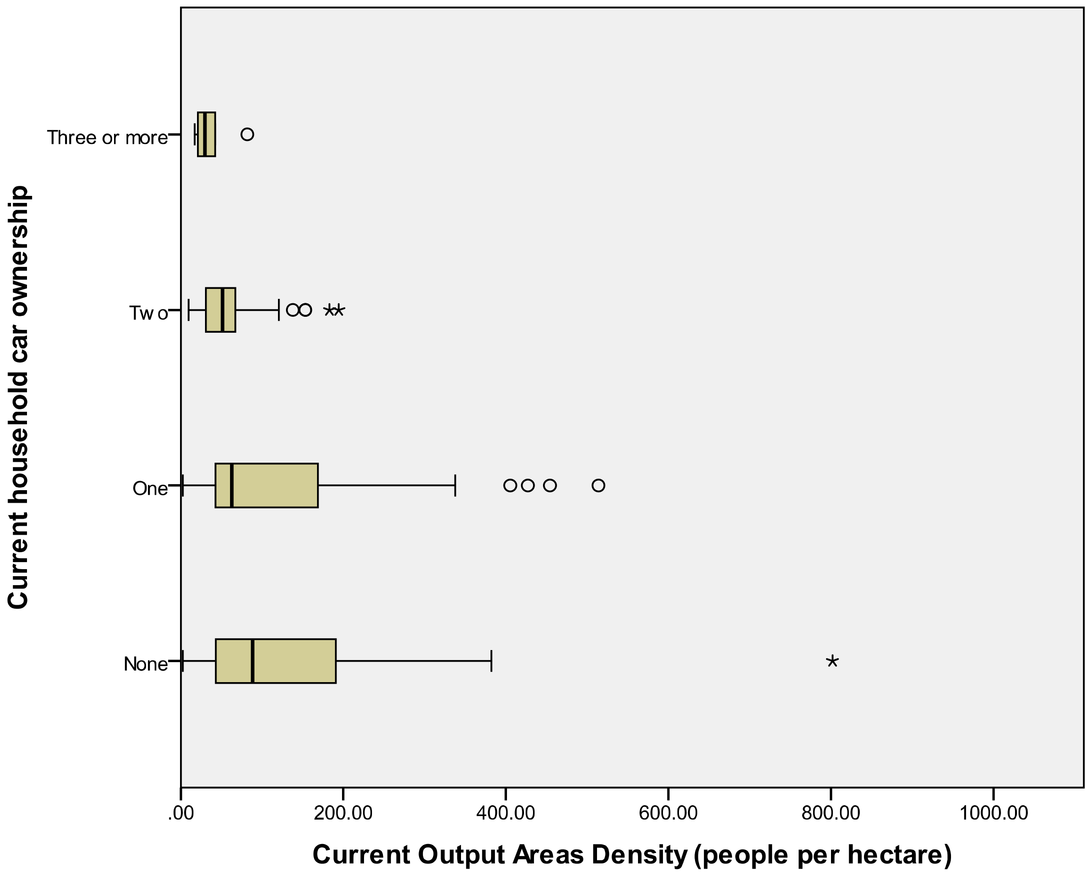

Figure 4.18 Boxplot of current population density at Output Area level against current household car ownership.

It can be seen from Figures 4.17 and 4.18 that it is possible to hypothesise negative relationships between population density at both Ward and Output Area and car ownership. More possible outliers were identified than in Figure 4.17 as density measured at the Output Area level produces a far greater degree of variability and more extreem values than density measured at a Ward level.

4.2.4. Change in Density and Change in Car Ownership

An initial inspection of the change in density and change in household car ownership is presented here for those respondents who reported a change of address. The majority of respondents reported no change in household car ownership, however it does appear that there may be a negative linear correlation between change in density measured at the ward level and change in household car ownership as expected and shown in Figure 4.19.

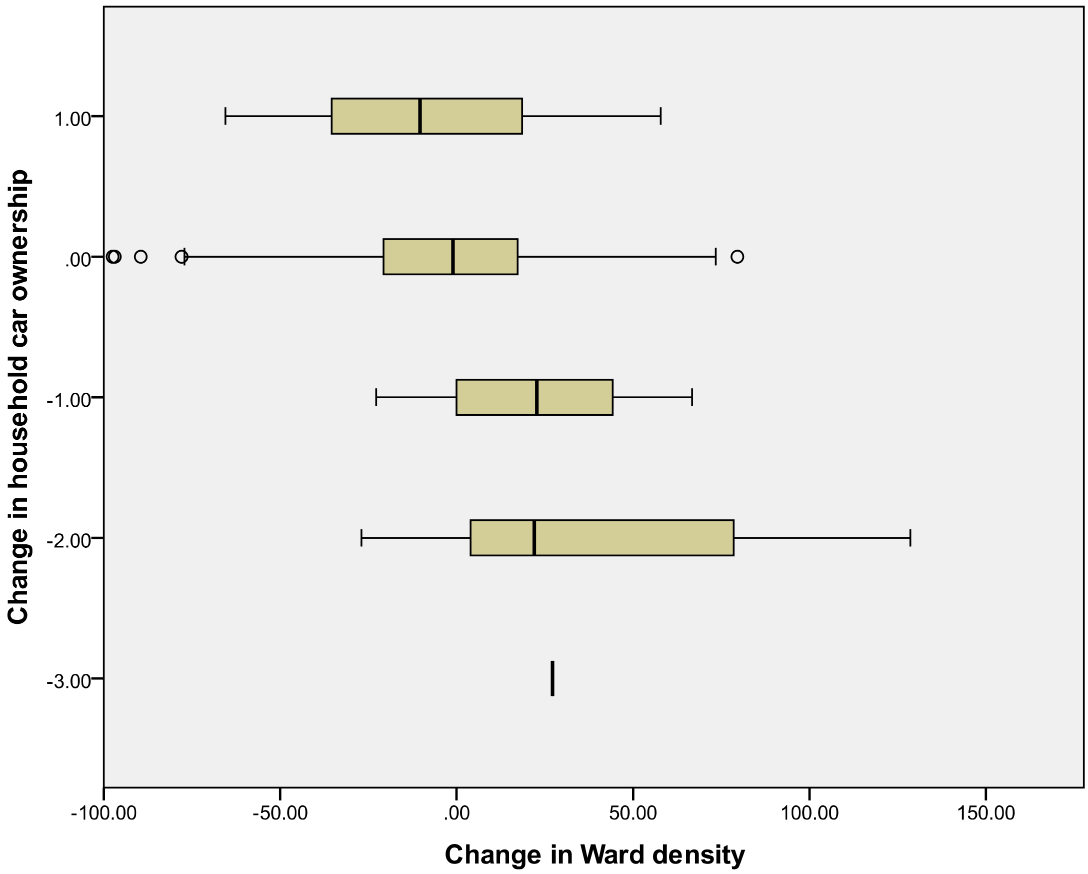

Figure 4.19 Boxplot of change in population density at Ward level against change in household car ownership.

A similar, but perhaps less obvious association also appears from initial inspection with change in density measured at the output area level as shown in Figure 4.20.

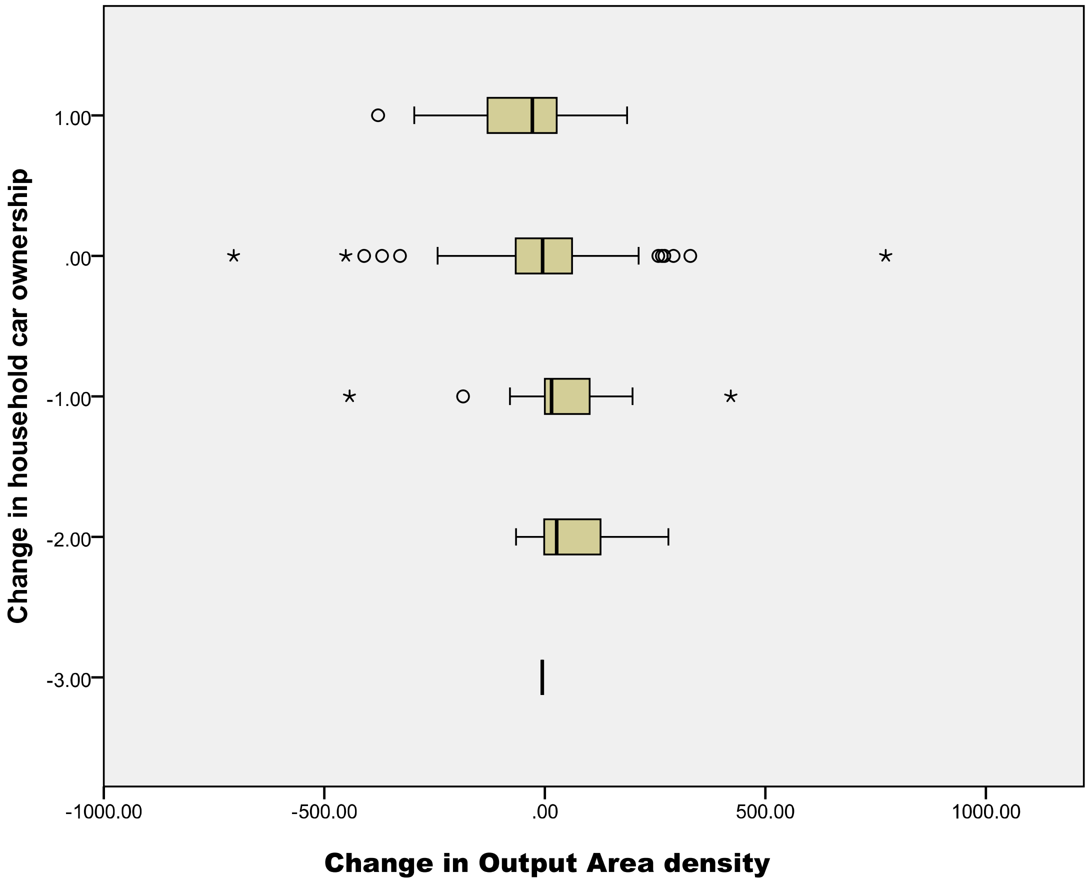

Figure 4.20 Boxplot of change in population density at Output Area level against change in household car ownership

4.2.5. Car Ownership and Vehicle Miles Driven

Figure 4.21 gives additional information of the spread of the data for each car ownership category and how distance driven appears to relate to car ownership.

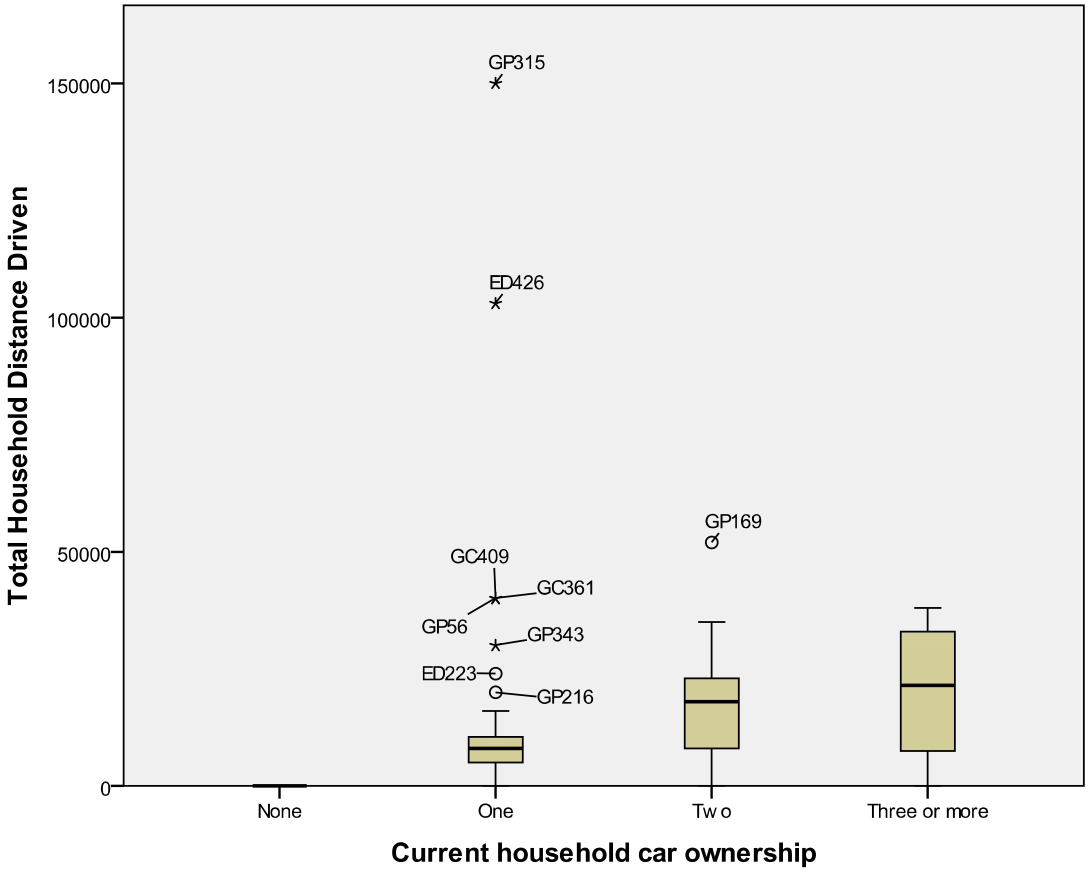

Figure 4.21 Boxplot of current total distance driven against current household car ownership for all respondents.

The data presented in Figure 4.21 appear to show a positive linear relationship between household car ownership and vehicle miles driven by the household as would be expected, which is more evident if the three outlying points above 100,000 miles are ignored. For households who have access to one car, the median was 7,000 miles, with an interquartile range of 6,000 miles. For two car households the median was 16,000 miles and the interquartile range was 15,000 miles. For three car or more households, the median was higher still at 24,500 miles with an interquartile range of 20,750. Compared to one car households, the total distance driven of two car households was approximately 9,000 miles higher and a further 9,000 miles higher for three car or more households. Households who did not currently have access to a car, were not asked their estimated car miles driven as it is assumed that without access to a private car their kilometres driven would be zero.

4.2.6. Change in Car Ownership and Change in Vehicle Miles Driven

		Compared to the end of 2002, how much do you use a car as a driver or passenger at the moment?					
		A lot less	A little less	About the same	A little more	A lot more	Total
Change in household car ownership	-3	0	0	0	1	0	1
	-2	5	1	2	1	1	10
	-1	13	7	6	0	1	27
	0	43	23	81	20	17	184
	1	4	2	10	2	16	34
Total		65	33	99	24	35	256

Table 4.8 Change in Car Ownership & Change in Distance Driven for all Respondents.

Given the limited number of categorical responses for change in car ownership and change in car use, the data is presented in Table 4.8 as a cross tabulation. Again it becomes apparent that the majority of households did not change their level of car ownership and only one household reduced their car ownership level by 3 cars, however, it does still appear as though there they may be a positive association between change in car ownership and change in car use. Of those who reported driving a lot less, only 6% had increased their car ownership while 28% had reduced their car ownership. Households who reported driving a lot more, 46% had increased their car ownership while 6% had reduced their car ownership.

4.3. Summary of Descriptive Statistics

This chapter presents the data collected and explores correlations between the datasets to inform any subsequent analyses. The data collected, whilst small in size (281) and representing a relatively low response rate (12%), contain a wide range of urban forms, socio-demographics, car ownership levels and distances driven, required for any analyses to be undertaken as to whether urban form influences car ownership and whether both also influence distance driven. Many of the urban form variables were correlated with one another, as expected and as highlighted in the literature. Similarly some measures of socio-demographics were correlated with one another as would be expected.

There was correlation between distance driven and measures of urban form such a population density (particularly when measured at the Ward level). Those households in lowest quartile of ward population density (less than 25 persons per hectare) had an average distance driven of 9,514 miles per anum, compared to 7,800 for those in the upper quartile (more than 69 persons per hectare).

Similarly, there was correlation between change in urban form and change in distance driven, as hypothesised. Of those reporting that "they drove a lot less" 71% had moved to a higher density ward, and 23% had moved to a lower density Ward. Of those reporting that "they drove a lot more" 20% had moved to a higher density ward, and 29% had moved to a lower density Ward. This result perhaps suggests a degree of hysteresis between change in urban form and change in distance driven, with a relocation to a more dense area being associated with a larger propensity to reduce distance driven (the greater the change in density, the greater the propensity for change in car use) compared to a corresponding move to a less dense area, which appears to increase distance travelled for a smaller proportion of people;. Such associations may however be spurious as no other factors have been accounted for in the simple tests of correlation presented in this chapter.

There was correlation between density and car ownership. No car households had a median population density of 44.3 residents per hectare, one car households 40.6, two car households 37.5 and households with three or more cars had a median population density of 38.6 residents per hectare.

Change in density was correlated with change car ownership. For those households who had reduced their car ownership by two, the mean change in Ward population density was 36.9 residents per hectare (median of 22), whereas for those who had increase their car ownership by one car, the mean change in Ward population density was -3.1 residents per hectare (median of 0).

As expected there was correlation between car ownership and distance driven and change in car ownership and change in distance driven. Households with no cars drive no distance each year by car. Those households who had 2 cars, drive nine thousand miles further than those with one, and those households with three or more cars drove nine thousand miles further still. Of those who reported driving a lot less, only 6% had increased their car ownership while 28% had reduced their car ownership. Households who reported driving a lot more, 46% had increased their car ownership while 6% had reduced their car ownership.

The exploration of the data shown in this chapter adds weight to the hypotheses presented that:

H1: Urban Form and Car Ownership have direct effects on Travel Behaviour
H2: Urban Form has a direct effect on Car Ownership

It is worth noting however, that these associations can only be confirmed carrying out analysis of the data, controlling for the effects of socio-demographics and other non-urban form variables. Chapter 5, Analysis describes how the limitation of having relatively few data sets is accounted for when carrying out statistical tests of correlation between the sets of variables described in this chapter. In so doing Chapter 5 builds on the descriptive analyses presented in this chapter in order to determine the effects of urban form and car ownership on travel behaviour, and the effects of urban form on car ownership accounting for socio-demographics.

5. Analysis

In this chapter regression analyses are presented that describe the effect of urban form on travel behaviour and car ownership including the novel application of Generalized Estimating Equations to describe cross sectional and longitudinal effects. This chapter builds on the descriptive statistics and cross tabulations shown in Chapter 4. The modelling presented makes reference to other studies already cited in this thesis.

As described in Chapter 3, the hypotheses being tested in this study are as follows:

H1: Urban Form and Car Ownership have direct effects on Travel Behaviour
H2: Urban Form has a direct effect on Car Ownership

The analytical methods used to test the hypotheses are described, followed by the specification within SPSS and finally the results of the analyses are presented.

5.1. Urban Form - Distance Driven

As described in Chapter 4 Descriptive Statistics, it appears from the simple tests of correlation that there is an association between urban form and annual household distance driven. In order to determine statistically if such an association exists, after other variables are controlled for, an explanatory statistical model was developed.

5.1.1. Analytical Method

Before undertaking any such analysis, it is important to consider the nature of the data available, the precise questions being asked and finally the statistical procedures most suited to the purpose. In this instance the household distance driven defined as the summation of annual mileage of all cars owned or available to the household is scalar and urban form measures available are scalar, and nominal in nature. There are a number of other variables that need to be "controlled" for, including socio-demographic variables that are scalar, ordinal, count and nominal.

In terms of the precise question being asked, one does not only want to know if a statistically significant association exists between urban form and distance driven, accounting for other control variables, but if so, what the nature of this relationship is in terms of its magnitude, direction and shape (linear, quadratic, exponential etcetera). Hence, regression analyses that fit the measured data to a particular mathematical relationship was the most appropriate form of analysis to undertake.

The Generalized Linear Model (GLM) extends the use of standard linear regression modelling to account for instances where the response is discrete, count or ordinal and where the response is not directly linearly related to the explanatory variables. While the response here is continuous, the relationship may not be linear as discussed in Chapter 4 Descriptive Statistics. In this instance, it would appear that the most suitable form of regression to undertake would be from the Generalized Linear Model family of regression models.

The Generalized Linear Model (GLM) has two components that need to be specified; a distributional assumption and a link function. The distributional assumption used in GLM is that the response variable has a probability distribution that belongs to the exponential family of distributions; whereas standard linear regression assumes that the response has a normal probability distribution. The link function transforms the linear combination of covariates to relate to the mean response or response probability distribution. In standard linear regression modelling where no link function is specified the mean response relates directly to a linear combination of covariates, whereas the GLM uses a non-linear link function to relate the covariates to the mean.

The general form of the GLM is shown below.

$$\mu_i = LINK\left(\sum_{k=1}^{p} \beta_k X_{ik}\right)$$

Where,

μ = Mean Response
$LINK$ = Function linking the linear combination of covariates to the response variable
β = Regression co-efficients
X_{ik} = The k^{th} covariate for the i^{th} subject

There are many different combinations of distributions and link functions available reflecting different modelling options. Possible distributions fall within the exponential family of distributions and commonly include (Myers et al, 2010):

Distributions

- Binomial - appropriate for binary response or number of events.
- Gamma & Inverse Gaussian - appropriate for positive scale values that are skewed towards larger positive values.
- Negative Binomial - the number of trials required to observe a number of successes and is appropriate for variables with non-negative integer values.
- Normal - appropriate for scale variables whose values take a symmetric, bell-shaped distribution about a central (mean) value.
- Poisson - the number of occurrences of an event of interest in a fixed period of time and is appropriate for variables with non-negative integer values.

The linear combination of predictor variables, relates to the mean response through a link function. Commonly used link functions include: Identity, Complementary log-log, Log, Log complement, Logit, Negative Binomial, Negative log-log, Odds power, Probit and Power.

In choosing the appropriate distribution and link function, a judgment must be made based on the distribution of data around the mean line, which are conceptually the most appropriate for the type of data concerned and which produce the best model fit. As described in Chapter 4, household distance driven follows a positively skewed bell shape with a long tail to the positive end of the range. Given that the data is also scale and positive, this limits the choice of distribution to Gamma, Inverse Gaussian and perhaps Normal. The Poisson distribution may fit the spread of data about the mean, although conceptually may not be an appropriate choice of distribution as it usually relates to events over time.

Having selected these three distributions, the link functions available were limited to the Power, Log and Identity link functions. All combinations of these distributions were tested and those giving the best model fit presented.

It was decided that missing data were removed on a listwise basis, given that only one dependent variable was considered in the analysis and there were no repeated measures for a particular respondent in this cross sectional analysis. That is, only the current situation of the respondents was considered. The sample size varied depending upon which records entered the model as a result of missing data.

In addition to the main effects of the independent urban form and socio-demographic variables on annual household distance driven, the effects of interactions were also tested. That is, the effect of each term individually was tested alongside other individual terms (main effects) and also the effects of combinations of these variables were also tested (interaction). An example would be whether density and car ownership individually are associated with vehicle miles driven or whether it is combinations of density and car ownership levels that are important. All 2-way interactions of explanatory variables were tested.

As described in Chapter 4, Descriptive Statistics, distance driven is taken as the summation of annual mileage for all cars owned or available to the household. Those households with no car, by definition, did not report any distance driven. It could therefore be expected that there might be two separate associations between urban form and vehicle miles driven for households with and households without access to a private car; with no car households' vehicle miles driven being perfectly explained by car ownership. The lack of variation of vehicle miles driven for no car households makes modelling of this instance trivial. Instead, this section looks at whether urban form is associated with vehicle miles driven for households with access to a car. The relationship between urban form and car ownership is explored in section 5.3.

5.1.2. Specification within SPSS

Through consideration of the distribution of the data and by trial and error the Gamma distribution with the log link function best reflected the data in terms of model fit and conceptually; a commonly used combination of distribution and link function.

For all model runs the hybrid method of parameter estimation was specified. The scale parameter method was set to maximum likelihood method. An intercept was included in the model (estimated from the data) and the covariance matrix was also based on model estimates. The type of analysis of model effects specified in SPSS was set to type three as there were no prior reasons for ordering predictors in the model. The confidence level was set to 95%.

The models were reduced using a backwards removal method, whereby all variables were initially entered into the model and those proving to be least significant were removed. The process is somewhat more iterative, as the while not significant, some variables add to the overall explanatory power of the model and so were kept in the model. Also, interpretation of significant variables is hampered if other variables are not controlled for. For example, it was felt important to control for income in the modelling, whether or not income itself was a significant predictor of distance driven or car ownership. Due to the relatively small sample size, those variables with 10% or lower significance (90% confidence) were considered to be statistically significant.

Due to the lack of variability in the current accommodation type, the variable was recategorised as being either a house or a flat. The 7 categories of accommodation type shown in Table 4.2 were reduced to two, with 31.4% of respondents currently residing in a house and 68.6% in a flat. Residential population density and the jobs to population ration measured at the Ward level gave a better model fit (based on the Information Criterion tests) than when measured at the Output Area level, with greater magnitudes of effect (beta values). The measures made the Output area level were thus removed from the model.

5.1.3. Results of Analysis of Urban Form and Household Distance Driven

The model presented here relates to the entire sample (movers and non-movers) with a Gamma distribution, Log link function and other modelling options as already described. The model is based on a sample of 169 cases due to the listwise exclusion of missing data. The SPSS file run created a warning that one or more cases were found with dependent variable data values that are less than or equal to zero. The warning means that empty values for vehicle miles driven will be excluded from the analysis as desired. On inspection of the data there are no car owners who stated that their vehicle miles driven was zero

The model produced had a deviance divided by the number of degrees of freedom and the Pearson's Chi Square value divided by the number of degrees of freedom close to one, suggesting that the model is suitably specified. If these ratios were not close to one, it usually indicates a poorly specified model, or a model reliant on outlier points.

The Information Criterion tests (AIC, AICC, BIC and CAIC) are relatively small suggesting a good model fit. These criteria can be useful in comparing similarly specified models with one another in order to refine models.

The Likelihood Ratio Chi-Square value was 64.659, with a significance of 0.000, hence suggesting that the model including the independent variables is significantly better than the intercept only model.

Source	Type III	
	Wald Chi-Square	Sig.
(Intercept)	621.273	**.000**
Age	11.801	**.038**
Household Income	6.592	.473
Current car ownership	13.114	**.001**
Gender	.111	.739
Current jobs:pop ratio	.109	.741
N^{o} of residents in household	1.151	.283
Current Ward density	1.652	.199
Distance to current centre	.437	.509
Current accom type	2.200	.138

Table 5.1 Tests of Model Effects of Urban Form and Distance Driven.

The statistic presented in Table 5.1 show the level of significance of each term in the model in describing the variability of the dependent variable (annual household distance driven in miles, for households with access to one or more cars). Values of less than 0.10 suggest that the term is not significantly associated with the dependent variable. Only the age of the respondent and the current car ownership are significant. For scalar variables, the significance levels are the same as those shown in the following Table 5.2. However, for categorical variables, Table 5.1 above gives the significance of the variable as a whole, whereas Table 5.2 shows whether or not each category of response is significantly different from a reference category; in this case set to be the last category of response.

Parameter	B	95% Wald Confidence Interval		Sig.	Exp(B)
		Lower	Upper		
(Intercept)	9.165	8.004	10.326	**.000**	9556.824
Age 16-24	.325	-.331	.981	.331	1.385
Age 25-34	.748	.242	1.254	**.004**	2.113
Age 35-44	.779	.288	1.271	**.002**	2.180
Age 45-54	.746	.211	1.280	**.006**	2.107
Age 55-64	.612	.044	1.180	**.035**	1.844
Age 65 +	0[a]	.	.	.	1
Income Nil	.164	-1.377	1.706	.834	1.179
Income Up to £10,399	-.515	-1.405	.374	.256	.597
Income £10,400 to £15,599	-.208	-.759	.342	.458	.812
Income £15,600 to £20,799	-.268	-.734	.198	.260	.765
Income £20,800 to £25,999	.275	-.229	.780	.285	1.317
Income £26,000 to £31,199	-.202	-.685	.281	.413	.817
Income £31,200 to £51,999	-.181	-.524	.163	.303	.835
Income £52,000 or more	0[a]	.	.	.	1
Current cars 1	-.799	-1.705	.107	**.084**	.450
Current cars 2	-.208	-1.110	.693	.651	.812
Current cars 3 or more	0[a]	.	.	.	1
Male	.041	-.202	.285	.739	1.042
Female	0[a]	.	.	.	1
Current jobs:pop ratio	-.012	-.083	.059	.741	.988
Nº of residents in household	.066	-.055	.188	.283	1.069
Current Ward density	.004	-.002	.010	.199	1.004
Distance to current centre	3.033E-5	-5.961E-5	.000	.509	1.000
Current accom house	-.292	-.679	.094	.138	.746
Current accom flat	0[a]	.	.	.	1
(Scale)	.536[b]	.440	.653		

a - Redundant reference category

Table 5.2 Parameter Estimates for Model of Urban Form and Household Distance Driven.

As can be seen in Table 5.2, higher car ownership was associated with higher mileage, and middle age groups had higher mileage than young or old groups. The Exp(B) column shows the effect of a difference of 1 unit of the independent variable on the dependent variable. Exp(B) values less than one show that higher values of the independent variable are related to a lower value of the dependent variable and vice versa. In reference to these results, it can be seen that age, as well as being statistically significant has a large magnitude of effect on distance driven for households owning at least one car. Compared to respondents who were aged 65 or over, respondents aged in categories from 24 and 64 years old reported on average, reported approximately double the annual household distance driven. Those respondents in the 16 to 24 years old category reported a household annual distance driven of 36.5% more than those respondents aged 65 or over. Household income was not statistically significant and no pattern in the effects between the different income groups was present. The number of residents in the household, similarly is also not statistically significant and has a small magnitude of effect. Those households with 1.148 (one standard deviation) more residents than the mean (2.22) reported, on average, a household distance driven 7.9% higher, all else being equal. Households who had access to one car, reported an annual distance driven of only 45% that of household with three or more cars. Households with two cars reported 81.2% of the distance driven than those with three or more cars. That is, 2-car households drove 80% further, and 3-car households 120% further than 1-car households all else being equal.

The current jobs:population ratio is not significant and the magnitude of the effect is very small. For every one unit increase in the ratio, the annual household distance driven is 1.2% lower. The range and unit of the jobs:population ratio means that households in an area with a jobs:population ratio one standard deviation (1.861) above the mean jobs population ratio (0.820) on average reported that they drove 2.2% fewer miles. The density of the ward in which the household was located, was not statistically significant and again, was small in terms of the magnitude of effect with a 23.23 persons per hectare (1 SD) higher density relating to 9.6% increase in household distance driven. Distance to current centre measured in metres has no statistically significant effect. The household distance driven for those residing 2,143 metres (1SD) further away from the nearest urban centre was 6.7% higher than those residing a mean distance (3,284m) from the current urban centre. Whether or not the household lived in a flat or house was close to being significant at the 10% level (sig 0.138) and had a large magnitude of effect. Those living in a house drove on average only 74.6% of the miles that those living in a flat did, all else being equal. Removing the accommodation type term from the model, did not change the significance and magnitude of the other urban form variables to any notable extent, suggesting that the effect is independent of other urban form measures.

In summary, the current distance driven was explained largely by the car ownership level of the household. Those households without a car reported having driven zero miles; hence car ownership perfectly described distance driven for this trivial case. Age was the only other variable that was statistically significant with middle aged groups reporting substantially greater distances driven than the young and elderly. No urban form variables were statistically significant and the magnitudes of effect were all small except for accommodation type, with those living in houses reporting substantially fewer miles driven per annum, although the result was not statistically significant.

When an interaction term "movers" was introduced to the model to distinguish the effects of those that had relocated in the previous three years to those that had not, different parameter estimates emerge, with different levels of statistical significance between the two groups. Interacting the "movers" term with all other terms or nesting "movers" within all other terms produced in effect two different models, one for movers and one for non movers, if the main effect of the "movers" term is included alongside the interactions. The main effect of the "movers" term was found not to be significant and indeed was redundant and hence removed from the model. The intercept for movers was not significantly different from that of non-movers. No 2-way interaction terms were found to be significant other than the interaction with the movers term and hence were removed from the model. The main effects alone, were found not to be significant and hence were removed. In all cases, the interaction with the "movers" term produced statistically stronger estimates than the main effects. This suggests that the association between the independent variables and household annual distance driven differed between those who had relocated within the previous three years and those who had lived in their current residence for longer than three years.

As previously the gamma distribution and log link function were specified with the same sample size of 169.

The Information Criterion tests (AIC, AICC, BIC and CAIC) were again small and the deviance and Pearson Chi-Square divided by the degrees of freedom were 0.619 and 0.849 respectively, suggesting a good model fit.

Source	Type III	
	Wald Chi-Square	Sig.
(Intercept)	470.551	**.000**
Movers * Age	19.850	**.031**
Movers * Household Income	16.850	.206
Movers * Current car ownership	16.848	**.002**
Movers * Gender	4.287	.117
Movers * Current accom type	6.928	**.031**
Movers * Current jobs:pop ratio	.586	.746
Movers * Nº of residents in household	8.907	**.012**
Movers * Current Ward density	.734	.693
Movers * Distance to current centre	.653	.721

Table 5.3 Tests of Model Effects of Urban Form and Distance Driven with Interaction of Movers.

As with the model without the "movers" interaction, the age of the respondent was significant along with the current car ownership as shown in Table 5.3. However, the effects of accommodation type and the number of residents in the household become significant (at the 10% level) when interacted with the "movers" term.

Parameter	B	95% Wald Confidence Interval		Sig.	Exp(B)
		Lower	Upper		
(Intercept)	9.091	7.424	10.757	**.000**	8871.439
Non-Mover * Age 16-24	-1.091	-4.019	1.838	.465	.336
Non-Mover * Age 25-34	.239	-2.539	3.017	.866	1.270
Non-Mover * Age 35-44	.111	-2.573	2.796	.935	1.118
Non-Mover * Age 45-54	-.156	-2.846	2.533	.909	.855
Non-Mover * Age 55-64	.418	-2.132	2.968	.748	1.519
Non-Mover * Age 65 +	-.456	-3.288	2.377	.752	.634
Mover * Age 16-24	.769	-.328	1.866	.170	2.157
Mover * Age 25-34	1.199	.204	2.194	**.018**	3.316
Mover * Age 35-44	1.356	.366	2.345	**.007**	3.880
Mover * Age 45-54	1.097	.048	2.147	**.040**	2.997
Mover * Age 55-64	.658	-.439	1.755	.240	1.931
Mover * Age 65 +	0^a	.	.	.	1
Non-Mover * Income Nil	.476	-1.254	2.207	.590	1.610
Non-Mover * Income Up to £10,399	.056	-1.641	1.753	.948	1.058
Non-Mover * Income £10,400 to £15,599	.131	-1.304	1.565	.858	1.140
Non-Mover * Income £15,600 to £20,799	-.712	-1.544	.120	**.094**	.491
Non-Mover * Income £20,800 to £25,999	-.124	-1.290	1.042	.835	.883
Non-Mover * Income £26,000 to £31,199	-.242	-1.868	1.384	.770	.785
Non-Mover * Income £31,200 to £51,999	-.676	-1.503	.150	.109	.508
Non-Mover * Income £52,000 or more	0^a	.	.	.	1
Mover * Income Up to £10,399	-.691	-1.946	.564	.281	.501
Mover * Income £10,400 to £15,599	-.024	-.661	.612	.940	.976
Mover * Income £15,600 to £20,799	.199	-.365	.763	.490	1.220
Mover * Income £20,800 to £25,999	.649	.092	1.207	.022	1.914
Mover * Income £26,000 to £31,199	.009	-.461	.478	.971	1.009
Mover * Income £31,200 to £51,999	.120	-.236	.475	.510	1.127
Mover * Income £52,000 or more	0^a	.	.	.	1
Non-Mover * Current cars 1	-.779	-2.368	.809	.336	.459
Non-Mover * Current cars 2	-.106	-1.780	1.567	.901	.899
Non-Mover * Current cars 3 or more	0^a	.	.	.	1
Mover * Current cars 1	-1.047	-2.099	.005	**.051**	.351
Mover * Current cars 2	-.498	-1.531	.535	.345	.608
Mover * Current cars 3 or more	0^a	.	.	.	1
Non-Mover * Male	-.362	-.813	.089	.115	.696
Non-Mover * Female	0^a	.	.	.	1
Mover * Male	.185	-.084	.454	.179	1.203
Mover * Female	0^a	.	.	.	1
Non-Mover * House	-.117	-.866	.632	.759	.889
Non-Mover * Flat	0^a	.	.	.	1

Parameter	B	95% Wald Confidence Interval		Sig.	Exp(B)
		Lower	Upper		
Mover * House	-.588	-1.028	-.147	**.009**	.556
Mover * Flat	0[a]	.	.	.	1
Non-Mover * Current jobs:pop ratio	.139	-.832	1.110	.779	1.149
Mover * Current jobs:pop ratio	-.025	-.093	.043	.477	.976
Non-Mover * Nº of residents in household	.420	.143	.696	**.003**	1.521
Mover * Nº of residents in household	-.019	-.154	.116	.782	.981
Non-Mover * Current Ward density	.006	-.007	.019	.393	1.006
Mover * Current Ward density	.000	-.007	.007	.942	1.000
Non-Mover * Distance to current centre	7.029E-6	.000	.000	.944	1.000
Mover * Distance to current centre	4.146E-5	-5.946E-5	.000	.421	1.000
(Scale)	.438	.359	.535		

a - Redundant reference category

Table 5.4 Parameter Estimates for Model of Urban Form and Household Distance Driven, with Interaction of Movers.

As can be seen in Table 5.4, different variables are significant predictors of household distance driven with different magnitudes and directions for movers and non-movers. Age is statistically significant only for movers with the same pattern and large magnitudes of effect as in the previous analysis. Middle aged groups had the greatest household distance driven, followed by the youngest, with the oldest age group reporting the fewest household miles driven all else being equal. Those respondents who were in the 35-44 years old age group, had a household distance driven 3.9 times that of those respondents in the 65 years or over age group. No such pattern emerges, nor is age statistically significant for those households who had not moved. As previously, household income was not statistically significant for either movers or non-movers. No clear pattern emerged for non-movers whereas for movers, those with no income reported the lowest household distance driven; half that of households with an income of £52,000 or more. Households with an income of £20,800 to £25,999 reported the greatest distance driven, 1.9 times that of households in the highest income category. There was no statistically significant difference in distance driven between car ownership levels for “non-movers”. The direction of the effect of car ownership was similar to the previous analysis though, with one-car households reporting 46% of the distance driven by three-car plus households (two-car household reported 90% of distance driven by three-car plus households). However, for "movers", car ownership is statistically significant and the magnitude of the effect is larger than for "non-movers" with one-car households reporting 35% of the distance driven by three-car plus households (two-car household reported 61% of distance driven by three-car plus households). Gender remains statistically insignificant for both groups; for "non-movers" men reported a household distance driven 70% of that of female respondents. For "movers" men reported a household distance driven 20% higher than female respondents, all else being equal. For "non-movers" there is no statistically significant difference between those living in flats and those living in houses. For "movers" however, those living in a house reported only 56% of the distance driven by households living in flats; a statistically significant difference (p-value 0.009).

The jobs:population ratio remains statistically insignificant for both movers and non-movers, but the direction and magnitude of the effect are different for each group. "Non-movers" in areas with a greater number of jobs compared to the residential population reported a higher household distance driven, whereas movers in areas with a higher jobs:population ratio reported fewer household miles driven. Households living in an area with 1.861 higher jobs:population ratio (1 SD) reported driving 27.7% more miles per anum if they had not moved home in the previous three year or 4.5% fewer miles per anum if they had, compared to the average jobs:population ratio of 0.82 jobs to every 1 resident. The number of residents in the household is not a statistically significant predictor of distance driven for "movers" but is for "non-movers" (p-values of 0.003 and 0.782 respectively). For "movers", having 1.148 more residents in the household (1 SD), compared to the mean number of residents in the household (2.22) was associated with 60% more miles driven per anum, all else being equal. A similar difference in the number of residents in households who had moved was associated with 2.2% fewer miles driven, all else being equal, although the effect is not statistically significant. Ward population density has no effect (either in terms of statistical significance or magnitude) for "movers". For "non-movers" the effect of the household residing in a ward with a population density 23.24 person per hectare (1 SD) higher than the mean (46.48) was that they reported 14% more miles driven per year, although the effect is not statistically significant. The distance to the current centre has a large magnitude of effect, but no statistically significant effect on the household distance driven for either “movers” of “non-movers”. For “non-movers” living 2,142 metres (1 SD) further from the urban centre related to 43% more miles driven per anum compared to those living a mean distance of 3,284 metres from the urban centre. For “movers”, the same difference in distance to urban centre was related to 30% more miles driven all else being equal.

5.2. Change in Urban Form – Distance Driven

Following on from the previous section, it is logical that analyses are undertaken that look at how changes in urban form and other control factors might relate to changes in distances driven.

5.2.1. Analytical Method

The assessment of within-subject changes in the response over time can be achieved through longitudinal analyses (Fitzmaurice et al, 2004). Hence, longitudinal analysis is presented here as to how residents’ distances driven changed over time compared to changes in residential built form.

The cross sectional analysis demonstrates that differences in very few independent variables are associated with differences in distance travelled by car, once car ownership is accounted for. It is important to note that even if many urban form measures were found to be strongly associated with distance driven, it still could not be said that changing these independent variables will lead to a change in distance travelled by car. That is, differences in X produce differences in Y which implies that changes in X produce changes in Y but this conclusions cannot be drawn as X and Y have been tested not changes in X and changes in Y, (Menard, 2002).

While the cross sectional analyses presented relates to the household, this analysis of change relates to the individual respondent. While the dataset is rich, it does not include changes in demographics and urban forms for other household members apart from the respondent. The quasi-longitudinal element of the study is therefore only focussed on the respondent and their reported change in distance driven.

The dependent variable "Change in Distance Travelled by Car" taken from the survey response, is by definition ordinal, and as such cannot be modelled using linear regression modelling which is only suitable for continuous response variables. It is therefore necessary to use a form of Generalized Linear Model. Given that the measures of the number of miles previously driven are not recorded in the dataset, only measures of change, the model specified will be unconditional in nature. By being unconditional it is not possible to state for example, whether urban form influences changes from a low to medium level of distance driven in the same way it influences changes from a medium to a high level of distance driven, as only the change is recorded. This, albeit unconditional, analysis of change is superior to the cross sectional analysis already presented in that it can provide estimates of the associations between changes in the dependent variable and independent variables as opposed to differences in the dependent variables. It also has the advantage that it may help to account for omitted explanatory variables also known as individual permanent effects (Finkel, 1995). That is, unobserved characteristics of the individual may well have remained constant over the three year time period, hence would be accounted for by considering only the change rather than absolute values.

5.2.2. Specification within SPSS

The Generalized Liner Model was set to be ordinal with the dependent variable being the reported change in car use by the respondent.

A negative-log-log link function was found to be the most appropriate conceptually and in terms of best fitting the data.

The mathematical form equation used for ordinal regression is similar to that used for the generalized linear regression (indeed is a special case of GLM) as can be seen in the following.

$$link(y_{ij}) = \theta_j - [\beta_1 x_{i1} + \beta_2 x_{i2} + ... + \beta_p x_{ij}]$$

Where,

Link ( ) is the link function
y_{ij} is the cumulative probability of the j^{th} category for the i^{th} case
θ_j is the threshold for the j^{th} category
p is the number of regression coefficients
x_{i1} .... x_{ip} are the values of the predicators for the i^{th} case
β_1.... β_p are regression coefficients.

In effect the model assumes an underlying continuous dependent variable that has been categorised.

Independent variables entered into the model were as follows:

- Change in residential population density measured at the Ward level
- Change in residential population density measured at the Output Area level
- Change in jobs/population ratio measured at the Ward level
- Change in distance from home to place of work
- Change in accommodation type
- Previous urban-rural classification (all current locations are in urban areas)
- Change in distance from home to city centre
- Change in income measured at the household level
- Change in car ownership
- Change in driving licence status
- Change in employment status

Change in accommodation type was defined as being either “no-change” (74%), “change from house to flat” (18%) or “change from flat to house” (8%). Change in employment status was defined as being “no change” (84%), “currently working, previously not working” (9%) and “currently not working, previously working” (7.3%). Change in license status is defined as “no-change” (95%) or “gained licence” (5%) and was computed from the response to Question C4 which asked the respondent to state the year they gained their license. If the year stated was 2004 or later, then the respondent had gained their licence over the preceding three years.

All “change” continuous variables are calculated in terms of the before situation minus the current situation with negative values relating to a lower current level than the previous level. .

Separate models were tested for density measured at the output area level and the ward level. Missing values were removed on a list-wise basis and the mode refined using stepwise removal.

5.2.3. Results of Analysis of Change in Individual Distance Driven

After the main effects are accounted for, no two-way interactions of the independent variables were statistically significant and were removed from the model.

The model gives a significant improvement over the intercept only model and has an adjusted McFadden pseudo-R square value of 0.155 (Cox and Snell = 0.363, Nagelkerke = 0.384). The large difference in the pseudo-R square values (Cox and Snell and Nagelkerke) and adjusted pseudo-R square value (McFadden) is due to the large numbers of parameters compared to the sample size.

	B	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Threshold				
Drive a lot less	-.992	.347	-3.061	1.077
Drive a little less	-.449	.671	-2.517	1.619
Drive about the same	1.328	.212	-.757	3.413
Drive a little more	2.286	.034	.171	4.401
Location				
Reduction in income	-.319	.270	-.886	.248
No change in income	-.643	**.019**	-1.180	-.107
Increase in income	0[a]	.	.	.
Age 16 – 24	-.747	.126	-1.705	.211
Age 25 - 34	.044	.894	-.610	.699
Age 35 – 44	-.230	.510	-.912	.453
Age 45 – 54	-.696	**.060**	-1.421	.029
Age 55 – 64	-.525	.205	-1.336	.286
Age 65 +	0[a]	.	.	.
No change in work status	.609	.306	-.556	1.774
Gained employment	1.143	.108	-.252	2.538
Lost employment	0[a]	.	.	.
Gained driving licence	2.536	**.000**	1.575	3.497
No change in licence	0[a]	.	.	.
No change in accom type	-.265	.439	-.937	.407
Change from house to flat	-.410	.395	-1.354	.535
Change from flat to house	0[a]	.	.	.
Change in distance to work	.013	**.086**	-.002	.027
Change in Ward Density	-.002	.581	-.010	.006
Change in dist to urban centre	8.576E-5	**.100**	-1.638E-5	.000
Change in jobs:pop ratio	-.093	**.073**	-.194	.009
Change in car ownership	.341	**.081**	-.042	.723
Previously Large Urban Area	-.213	.763	-1.596	1.170
Previously Other Urban Area	-.793	.388	-2.595	1.009
Previously Accessible Small Town	1.182	.253	-.843	3.207
Previously Accessible Rural	-.217	.852	-2.503	2.069
Previously Remote Rural	-.566	.679	-3.245	2.113
Previously Greater London	0[a]	.	.	.

a - Redundant reference category

Table 5.5 Parameter Estimates for Model of Change in Urban Form and Change in Distance Driven

The model presented is for all respondents including those who had and had not moved home in the previous three years. Those that had not moved home by definition will have had no change in accommodation type, distance to urban centre, Ward population density or jobs to population ratio.

Of the socio-demographic variables, the change in household income was statistically significant. Those with no change in household income had a statistically significant, 0.643 increased ordered log odds of being in a lower level of change in car use compared to households with an increased income. That is, having an increase in income was associated with an increased probability of having increased car use compared to those who had no change in income.

Change in work status was not statistically significant. Having gained a driving license was statistically significantly associated with a large increase in probability of having increased car use (ordered log odds of 2.536) compared to those who had no change in licence status. No clear pattern emerges as to how age effects the change in car use. However, it appears that those in the 35-44 age group appeared to be more likely to have reduced their car use over the previous three years compared to those in the oldest age group of 65 year or over. The change in distance travelled to the place of work was statistically significant. An increase of 16.45km in the distance to the place of work (the standard deviation of change in distance to work for all respondents) was related to a 0.213 increase in the ordered log odds of having a higher level of change in car use. That is, increased distance to work was associated with an increase in car use, all else being equal.

Removal of the change in distance travelled to work did not change the statistical confidence of magnitude of the effect of any other terms within the model to any notable extent, hence the results presented here are distinct of the effect of any change in the distance travelled to work.

Change in car ownership was statistically significant with increased car ownership relating to an increase in car use. For every increase of one car, there was an increase of 0.341 ordered log odds of being in a higher category of change in car use.

Of the urban form variables, the change in Ward population density and previous urban rural classification had no statistically significant effect on change on distance driven all else being equal. The change in distance to the urban centre had a statistically significant effect (p-value of 10%). An increase in distance to the nearest urban centre of 2,059m (the standard deviation of the change in distance to urban centre for those who had moved home) was associated with a 0.177 increased ordered log odds of being in a higher category of change in car use. That is, increased distance to the urban centre was related to increased car use. The change in jobs to population ratio also had a statistically significant effect, with an increase in the number of jobs compared to the population being associated with a reduction in car use. Specifically, for every increase of 2.95 (standard deviation of change for movers) in the jobs to population ratio, there was an increased ordered log odds of 0.274 of being in a lower category of change in car use.

5.3. Urban Form - Car Ownership

As shown in the previous analyses, differences in household car ownership explain much of the difference in household distance driven and change in car ownership is a statistically significant explanatory variable for the change in individuals' car use. It is therefore important to carry out analyses to determine whether car ownership is associated with urban form.

5.3.1. Analytical Method

The dependent variable car ownership is measured as "None", "One", "Two" or "Three or more" as already mentioned. The dependent variable is a categorical ordinal variable. Similar to the analysis of change in urban form and change in vehicle miles driven presented in section 5.2, ordinal regression analysis can be undertaken on the data to determine associations with various explanatory variables.

One assumption that needs greater consideration in this case is the assumption that there is an underlying continuous response which has been categorised into ordinal groups. Given that the data in this case is made up of categories of counts of cars, this assumption seems sensible.

5.3.2. Specification within SPSS

On inspection of household car ownership as described in Chapter 4, Descriptive Statistics, the logit link function was selected. Missing data were excluded on a listwise basis and the model was refined using backwards removal method. Variables were considered significant at the 90 percent confidence level (p-value of 0.1). The following output relates to a regression analysis for all respondents, movers and non-movers.

SPSS produced warnings relating to a large number of cells with zero frequencies. Having large number of categorical variables in a model with many categories or having a continuous variable in the model alongside categorical means that the number of combinations of these various categories, or points on a scale become very large compared to the sample size. Hence, for some combinations, there are no responses. On inspection of the data, there were frequent combinations of age group and income group for which there were no respondents and as such no specific conclusions should be drawn as to the effects of being in one such combination. In this instance age and income were included in the model as control variables and as such are not the focus of any conclusions being drawn.

5.3.3. Results of Analysis of Analysis of Urban Form and Car Ownership

Preliminary analysis showed that accommodation type was found not to be significant and was hence removed from the model. Similarly, no two-way interactions of the independent variables were found to be significant and were thus removed.

The -2 Log Likelihood statistic was 503 for the intercept only and 360 for the final model. While the -2 Log Likelihood values themselves should be treated with caution due to the large number of empty cells, the difference in their values and hence the chi-square statistic (139) should still be reliable. The statistics suggest the model is significantly better than the intercept only model.

The goodness of fit statistics (Pearson = 576, Deviance = 360) with significance levels of 1 show that the model predictions are very close to the observed data and that the model is well specified.

The Pseudo R-Square values indicate how much of the variance in the dependent variable is described by the independent variables (Cox and Snell = 0.440, Nagelkerke = 0.501, McFadden = 0.274). The difference in the values relates to the differences in the way these statistics are computed and depend on how the R-square is defined. The McFadden R-square value would suggest that 27.4% of the variability of the dependent variable can be described by the independent variables. This is considered to be a good model. None of the Pseudo R-square values should be considered more or less correct than the others, they are defined differently. The values can be used to compare one model run with another and give some indication of how much of the variability can be described.

	Estimate	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Threshold				
Current cars none	-4.164	.000	-5.829	-2.499
Current cars one	-.311	.695	-1.865	1.242
Current cars two	2.947	.001	1.153	4.742
Location				
Nº of residents in household	.235	**.035**	.017	.453
Current Ward density	-.014	**.041**	-.028	-.001
Distance to current centre	.000	**.034**	1.433E-5	.000
Current jobs:pop ratio	-.241	**.002**	-.394	-.088
Age 16-24	-.561	.429	-1.952	.830
Age 25-34	-.669	.237	-1.779	.440
Age 35-44	-.174	.760	-1.291	.943
Age 45-54	-.652	.278	-1.830	.526
Age 55-64	-.764	.218	-1.981	.452
Age 65 +	0[a]	.	.	.
Income Nil	-6.376	**.000**	-9.477	-3.274
Income Up to £10,399	-5.479	**.000**	-7.123	-3.835
Income £10,400 to £15,599	-2.890	**.000**	-4.111	-1.669
Income £15,600 to £20,799	-2.392	**.000**	-3.551	-1.233
Income £20,800 to £25,999	-2.412	**.000**	-3.566	-1.259
Income £26,000 to £31,199	-2.332	**.000**	-3.475	-1.188
Income £31,200 to £51,999	-1.583	**.000**	-2.413	-.754
Income £52,000 or more	0[a]	.	.	.

a - Redundant reference category

Table 5.6 Parameter Estimates for Model of Urban Form and Car Ownership.

The parameter estimates shown in Table 5.6 demonstrate the strength, magnitude and direction of any associations between the dependent variable car ownership and the independent variables. Of the socio-demographic variables, age did not have a statistically significant effect on household car ownership, all else being equal and no clear pattern emerges as to the magnitude of the effect. Household income was statistically highly significant (p-values of close 0.000) and had a large magnitude of effect on household car ownership. Compared to those in the highest household income group (£52,000 +), those in the lowest group (no income) had a 6.376 increase in ordered log likelihood of being in a lower category of car ownership, those in the up to £10,399 group had a 5.479 increase in ordered log likelihood of being in a lower category of car ownership. This differs considerably to that of the £10,400 to £15,599 category which had a 2.890 increase in ordered log likelihood of being in a lower category of car ownership. There was little difference between the middle income categories with those in the £15,600 to £20,799, the £20,800 to £25,999 and the £26,000 to £31,199 income groups with increase ordered log odds of being in a lower category of car ownership of 2.329, 2.412 and 2.332 respectively. Those in £32,200 to £51,999 had only a 1.583 increase in ordered log likelihood of being in a lower category of car ownership compared to the highest income group.

The number of residents in the household was also statistically significant with a larger magnitude of effect. Those households with 1.148 (one standard deviation) more residents than the mean (2.22), on average had a 0.270 increase in the ordered logs odds of being in a higher category of car ownership all else being equal.

All of the urban form variables were statistically significantly associated with car ownership. A 23.23 persons per hectare (1 SD) higher Ward population density related to 0.325 increased ordered log odds of having a lower category of car ownership all else being equal. Those residing 2,143 metres (1SD) further away from the nearest urban centre had a 0.394 increased ordered log odds of being in a higher category of car ownership.

One standard deviation (1.861) increase in the jobs to population ratio is associated with a 0.449 increase in the ordered log odds of being in a lower category of car ownership all else being equal.

In summary, higher household income, more people in the household, a higher population density, closer to the urban centre with a higher proportion of jobs compared to residents was associated with higher household car ownership.

5.3.4. Results of Analysis of Analysis of Urban Form and Car Ownership with "movers" term interaction.

In order to test whether or not the effect of urban form differed for movers and non-movers this term was interacted with all urban form variables. As a main effect, the "movers" term was not significant and hence removed from the model.

The -2 Log Likelihood statistic was 498 for the intercept only and 357 for the final model with chi-square statistic of 141 suggesting that the model is significantly better than the intercept only model.

The goodness of fit statistics (Pearson = 588, Deviance = 354) with significance levels of 1 show that the model predictions are very close to the observed data and that the model is well specified.

The Pseudo R-Square values indicate how much of the variance in the dependent variable is described by the independent variables (Cox and Snell = 0.449, Nagelkerke = 0.511, McFadden = 0.282). Thus the inclusion of the "movers" terms interacted with urban form variables produced a slightly better model fit.

	Estimate	Sig	95% Confidence Interval	
			Lower Bound	Upper Bound
Threshold				
Current cars none	-4.289	0.000	-6.043	-2.536
Current cars one	-.392	0.639	-2.028	1.245
Current cars two	2.899	0.002	1.033	4.765
Location				
Non-Mover * Current Ward density	-.012	0.211	-.031	.007
Mover * Current Ward density	-.015	**0.050**	-.030	-8.688E-6
Non-Mover * Distance to current centre	.000	**0.059**	-6.967E-6	.000
Mover * Distance to current centre	.000	**0.074**	-1.796E-5	.000
Non-Mover * Current jobs:pop ratio	-1.135	0.232	-2.995	.724
Mover * Current jobs:pop ratio	-.201	**0.014**	-.361	-.041
Age 16-24	-.795	0.292	-2.275	.684
Age 25-34	-.775	0.208	-1.981	.432
Age 35-44	-.345	0.589	-1.596	.905
Age 45-54	-.682	0.285	-1.932	.568
Age 55-64	-.816	0.200	-2.064	.432
Age 65 +	0[a]	.	.	.
Income Nil	-6.393	**0.000**	-9.666	-3.120
Income Up to £10,399	-5.514	**0.000**	-7.193	-3.835
Income £10,400 to £15,599	-2.797	**0.000**	-4.063	-1.530
Income £15,600 to £20,799	-2.435	**0.000**	-3.615	-1.254
Income £20,800 to £25,999	-2.341	**0.000**	-3.528	-1.153
Income £26,000 to £31,199	-2.312	**0.000**	-3.506	-1.118
Income £31,200 to £51,999	-1.623	**0.000**	-2.466	-.780
Income £52,000 or more	0[a]	.	.	.
Nº of residents in household	.283	**0.017**	.051	.514

a - Redundant reference category

Table 5.7 Parameter Estimates for Model of Urban Form and Car Ownership with Interaction of Movers.

With the introduction of the "movers" interaction term, the model differs considerably for those who had and had not relocated home within the preceding three years. Of the socio-demographic variables, age remained statistically not-significant. Household income remained statistically highly significant (p-values of close 0.000) and had a large magnitude of effect on household car ownership. Compared to those in the highest household income group (£52,000 +), those in the lowest group (no income) had a 6.393 increase in ordered log likelihood of being in a lower category of car ownership, those in the up to £10,399 group had a 5.514 increase in ordered log likelihood of being in a lower category of car ownership. This differs considerably to that of the £10,400 to £15,599 category which had a 2.797 increase in ordered log likelihood of being in a lower category of car ownership. There was little difference between the middle income categories with those in the £15,600 to £20,799, the £20,800 to £25,999 and the £26,000 to £31,199 income groups with increase ordered log odds of being in a lower category of car ownership of 2.435, 2.341 and 2,312 respectively. Those in £32,200 to £51,999 had only a 1.623 increase in ordered log likelihood of being in a lower category of car ownership compared to the highest income group. There was no change in the effect of the number of people in the household with those households having 1.148 (one standard deviation) more residents than the mean (2.22), on average had a 0.270 increase in the ordered logs odds of being in a higher category of car ownership all else being equal.

Of the urban form variables the Ward population density was significant for “movers” but not for “non-movers”. The magnitude of the effect was also slightly larger for movers with a 23.23 persons per hectare (1 SD) higher Ward population density relating to 0.348 increased ordered log odds of having a lower category of car ownership all else being equal.

Distance to urban centre remained statistically significant for both movers and non-movers. Those residing 2,143 metres (1SD) further away from the nearest urban centre had a 0.414 or 0.398 increased ordered log odds of being in a higher category of car ownership for “movers” and “non-movers” respectively. It could not be said with 95% confidence however that the association for non-movers was different from 0.

For the jobs:population ratio, it can only be said for movers, that the effect is different from zero with 95% confidence. One standard deviation (1.861) higher jobs to population ratio was associated with a 0.374 higher ordered log odds of being in a lower category of car ownership, all else being equal.

In summary, the association between urban form and car ownership is statistically more significant (and hence there is a higher degree of confidence that urban form has an effect) for those who had moved home in the preceding three years than those who had not. Similarly, the magnitude of the effect is also greater for those who had recently relocated.

5.4. Change in Urban Form – Change in Car Ownership

The previous analyses determined the effect of difference in urban form on differences in car ownership. However in order to determine whether a change in urban form resulting from a residential relocation relates to a change in car ownership analysis of the retrospective recalled data is required.

5.4.1. Analytical Method

Change in car ownership was computed by subtracting the current household car ownership from the previous household car ownership. Previous and current car ownership were ordinal. Change in car ownership is thus a count of the number of categories of car ownership by which the respondent had increased or decreased. A Generalised Linear Model (GLM) was therefore determined the most appropriate for of regression analysis.

On inspection of the distribution of change in car ownership, a normal distribution with identity link function was specified. This forms a special type of GLM; the Linear Regression model. A model was developed including change in urban form measures and change in socio-demographic variables. As with the model of change in distance driven presented in section 5.2.3 this model is unconditional in nature and hence not able to determine whether it is a change from a low to medium density or medium to high density that has an effect as only the change is tested.

5.4.2. Specification within SPSS

A liner model was specified by developing a Generalized Linear Model with an identity link function and a normal distribution. All two-way interactions between the explanatory variables were tested. Those variables that were not statistically significant and which did not add to the explanatory power of the model were removed using a backwards removal method. A significance of less than 10% was considered insignificant due to the relatively small sample size.

5.4.3. Results of Analysis of Change in Car Ownership and Change in Urban Form.

The intercept was found not to be significant and was thus removed from the model. Similarly, none of the two-way interaction terms were found to be significant and were removed along with the main effects of the previous urban rural classification and distance to urban centre. The final model was based on 190 cases after missing data were removed on a listwise basis. All change variables are as per previously defined.

The likelihood ratio Chi-square statistic (84.272) shows that the model is significantly different compared to the null model (with no explanatory variables). The goodness of fit statistics (Pearson Chi-square & Deviance = 51) with significance levels of 0.288 show that the model predicts a reasonable amount of the variation in dependent variable.

Table 5.8. shows the parameter estimates and levels of significance for all variables in the final model.

Parameter	B	95% Wald Confidence Interval		Sig.
		Lower	Upper	
A lot less income	-.233	-.673	.206	.298
A little less income	-.051	-.657	.556	.870
About the same income	.107	-.378	.591	.666
A little more income	.190	-.286	.666	.434
A lot more income	.228	-.265	.722	.364
No change in work status	-.172	-.544	.199	.363
Gained employment	.070	-.380	.520	.761
Lost employment	0[a]	.	.	.
Gained driving licence	.223	-.161	.607	.255
No change in licence	0[a]	.	.	.
Change in jobs:pop ratio	-.040	-.073	-.007	**.018**
Change in Ward Density	-.003	-.006	-.001	**.016**
No change in accom type	.066	-.227	.358	.660
Change from house to flat	-.528	-.889	-.168	**.004**
Change from flat to house	0[a]	.	.	.
(Scale)	.270[b]	.221	.330	

a - Redundant reference category

Table 5.8 Parameter Estimates for Model of Change in Urban Form and Change in Car Ownership.

As can be seen in Table 5.8 a number of variables were significantly associated with the change in household car ownership category. None of the categories of change in income were statistically significant alone, although the cumulative significance of change in income was (p-value overall of 0.01). Having an income which was a lot less than three years previously was associated with a 0.233 reduction in car ownership category. A little less income was associated with a 0.051 reduction. Those whose household income remained about the same had an increase in car ownership group of 0.107. A little more income and a lot more income were associated with 0.190 and 0.228 increased car ownership category respectively. The change in work status was not significant although added to the overall explanatory power of the model and was left in the model as a control. Similarly, having gained a driving licence was associated with an increase in car ownership category of 0.040

although the association was not statistically significant and hence it cannot be said with 90% confidence that gaining a driving licence has any effect.

Change in the jobs to population ratio was statistically very significant (p-value of 0.018), although the magnitude of the effect was small, with a one standard deviation increase (2.33) in the number of jobs compared to the population being associated with a reduction of 0.093 in car ownership category. Similarly Ward population density was statistically significant with an increase in density of 29.09 (1 SD) being associated with a reduction in car ownership category of 0.087. Change in accommodation type was statistically significant. While those who had not changed their accommodation type could not be distinguished from those who had moved from a flat to a house, those who had moved from a house to a flat had a reduction in car ownership category of 0.528 compared to those who moved from a flat to a house. Removing the change in accommodation type variable did not change the significance or magnitude of the effect of Ward population density of the jobs to population ratio to any notable extent and thus the effect of change in accommodation type can be considered to be distinct from that of density and jobs to population ratio. The effects of the change in urban form variables relate solely to those who had moved, as those who had not, by definition had no change in urban form. Introducing the "movers" term to the model did not show any notable differences in significance and explanatory power of the socio-demographics variables, but highlighted that the urban form variables were redundant for non-movers.

5.5. Longitudinal and Cross-sectional Analysis of Urban Form and Car Ownership

The analyses presented so far shows associations between urban form and current car ownership and also between change in urban form and change in car ownership. These associations are not the same in terms of the variables which are significant and the magnitude of the effect. Hence, in order to determine the overall effect of urban form, it is useful to carryout analysis of the between subject effects (cross section analysis of the current) and the within subject effect (quasi-longitudinal analysis of change) at the same time to give an indication of the overall effect.

5.5.1. Analytical Method

In the case of the car ownership data collected as part of this study, having information recorded on respondents over two or more time periods produces a number of problems and also opportunities for analysis.

The quasi-longitudinal element to the data set allows for analysis to be made of within-respondent changes in the response variable over time. In the case of this data set, it allows analysis to be undertaken of how the households' car ownership had changed over time and how this related to how the households' urban form and socio-demographics had changed as with the case of the previous analysis presented in Section 5.4. The results of that analysis showed that a change in a number of urban form variables (difference within the respondent) was associated with a change in car ownership. The analysis presented in Section 5.3, showed how differences between respondents in terms of their urban form related to a difference in car ownership levels between those respondents. However, those variables found to be significant were not always the same when explaining within subject difference as when explaining between subject difference. That is, the cross section effects of urban form appear to differ to the longitudinal effects, and hence it is difficult to draw conclusions as to the overall effect of urban form on car ownership. It is therefore desirable that analyses be undertaken to determine the average effects of the between and within subject effects already presented. In so doing, it would be possible to investigate trends or changes for respondents over time and how these trends or changes vary between respondents. That is; how the within-respondent changes or trends are relate to inter-respondent differences (Applied Longitudinal Analysis, 2006).

It should be noted here that in the modelling of such datasets as this, two distinct classes of model can be distinguished. First, is the use of a conditional model, where the earlier response is considered a covariate as opposed to a response. The second is the unconditional model, usually referred to as a repeated measures model, where both rounds of data are considered responses (Goldstein, 1995).

The use of repeated measures has several benefits. Not only is it possible to analyse within-respondent and inter-respondent differences, which a cross sectional study cannot, another benefit of having repeated measures on the same respondents through time is that the repeated measures of the same respondent act as a control for the unobserved heterogeneity (differences between the respondents that are not described by the data collected) amongst the respondents and may also help control for reporting error in situations where respondents consistently under or over-report a particular response. This increases the explanatory power of the model compared to a cross sectional model or a longitudinal study that does not have repeated measures on the same households, such as the models already presented in this chapter. One possible drawback with the use of repeated measures is a potential lack of variability in the data if respondents' car ownership or other circumstances have not changed greatly. As presented in Chapter 4, a good degree of variability exists in the data-set, both between respondents and within.

Despite these considerable benefits of a repeated measures longitudinal study, the use of such study designs in travel behaviour research is rare.

5.5.2. Model Selection

In order to utilise the repeated measures collected as part of this study, a suitable model, which was able to determine average effects of urban form, was required.

One of the challenges but also possible benefits of repeated measured from the same individuals is that there is likely to be co-variance in the response variable throughout time. That is to say that the number of cars owned by a household at one point in time will be statistically related to the number of cars owned by the household at another point in time. In the case of this study, it is expected that this co-variance will be positive. The way in which this covariance is modelled is an important consideration in the analysis of repeated measures data. The use of Generalized Linear Models (GLM) is not appropriate for the modelling of repeated measures on the same cohort as it ignores the correlation between the repeated observations. Generalized Estimating Equations (GEE) models were first introduced by Liang and Zeger (1986) as a modification of GLM that can accommodate the correlation between the repeated observations. The ability to use GEE to investigate cross sectional changes, longitudinal trends and the relationships between changes in explanatory variables, static explanatory variables and changes in the explanatory variables has obvious benefits to this study of car ownership and urban form over time. It is believed that while the technique may offer many advantages to those interested in urban form travel behaviour or car ownership research there have been no such studies to date utilising this technique. Yee and Niemeier (1998) used a Generalised Estimating Equations (GEE) model to analyse the trends in how mode frequencies changed over four waves of data collection, and how these related to income and life cycle stage, but otherwise, GEE models have rarely been applied to travel behaviour research. This is perhaps due to that fact that very few studies have utilised longitudinal or current and retrospective recalled data as is presented here. A GEE model was therefore developed to analyse the repeated measures of car ownership collected as part of this study in order to show population averaged responses to marginal effects of urban form.

In this instance, the repeated measures dataset can be said to be balanced. That is, data were collected from all respondents at the same set of *n* occasions, in this case two occasions. The data was also been collected at the same two points in time for all respondents.

The covariance matrix can be considered unstructured or a structure can be placed on the covariance matrix based on the assumption that the covariances are not arbitrary but follow some sort of pattern throughout time. The benefit of the unstructured approach is that no assumptions are made regarding the variances and co-variances, which are then estimated from the data. The main drawback of the unstructured approach is that the number of covariance parameters to be estimated grows rapidly as the number of occasions that the data are collected increases. Given that the data set in this study contains information collected at only two occasions in time, equal to all respondents, the covariance matrix was specified as unstructured.

5.5.3. Specification within SPSS

In order to run analyses on the repeated measures data, the dependent variable, car ownership, was considered to be a count variable. Whilst the actual question used elicited an ordinal response, with the uppermost category being three cars or more, very few people reported having three cars and it is suggested that only a small proportion of those households would have had more than 3 cars. Hence, for the analysis presented here it is assumed that those households who stated they had three or more cars, in fact had three.

Of the distribution and link functions considered suitable, the normal distribution with log link function was found to best describe the data.

From the previous analysis of change in car ownership without interaction of the movers term it could be concluded (and was subsequently shown) that the effects of urban form were related to solely to those who had moved, as those who had not had no change in urban form. However in the case of the GEE model, between respondent differences in urban form are considered alongside within subject differences. Hence, the GEE model required an interaction of explanatory variables with the "movers" term in order to uncover any differences between these two groups. The model was constructed with an interaction between the "movers" or "non-movers" variable and all other independent variables in order to try to describe household car ownership expressed as a scale variable with four categories from "no cars", to "three cars". The independent variables were entered into the model using a backwards removal method. Incomplete data were deleted on a listwise basis. The lack of variability in the current Urban Rural Classification meant that between respondent variation in this case cannot be analysed and was hence removed from the model. No two way interactions of urban form or socio-demographic variables were found to be significant and were hence removed from the model.

5.5.4. Results of Analysis of Change in Car Ownership and Change in Urban Form.

441 records of car ownership were included in the analysis, relating to 238 different households. Some households only gave information on their current car ownership and associated explanatory variables, hence the total of 441 is less than double the 238 households.

The goodness-of-fit statistics (QIC = 205, QICC = 198) were small suggesting a good fit between the model and the data collected. The goodness of fit statistics were primarily used to help optimise the model in the backwards removal method as previously described.

Source	Type III	
	Wald Chi-Square	Sig.
(Intercept)	105.648	**.000**
Movers * Age	17.081	**.073**
Movers * accomm type	5.995	**.050**
Movers * Household Income	101.357	**.000**
Movers * Licence Status	41.469	**.000**
Movers * Jobs:Pop ratio	44.340	**.000**
Movers * Ward density	17.706	**.000**
Movers * Distance to centre	5.779	**.016**

Table 5.9 Tests of GEE Model Effects of Urban Form and Car Ownership

Given that the GEE model utilised a larger dataset than the previous analyses, variables with a significance of 5% or less were considered, as opposed to 10% previously. As can be seen in Table 5.9, although Age overall was not significant it was kept in the model as it was felt important that the results be interpreted after age has been accounted for. The main effect of the movers term was redundant and hence removed from the model.

Parameter	B	95% Wald Confidence Interval		Sig.	Exp(B)
		Lower	Upper		
(Intercept)	.836	.595	1.077	**.000**	2.307
Non-Mover * Age 16-24	-.159	-.527	.209	.397	.853
Non-Mover * Age 25-34	-.415	-.742	-.089	**.013**	.660
Non-Mover * Age 35-44	-.295	-.623	.034	**.079**	.745
Non-Mover * Age 45-54	-.192	-.501	.116	.222	.825
Non-Mover * Age 55-64	-.220	-.530	.089	.163	.802
Non-Mover * Age 65+	-.207	-.526	.111	.202	.813
Movers * 16-24	.006	-.183	.194	.954	1.006
Movers * 25-34	-.108	-.251	.036	.141	.898
Movers * 35-44	-.107	-.253	.038	.148	.898
Movers * 45-54	-.107	-.259	.045	.169	.899
Movers * 55-64	-.134	-.311	.043	.138	.875
Movers * 65+	0^a	.	.	.	1
Non-Mover * Accom house	-.068	-.190	.054	.276	.934
Non-Mover * Accom flat	0^a	.	.	.	1
Movers * Accom house	.091	.010	.173	**.028**	1.096
Movers * Accom flat	0^a	.	.	**.**	1
Non-Mover * Income Nil	-.529	-.703	-.354	**.000**	.589
Non-Mover * Income Up to £10,399	-.513	-.691	-.336	**.000**	.598
Non-Mover * Income £10,400 to £15,599	-.366	-.524	-.208	**.000**	.694
Non-Mover * Income £15,600 to £20,799	-.212	-.397	-.027	**.025**	.809
Non-Mover * Income £20,800 to £25,999	-.276	-.482	-.070	**.009**	.759
Non-Mover * Income £26,000 to £31,199	-.294	-.463	-.125	**.001**	.745
Non-Mover * Income £31,200 to £51,999	-.127	-.232	-.022	**.018**	.881
Non-Mover * Income £52,000 or more	0^a	.	.	**.**	1
Mover * Income Nil	-.339	-.726	.048	**.086**	.713
Mover * Income Up to £10,399	-.661	-.832	-.491	**.000**	.516
Mover * Income £10,400 to £15,599	-.352	-.561	-.143	**.001**	.703
Mover * Income £15,600 to £20,799	-.194	-.341	-.047	**.010**	.824
Mover * Income £20,800 to £25,999	-.185	-.297	-.073	**.001**	.831
Mover * Income £26,000 to £31,199	-.125	-.229	-.021	**.018**	.882
Mover * Income £31,200 to £51,999	-.116	-.204	-.029	**.009**	.890
Mover * Income £52,000 or more	0^a	.	.	**.**	1
Non-Mover * Driving licence	.373	.230	.515	**.000**	1.451
Non-Mover * No Driving licence	0^a	.	.	**.**	1
Movers * Driving licence	.302	.150	.454	**.000**	1.352
Movers * No Driving licence	0^a	.	.	**.**	1
Non-Mover * Jobs:Pop ratio	-.088	-.118	-.058	**.000**	.916
Movers * Jobs:Pop ratio	-.031	-.050	-.013	**.001**	.969

Parameter	B	95% Wald Confidence Interval		Sig.	Exp(B)
		Lower	Upper		
Non-Mover * Ward density	.000	-.003	.002	.871	1.000
Movers * Ward density	-.003	-.004	-.002	**.000**	.997
Non-Mover * Distance to centre	3.350E-5	6.187E-6	6.081E-5	**.016**	1.000
Movers * Distance to centre	2.051E-6	1.872E-7	3.916E-6	**.031**	1.000
(Scale)	.312				

a - Redundant reference category

Table 5.10 Parameter Estimates for GEE Model of Urban Form and Car Ownership

As can be seen in Table 5.10, different variables are significant predictors of car ownership for movers and non-movers. Overall, the Age variable is not statistically significant for either movers or non-movers. Household income was statistically significant for both movers or non-movers. A general pattern emerged for non-movers with greater income being associated with greater car ownership. The lowest income group was associated with 59% of the car ownership of the highest income group. There is little difference in magnitude of car ownership between the middle income groups (£15,600 to £31,199). For movers, the lowest income group was associated with 71% of the car ownership of the highest income group; however the group with the lowest car ownership was households with up to £10,399 income. Having a driving licence is statistically significantly associated with household car ownership. Having a license was associated with 45% higher car ownership for non-movers and 35% higher car ownership for movers.

For "non-movers" there is no statistically significant difference between living in a house or flat. For "movers" however, living in a house was statistically significantly associated with a 9.6% greater household car ownership. The job:population ratio was significant for movers and non-movers. For non-movers a jobs:population ratio of 2.11 (1SD) higher than the mean of 0.95, was associated with 17.7% fewer cars per household for non-movers and 6.5% fewer for movers (elasticity of -7.97% and -2.93% respectively). Ward population density has no discernable effect (either in terms of statistical significance or magnitude) for non-movers. For movers the effect of the household residing in a ward with a population density 28.77 person per hectare (1 SD) higher than the mean (48.02) was associated with 8% fewer cars per household (an elasticity of -13.35%). The distance to the current centre is statistically significant for both movers and non-movers. Living 5,721 metres (1 SD) further from the urban centre than the mean (3,468m) related to 19% more cars per household for non-movers and 1% more for movers (11.52% and 0.61% elasticity respectively).

5.6. Summary of results

The analysis presented here shows that the differences in distances driven between households are largely explained by car ownership regardless of whether the respondents had moved home in the previous three years and after controlling for socio-demographic factors, including household size. That is, for two person households, those owning two cars drove substantially further than those owning one car. For both movers and non-movers, not having access to a car meant, by definition that they drove zero miles each year. Having one car was associated with driving a distance 46% that of three car plus households for non movers and 35% that of three car households for movers. Having two cars was associated with driving a distance 90% that of three car plus households for non movers and 61% that of three car households for movers. Thus, car ownership explains more of the variation in distance driven for those who had moved home in the previous three years than those who had not.

For movers who owned at least one car, living in a house was associated with driving a distance 56% that of those living in a flat, all else being equal. No other urban form variables were statistically significantly associated with distance driven once car ownership, accommodation type and socio-demographic variables were accounted for.

However, while change in car use was also explained to a large extent by change in car ownership for all households, a small number of urban form variables were also statistically significant predictors of change in car use for those who had moved home in the previous three years. For such households, an increase in distance to the nearest urban centre of 2,059m (the standard deviation of the change in distance to urban centres) was associated with a 0.177 increased ordered log odds of being in a higher category of change in car use. Increased distance to urban centre was associated with increased car use, all else being equal. Also, an increase in the jobs:population ratio of 2.95 (standard deviation) was associated with an increased ordered log odds of 0.274 of being in a lower category of change in car use. An increase in the number of jobs compared to the number of residents was associated with a reduction in car use.

After car ownership had been accounted for, urban form had little effect on distance driven and change in urban form only a small effect on change in distance driven. However, analysis of car ownership and change in car ownership showed urban form to have an effect.

A household moving in the last three years and living 2,143 metres (1SD) further away from the nearest urban centre, compared to the mean distance, had on average 0.398 more cars. Those moving to an area further away from Glasgow or Edinburgh City centre had higher car ownership compared to those moving to an area close to the city centre. Those relocating to an area with a jobs:population ratio 1.861 higher than the average area people relocated to, had a 0.374 higher ordered log odds ratio of being in a lower category for car ownership. Moving to an area with a high number of jobs compared to residents was associated with lower car ownership than those moving to an area with fewer jobs per resident and those moving to areas with a Ward higher population density had lower car ownership than those moving to areas less densely populated. For those who had not moved home, living in an area closer to the city centre was associated with lower car ownership, but no other differences in the current location of non-movers were statistically significantly related to the differences in car ownership.

Similarly, for those who had moved home, the change in jobs:population ratio from the previous location to their new location was associated with a change in car ownership. An increase of 2.33 jobs per resident was associated with a reduction of 0.093 in the car ownership category. An increase in population density of 29.09 people per Ward was associated with a reduction in car ownership category of 0.087.

Moving from a house to a flat was associated with reduction in car ownership category of 0.528 compared to those who had moved from a flat to a house.

The Generalized Estimating Equations model determined the average effect of urban form on car ownership, taking into account the characteristics of the previous residential location and the current residential location. More urban form variables have an effect on car ownership for those who had moved home. For such households, living in a house was associated with 9.6% more cars than living in a flat; having 2.11 more jobs per resident was associated with 6.5% fewer cars; living in area with 28.77 more residents per hectare was associated with 8% fewer cars and living 5,721m further from the urban centre was associated with 1% more cars. For those who had not moved house, neither the population density nor the accommodation type were statistically significantly associated with car ownership, but the effect of the jobs to population ratio and distance to urban centre were greater. 2.11 more jobs per resident was associated with 17.7% fewer cars per household and living 5,721m further from the urban centre was associated with 19% more car per household.

For movers, the combined effect of living in a sub/extra-urban area (i.e. in a house, living 5,721m further from the urban centre, with 28.77 fewer residents per hectare, with 2.11 fewer jobs per resident) was 25.1% higher car ownership all else being equal.

For non-movers, the combined effect of living in a sub/extra-urban area (5,721m further from the urban centre, with 2.11 fewer jobs per resident) was 36.7% higher car ownership, all else being equal.

This chapter describes the statistical analysis of urban form and the effect on distance travelled and car ownership. Chapter 6, Discussion and Conclusions, synthesises the results of the various statistical tests presented here, discusses their meaning and compares the findings with those found in the literature. Further work and limitations of the analyses presented here as also discussed.

Discussion and Conclusions

The previous chapter described the models created to test the hypotheses that urban form and car ownership have direct effects on travel behaviour and that urban form has direct effects on car ownership.

This chapter synthesises the results of the analysis presented in Chapter 5 and places these in the context of the literature, discusses the limitations of this research, draws conclusions and finally suggests further work.

5.7. Discussion

The analyses presented in this thesis sought to test the hypotheses that:

H1: Urban Form and Car Ownership have direct effects on Travel Behaviour
H2: Urban Form has direct effects on Car Ownership

The analysis presented in Chapter 5 suggests that household car ownership explains much of the variation in household distance driven and, residential population density, the jobs to population ratio and, distance to urban centre add little else, for those who have lived in their current home for more than 3 years. The only urban form characteristic that was statistically significantly associated with distance driven was the accommodation type, with those who owned at least one car and who had moved to a flat in the previous three years having a greater distance driven, than those who had moved into a house all else being equal. This association is unexpected in its direction, as it would be expected that living in a house would be associated with driving further. However, it is important to recognise that the association is for households with at least one car, all else being equal. Car ownership and other socio-demographics are not equal for those in houses and those in flats. Those living in flats had lower levels of car ownership (mean of 1.85) than those in houses (mean of 2.26).

These results are similar to those presented by Stead (2001) who found that socio-demographic variables, including car ownership explained between 19% and 24% of distance travelled, while urban form explained only 3%, with Ward density being the only variable to demonstrate any significant effect. The results presented here similarly show little effect of urban form on distance driven, after car ownership is accounted for. In terms of the first hypothesis, it can be confirmed that car ownership does have direct effects on distance driven however the effect of change in car ownership from 1 to 3 cars was inelastic. The effect of a difference between 0 and 1 cars was elastic. However the hypothesis that the urban form in which a household is located has direct effects on distance driven must be rejected. The differences between where households reside had no statistically significant effect on distance driven, once car ownership, other socio-demographic factors and the type of accommodation were accounted for, for those living in an urban and suburban setting.

The longitudinal analysis, while based on the individual as opposed to the household, showed that moving further from the nearest urban centre, to an area with fewer jobs per resident was associated with an increased likelihood of having reported an increase in car use, although the effect is small compared to other socio-demographic factors, especially changes in car ownership. The fact that the differences in urban form of where people lived, did not explain the difference in car use, but that changes in the distance to current centre and changes in the jobs to population ratio did explain some of the variation in changes in car use is consistent with the notion that households, when moving home, consider their travel preferences in the choice of urban form in which to live (Schwanen and Mokhtarian, 2005), whereas those who have not moved home more recently might well be living in an urban form which does not match their current lifestyle and travel behaviour. For those who did move home in the preceding three years, the characteristics of their residential location did not explain their distance driven. This could be because the variability of urban forms within Glasgow and Edinburgh were not sufficiently high to affect–distance driven, whereas the variability between the previous location and the current (for example from a rural area to Glasgow City centre) was great enough to affect change in car use. An alternative explanation could be as a result of the cross sectional analysis being based on the household, whereas the longitudinal analysis was based on the individual. It is also possible that the self reported change in car use is a less accurate measure of change in distance driven, than the cross sectional questions relating to annual mileages for all vehicles owned or available to the household. It is possible that residents over-estimated how much their car use had changed. It seems plausible that those who had moved home might, in particular, over-estimate how much their car use had changed over the same time period.

Although the associations between urban form and distance driven after car ownership was accounted for were weak, the car ownership was affected by urban form. Thus the direct effects of urban form on distance driven were minimal, but there were indirect effects through car ownership. Aditjandra et al (2011) similarly concluded that changes in urban form influence changes in travel behaviour directly but also indirectly through changes in car ownership in the North East of England. The urban form in which the household resided was statistically significantly related to the car ownership of the household for those households who had recently moved home. For movers, living in an area further from the city centre, in a less densely populated Ward, with fewer jobs per resident was associated with higher car ownership. These findings compliment those of Giuliano and Dargay (2006) who found that higher residential density was associated with lower car ownership as was living in a row/terraced house and being closer to public transport. From the analyses presented in this study, the effect was less pronounced for those households who had not recently relocated. For such households, living further from the city centre was associated with having more cars, but no other urban form variables had any statistically significant effect. This gives further weight to the notion that during a residential relocation, households re-evaluate the number of cars they own in order to better match their new residential location, whereas those who have not recently moved home might be living in an urban form which less well suited to their level of car ownership. This supports the idea of dissonance between lifestyles and urban forms discussed by Schwanen and Mokhtarian (2005). Hence, the second hypothesis that urban form has direct effects of car ownership is accepted for those who have recently moved home. For those who have not, the effects are limited. For those who had recently moved home, not only were characteristics of their residential location associated with car ownership, but the changes in their residential locations were associated with a change in car ownership level. For such households, moving to a higher density Ward, with more jobs per resident, and moving from a house to a flat was associated with a reduction in the number of cars owned by the household.

In order to determine the overall effect (cross sectional and longitudinal) of urban form on car ownership, a GEE model was developed. The model showed that while more urban form variables were associated with car ownership for those who had recently moved home, the magnitude of the effect of each of these variables was not always greater for movers. The beta value for the effect of jobs to population ratio was -0.088 for non-movers but only -0.031 for movers, for distance to urban centre it was 3.35 x 10^{-5} for non-movers and 2.05 x 10^{-6} for movers. However, for movers, living in a house as opposed to a flat was associated with a slightly higher car ownership (beta value of 0.091) and greater Ward population density was associated with fewer cars (beta value of -0.003). This results does entirely match the findings of the cross sectional analyses and the longitudinal analyses. An explanation for this seemingly odd result relates to how the GEE model works. The GEE model, uses two rounds of data on all households who gave information on their previous and current residential locations, car ownership and socio-demographics. It then accounts for the fact that for most households, there is strong positive correlation between the car ownership, socio-demographics and, in the case of non-movers, urban form between the two rounds of data collected. As such one benefit of the GEE is that it considers not only the effect of the current urban form on car ownership, but also on the previous urban form on car ownership. It seems highly plausible that the previous urban form for those who recently moved home, did not match well their car ownership levels. Indeed it can be speculated that this might have been one instigator for the relocation. As such the magnitude of the effects of urban form variables for movers, using both waves of data appear weaker than the analysis of the current location and of the change in location.

In order to test this theory, one further model was developed for movers, with previous car ownership as the ordinal dependent variable in order to test whether the previous urban form was statistically significantly associated with the previous car ownership. The model was specified as per the ordinal model presented in section 5.3. The results showed that only previous Ward population density was associated with previous car ownership for those who had moved in the preceding three years (beta value of -0.015 and significance of 0.003). The magnitude of the effect of population density was therefore the same for the previous location as for the current location for movers. However, no other urban form variables were close to being statistically significant at the 10% level, neither were income or age as were the case for the current residential location. This result gives added weight to the notion that during the residential relocation, households match their urban form with their car ownership level and other socio-demographic factors.

As stated in section 2.1.1, one explicit aim of planning policy in Scotland, and elsewhere, is to reduce car use. The findings of this research suggest that land use planning may be somewhat limited in bringing about such changes in car use and indeed might be counterproductive in tackling congestion, local air pollution and parking problems.

From the results presented here, it can be seen that car ownership has an inelastic association to measures of urban form. For those who had recently moved home, a 100% increase in population density related to 13.35% reduction in car ownership. Similarly, the elasticity of car ownership with respect to the Distance to Urban Centre was 11.52% for movers and 0.61% for non movers. The jobs to population ratio had an elasticity of -7.97% for recent movers and -2.93% for non-movers. Intensification policies therefore, are likely to relate to a small reduction in average car ownership for those moving into the newly intensified areas, but an increase in the number of cars in the intensified area. Thus, the effects of intensification may be counterproductive with more cars in the intensified area despite a small reduction in the average car ownership, exacerbating problems of parking, air quality, and congestion.

While there was no statistically significant association between population density and household distance driven, this was after car ownership had been accounted for. Intensification therefore, has an indirect effect on distance driven through its relationship with car ownership. The jobs:population ratio does also have a direct effect although it is very small (elasticity of -1.2% for all households). The slightly lower car ownership of households in denser areas would relate to slightly lower car use. Households may reduce from having one car to having none, and hence would see a 100% reduction in their distance driven. Those going from 2 cars to 1 car would experience a 42% reduction and those going from 3 cars to 2 cars a 39% reduction. The relationship between car ownership and distance driven are overall inelastic. Intensification will therefore lead to an increase in car miles travelled within the intensified area. While the average distance driven for the entire population (including the areas not intensified) may reduce slightly, there will be more cars in the intensified area and a greater distance driven by the increased population of the intensified area.

5.8. Limitations

It is important to recognise the limitations of the study. While it would have been possible to ask the respondent how many miles they drove three years ago, it was felt that the responses would have been unreliable as many people would not be aware how many miles they drove such a long period ago, however, it was felt that respondents would be able to judge change in distance driven. In addition to the problems of respondents over or under-estimating their change in car use already mentioned, this also led to the unconstrained analysis being carried out (only change variables being analysed without being benchmarked against previous or current measures). The result of only using change variables is that it is not possible from this study to say whether or not it is a change from low to medium jobs to population ratio or from medium to high that has the greater affect on car miles driven, although given the lack of strong associations found, this problem is not particularly relevant.

Another issue with the analysis of change in such unconditional models is the issue of regression fallacy. The problem is that measures of change are related to the initial values of the change variable. For example, that the change in car miles travelled is correlated with the initial number of car miles travelled. It maybe that those with an initially very low number of car miles travelled are likely to have increased the amount they drive and those who initially had a very high number of miles travelled by car are likely to have reduced the amount they drive. The importance of this problem of regression towards the mean is debated in the field of statistics (Taris, 2000). Drawing on finding from Alison (1990), Taris (2000) states that, “The participants in a longitudinal study can post hoc be assigned to a control group and a treatment group; the participants in the treatment group experienced a particular event between the waves of the study, the participants in the control group did not. By comparing the scores of the control and treatment group insight is obtained into the effects of the ‘treatment’……The non-equivalent control group design is especially appropriate in the case of surveys, as in this case the treatment is not under the control of the researcher.” In this case, the analysis presented here including the interaction term for movers and non-movers would appear to allay the fears noted regarding regression fallacy as it enables comparisons to be made between those who (by self selection) received the treatment (residential relocation) with a control group of those who did not (non-movers).

It is also possible here that respondents may find it easier to recall their travel behaviour for non-discretionary travel such as the journey to work from three years ago and hence changes in discretionary travel such as leisure travel may well be poorly recorded, which may introduce systematic error in the results.

It is also very important to recognise that while studying those people who have moved home and how the change in their residential urban form relates to changes in car ownership and vehicle miles driven, in terms of urban planning, there are problems with assuming that changing urban form for those who are not moving home (intensification policies) will have the same effect. Changes in urban form as a result of intensification are likely to take place over a long time period whereas changes in urban form resulting from a residential relocation are more immediate. Residential relocation is voluntary to the individuals whereas changes brought about through policy are not. Also much relies on the general housing market and existing stock of housing as mentioned in Section 3.3.5 and discussed further in Jenks and Jones (2010).

Further limitations relate to the use of case study areas in this study. While useful in terms of data collection and the design of the activity diary and questionnaire, the clustering of responses within these areas poses some problems. Firstly, by using data from these defined areas of Glasgow and Edinburgh, including data on those who had moved to these areas from other parts of the UK, it is difficult to draw conclusions as to what the overall response of the Scottish population would be to changes in urban form. Or to be more precise, what the response of household would be to a change in residential density following relocation to a different urban form in Scotland. The dataset omits those who have moved from an urban location to a rural location. However as already described, Scottish planning policy encourages development in existing urban areas, and hence those moving to rural areas are of less interest to this study. The second problem associated with the clustering of data geographically into case study areas is that of spatial autocorrelation, which is caused by data collected geographically having a tendency to be dependent. That is, as Overmars et al (2003) states, "Values over distance are more or less likely to be similar than expected for randomly associated pairs of observations." In the context of this study, it is possible that there are attributes of the case study areas or Wards within, that have not been captured in the study such as more detailed socio-cultural factors, that are producing similar behaviours or car ownerships rather than the urban form metrics collected at the Ward or case study area level. It should be noted however that clustering of the previous residential locations into particular wards does not occur for those who had moved house, and therefore while spatial autocorrelation may exist for the second set of repeated measures (after the move), spatial auto-correlation should not occur for the analysis of change between the two residential locations and hence the analysis based on the change in vehicle miles drive or change in car ownership should not be effected.

The issue of residential preferences was explored in the review of literature and development of hypotheses. While some studies have seen residential location preference as a factor that needs be controlled to avoid spurious results (Handy et al, 2005; Sermons and Seredich, 2001; Khattak ad Rodriguez, 2005), it was decided that in this study, no such account should be made. Studies cited in the literature review (Scheiner, 2010; Cevero and Duncan, 2002) discuss that urban areas with ubiquitous public transport might not demonstrate strong residential sorting based on travel preferences. Moreover, controlling for residential location preference possibly ignores a causal path through which urban forms and travel behaviours relate. Firstly, it is possible that previous residential location and travel behaviours help shape current preferences. Secondly, even if sorting based on travel preferences were found to occur, this still does not negate the possibility of the planning system being able to influence travel behaviours through manipulating the choice set of residential locations available to the household (for example, by making suburban car oriented living more expensive). That is regardless of people's preferences, free choice on residential location does not exist, it is constrained. Lastly, it should be noted that even in studies which have found a degree of residential sorting based on travel preferences, this points to a different causal mechanism, as opposed to no association between urban form and travel behaviour, not that there is no association at all. It was therefore felt that residential sorting based partly on travel preference should not be controlled for, as this could ignore a mechanism by which urban form influences travel behaviour.

5.9. Conclusions

The objectives of this study were:

- To estimate the effect of urban form on travel behaviour,
- To estimate the effect of car ownership on travel behaviour,
- To estimate the effect of a change in urban form on individual and household travel behaviour following residential relocation,
- To estimate the effect of urban form on car ownership,
- To estimate the effect of a change in urban form on car ownership following residential relocation.

The majority of research based in the US has demonstrated that "neo-traditional" attributes were associated with less distance travelled by car or fewer trips made by car (Cervero and Kockelman, 1997; Cervero, 2002; Ewing et al, 2003; Khattak and Rodriguez, 2005). A similar pattern of findings has been reported in Europe. In Europe there has been less focus on "neo-traditional" or other urban forms specifically designed to reduce car use; however, findings from studies of a range of urban forms also suggest a statistically significant association between higher residential density, proximity to urban centre, and mixed land uses with a reduced demand for travel by car (Dieleman et al, 2002; Snellen et al, 2002; Naess, 2005; Stead, 2001). However, few studies have been carried out in the UK and lesser so in the context of Scotland. Also, analysis of difference in urban form and travel behaviour or car ownership does not demonstrate that changes in urban form relate to changes in travel behaviour and car ownership. It was therefore felt that little evidence could be found in the literature as to how increased density, land use mix, close to urban centres, inherent in Scottish planning policy might relate to changes in distance driven and changes in car ownership.

The analyses presented here show that, after the decision as to how many cars to own is accounted for, little about the residential location has any effect on distance driven for residents in Glasgow and Edinburgh, whether they have moved home in the last three years or not. While the change in residential location showed more effect on personal distance driven, it seems highly plausible from these results that such an effect might dissipate over time, as the household remains in their current location, but with gradually changing lifestyles, socio-demographics and distance driven. Referring back to the hypothesised causal path diagram in Figure 6.1 below, the results suggests that the direct influence of urban form on vehicle miles driven is small and possibly ephemeral, while the relationship between car ownership (especially the choice of whether to own at least one car) and vehicle miles driven is strong, as expected.

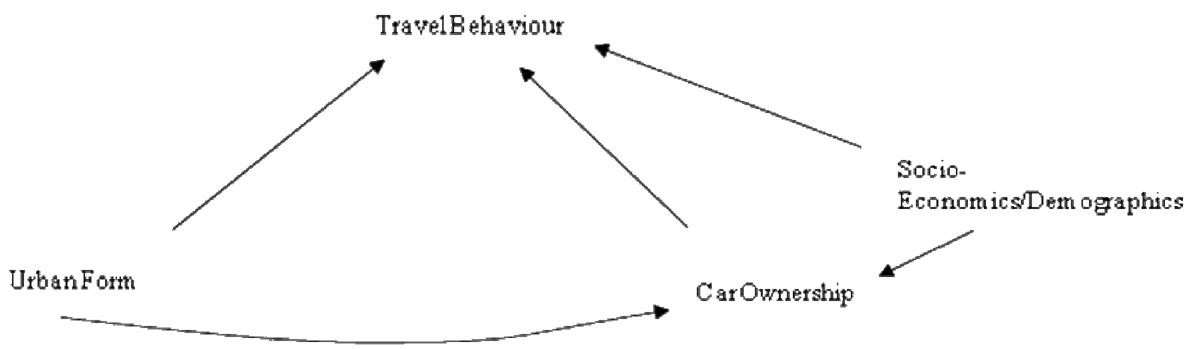

Figure 0.1 Hypothesised Urban Form, Car Ownership, Travel Behaviour Interactions.

Statistically strong associations were found between urban form characteristics and car ownership and changes in both. The data suggests that urban form influences car ownership which in turn influences vehicle miles driven, particularly for those who have recently moved home, with higher Ward population density, a greater number of jobs per resident and residing close to the city centre being associated with owning fewer cars, however the relationship is inelastic. Doubling population density would lead to a reduction in car ownership of 13%, which in turn would lead to a reduction in average car use, of less than 13 (as the relationships between car ownership levels and distance driven are also inelastic). Hence, intensification will lead to a 74% increase in cars and a greater increase in their use in areas with a 100% increase in population.

These findings are similar to those of other studies such as Echenique et al (2012) which estimated through simulation modelling that a doubling of density would relate to a 10% reduction in vehicle miles travelled (VMT) for three case study areas in the Southeast of England. Ewing and Cevero (2001, 2010) similarly found a 5% reduction in VMT as a result of doubling density. Others have noted the unintended consequence of intensification being an increase in congestion (Echenique at al, 2012; Sorensen, 2009) with associated problems of increased respiratory disease (Schweitzer and Zhou, 2010). The results of this study similarly call into question the use of intensification as a policy tool to reduce congestion, improve air quality and alleviate parking problems.

Cities are both the manifestation of current and previous lifestyles and travel behaviour, which also influence current lifestyles and travel behaviour. Where people choose to reside within these complex systems, both reflects preferences and influences behaviours. One of the roles of planning policy is to help shape the urban forms in such a way that creates more sustainable travel behaviours. By increasing the ability or those living in suburban areas to move to compact urban areas by increasing supply and hence reducing the price, planning policy can encourage households to relocate to areas where they are likely to own slightly fewer cars and hence drive very slightly less, regardless of preferences which might be towards more suburban locations. Increasing the supply of good schools, access to green space and improving the attractiveness of compact urban forms would also encourage more people to relocate to such areas. Conversely, by reducing the supply (and increasing the price) of suburban residential locations, households will be encouraged to located to compact urban areas, regardless of their preferences, which might be towards more suburban car oriented living. However, the effect of this as already mentioned is likely to be to increase driving in the intensified areas.

Whether or not planning policy can create the higher density, mixed use compact urban forms required is not within the scope of this thesis, and is questionable against a backdrop of residential preferences towards more suburban living, which were found in the sample (Jenks and Jones, 2010). Glasgow has experienced a dramatic loss of population over the last four decades and hence a reduction in population density, although the population has more recently stabilised and is predicted to increase by a relatively modest 1.4% by 2033 compared to 2008 levels, whereas Edinburgh on the other hand, is predicted to have 16.8% more residents in 2033 compared to 2008 (General Register Office for Scotland, 2010). In cities with a lack of housing supply and high housing costs, it seems likely that new high density developments would be economically viable, as the choice set available to households with a particular budget is more limited. In cities that have suffered dramatic population loss, with vacant high-density housing, it is questionable whether or not intensification is achievable against a backdrop of preferences for suburban living and a relatively affordable stock of such housing.

Further work on the availability and pricing of urban forms is required in order to determine if intensification could be achieved. It may also be the case that other policies with the same aim might be more successful in reducing distances driven, such as increasing the costs of owning and using a car or through better public transport provision.

It is not explored in this thesis, whether reducing vehicle miles travelled is something that should be aimed for. While reducing car use is often seen as a positive measure towards creating more environmentally sustainable lifestyle, the increase in mobility afforded by increased car ownership and use, undoubtedly has some positive effects including some positive impacts on the economy (SACTRA, 1999). However, proponents of increasing car ownership and use as a means to foster economic growth, rely on the premise that transport will in the future continue to be cheap. It is the view of the author of this thesis, that such a premise is doubtful. By shaping urban forms to encourage lifestyles less dependent on cheap personalised transport, it may help to minimise the impacts of any future rises in the costs of such transport. An alternative to using the planning system to "force" people into compact urban forms, might sensibly be to pursue policies aimed at increasing the cost of car use and more importantly ownership thus creating more demand for residential locations that are compact, dense and mixed.

5.10. Further Work

In order to investigate further the dissonance of urban form and car ownership, further work should be carried out over a longer time frame with more repeated measures of both. The data collected as part of this study were collected for two time periods, three years apart. Having more waves of data over a longer time period would enable an assessment to be made as to whether, and over what time periods the effect of urban form on car ownership following a residential relocation dissipate.

Further work which includes residential locations outside the main cities in Scotland, including suburban and extra-urban settlements, would enable stronger conclusions to be drawn as to the effect of encouraging development in Glasgow and Edinburgh as opposed to outside of Glasgow and Edinburgh.

In order to determine the effectiveness of intensification, further work should determine the proportion of the population moving to Scotland (or within) that are wish to reside in compact urban areas. Similarly, further work, utilising house price data would enable the effectiveness of intensification policies to be better tested, perhaps using stated preference survey designs in order to determine the trade-offs between price and residential preference that people are willing to make, thus determining a price differential required in order to "force" people into more compact urban areas regardless of their preference for suburban living.

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Appendix A. Record of US Based Research

The following table provides a summarised description of all US based studies not otherwise referred to in the main body of this thesis.

Table A1. Record of US Based Research.

Year	Study	Location of study	Description	Key Measures	Results
1976	Kain and Fauth (1976)	US	Travel demand model based on census data to determine how arrangement of land uses, density, location of residences and workplaces affect levels of car ownership and mode choice.	Car ownership Mode choice.	Most variation in mode choice is explained by car ownership. Public transport provision, parking charges and work place and residential densities play a role in determining the level of car ownership.
1989	Boarnet and Sarmiento (1998)	US	Ordered probit regression analysis based on data from 769 individuals controlling for gender, race, income, household size and other socio-economic factors.	Non work car trips per individual.	No significant relationships found including for the proportion of four-way intersections within 1/4 mile of residence.
1990	Replogle (1990)	US	Discrete choice analysis carried out to test association between urban form and the probability of using public transport and the probability of accessing public transport by	Probability of using public transport and the Probability of accessing public transport by foot.	Use of public transport is more likely in zones with higher public transport serviceability index, walk access to public transport is more likely in zones with higher transit serviceability index.

			foot using composite urban form measures built up from sidewalk conditions, land use mix, building setbacks, public transport, stops amenities, bicycle conditions.		
1993	Sasaki Associates (1993)	US	Descriptive study of 10 neighbourhoods with variety of urban forms.	Public transport share of work trips.	Public transport use is higher in public transport oriented and pedestrian oriented neighbourhoods.
1993	San Diego Association of Governments (1993)	US	Descriptive analysis of data from 251 households in 13 traditional communities compared to the regional average. No statistical methods or control variables.	Number of trips by purpose per household, Public transport, walking and bicycle share of home based trips.	Trip frequency is lower in traditional communities, walk and bike shares are higher in traditional communities and public transport share is lower in traditional communities.
1993	Handy (1993)	US	Descriptive analysis of data from 34 census areas and traffic analysis zone data.	Average shopping trip length, Number of shopping trips, Person miles travelled	Shopping trips are shorter at locations with high local or regional accessibility. Person miles travelled for shopping is lower at locations with high local or regional accessibility.

				on shopping trips.	
1993	Parson Brinkerhoff Quade Douglas (1993)	US	Regression analysis carried out on data from 2,421 households in different traffic analysis zones, controlling for household size, car ownership, income and other socio-economics.	Vehicle miles travelled per household, Vehicle miles travelled per person, Number of vehicle trips.	Vehicle miles travelled is lower where household densities are higher or more employment is accessible by either mode. Vehicle trips are more frequent where more employment is accessible by car, and less frequent where more employment is accessible by public transport. Vehicle miles travelled and vehicle trips per household decrease as the pedestrian environment factor increases.
1994	Ewing et al (1994)	US	ANOVA analysis carried out on data from 163 households in 6 urban forms around Palm Beach County, Florida.	Vehicle hours travelled per person, Number of trips per person for work and non-work purposes, Share of trips for public	Inverse relationship between accessibility and vehicle hours travelled per person. Density, mixed use, and a central location all appear to depress vehicular travel.

				transport and walking/cycling. Density, Land use mix and Centrality.	
1994	Friedman et al (1994)	US	Descriptive study of data from 1105 households in 35 different urban forms. No statistical methods or control variables.	Trips per household, Mode split of trips by purpose.	Trip frequency is lower in traditional communities. Walk, bike and public transport shares of trips are higher in traditional communities.
1994	Franc and Pivo (1994)	US	Regression analysis carried out on census tract areas at an aggregate level. Travel data aggregated from the Puget Sounds Transportation Panel survey carried out in 1989 controlling for household size, car ownership, and other socio-economics.	Mode splits of work and shopping trips , Gross population density, Gross employment density, Land-use mix, Socio-demographic variables.	Public transport share of work trips is greater at high employment densities. Public transport share of shopping trips is greater at higher population and employment densities.

1994	Holtzclaw (1994)	US	Regression analysis carried out on aggregate census data from 29 communities with various urban forms controlling for average community income.	Average vehicle miles travelled per household	Vehicle miles travelled is lower at higher net household densities.
1994	Parson Brinkerhoff Quade Douglas (1994)	US	Regression analysis carried out on data from 2,223 households controlling for household size, car ownership, income and other socio-economic variables	Vehicle miles travelled per household	Vehicle miles travelled is lower where household densities are higher or more employment is accessible by car. Vehicle miles travelled is lower in areas where a higher proportion of the commercial buildings were built before 1951.
1994	Cervero (1994a)	US	Regression and Logit analysis of data from 2,560 households in 27 different areas close to rapid public transport controlling for socio-economic and destination site variables	Train travel share of work trips, Mode of transport to access stations.	Train use commute share is greater for higher density residential settings. Higher densities induce more walk access trips to train stations.

1994	Cervero (1994b)	US	Regression analysis of data from 18 office buildings around rapid public transport stations controlling for occupational mix, differences in origins and socio-economics.	Train travel share of work trips, Mode of transport to access stations.	Train use commute share is greater for higher density work settings. Train users have higher shares of mid-day trips by foot. Parking supply at work place discourages public transport use for commuting, and walking and cycling to train stations.
1995	Cervero and Gorham (1995)	US	Descriptive study of 14 neighbourhoods paired by socio-economic and other factors but with various urban forms. No statistical methods used.	Modal splits of work trips	Walk, cycle and public transport mode splits are higher in transit oriented neighbourhoods.
1995	Handy (1995)	US	Study of 389 people in four neighbourhoods paired by regional location. Two way ANOVA carried out controlling for household size and work status.	Number of walking for leisure trips per person, Number of walking to shops trips per person, Number of trips to supermarkets per person,	Walk trip frequency is lower to shops in traditional neighbourhoods. Trip frequencies to convenience stores are higher in traditional neighbourhoods.

				Trip time to supermarkets, Number of trips to convenience stores per person, Number of trips to regional malls per person, Others.	
1995	Kulkarni et al (1995)	US	Difference of means test of data from 524 households in 20 different urban forms. No control variables included.	Number of trips per household, Number of public transport trips per household, Number of walking and cycling trips per household.	Trip frequency is lower than average in traditional neighbourhoods and higher than average in planned unit developments. Frequency of public transport trips is higher in traditional neighbourhoods. Frequency of walking and cycling trips is lower in planned unit developments.
1996	Rutherford et al (1996)	US	Descriptive analysis of data from 663 households in 3 mixed use	Average trips per household,	Trips are shorter in mixed use neighbourhoods. Walk share is higher

			areas and three large sub-areas in the Seattle Area. Comparison between the two, with cross tabulations of income and life cycle.	Average proportion of short trips, Average walk share of trips, Average distance travelled per person, Average hours travelled per person, Others.	in mixed use areas. Distances travelled per person are lower in mixed use areas.
1996	Cervero and Radisch (1996)	US	Binomial Logit model fitted to data from 820-990 people from two neighbourhoods that were matched by median income, location and rapid public transport access. Controlled for household size, car ownership, income and other socio-economics.	Number of work and non-work trips per person, Probability of using car or non car for work and non-work trips.	Non-work trips in traditional neighbourhoods are more likely be made by car than non-work trips in other neighbourhoods.
1996	Handy (1996)	US	ANOVA analysis of data from 1,368 people from six neighbourhoods matched in terms	Number of leisure walking trips, Number of walking trips	Frequency of walking trips to shops is higher in traditional neighbourhoods than in early modern neighbourhoods

			of socio-economics.	to shops, Others.	and higher in early modern neighbourhoods than in late modern neighbourhoods.
1996	Ewing (1996)	US	Regression analysis carried out on patronage per bus stop for 157 bus stops not controlling for any socio-economic variables.	Patronage per bus stop	Bus patronage is greater at higher employment densities.
1996	Messenger and Ewing (1996)	US	Aggregate analysis using simultaneous equations of data from 690 traffic analysis zones controlling for aggregate housing type income and car ownership.	Bus share of work trips (home zones), Bus share of work trips (work zones).	Bus share of work trips is greater at higher overall densities through the effects of density on car ownership and parking costs.
1996	Parson Brinkerhoff Quade Douglas (1996)	US	Regression analysis of data from 261 light rail stations in 11 US metropolitan areas controlling for average household income.	Daily boardings per light rail station.	Rail ridership is higher at higher densities.
1996	Schimek (1996)	US	Regression analysis carried out on data on 15,916 households controlling for household size, car	Vehicle miles travelled per household, Vehicle trips per	Vehicle miles travelled is lower at higher densities. Vehicle trips are less frequent at higher densities.

			ownership, income and other socio-economic variables.	household.	
1996	Strathman and Dueker (1996)	US	Logit analysis carried out on 3,645 commuting round trips controlling for income, gender, age and other socio-economic variables.	Probability of choosing public transport over drive-alone, Two other mode choice variables.	Use of public transport is more likely at higher densities.
1996	Morall and Bolger (1996)	Canada	Regression analysis carried out on mode splits for public transport averaged for 21 central business districts not controlling for socio-economic variables.	Public transport share of work trips.	Public transport share of work trips is lower in downtowns with more parking spaces per employee.
1997	Douglas and Evans (1997)	US	Descriptive analysis of data from 3,207 employees in four different areas. No statistical methods used or control variables used.	Public transport share of commute trips, Number of mid-day trips per employee, Walk share of mid-day trips, Mid-day vehicle miles	Public transport share of commuting trips is higher in urban and suburban downtowns compared to suburban office campuses and office parks. Walking and public transport share of mid-day trips are higher for suburban and urban downtowns compared to suburban office

				travelled, Vehicle miles travelled per day per employee, Others.	campuses and office parks. Midday vehicle miles travelled is higher for suburban office campuses and office parks. Daily vehicle miles travelled is higher for suburban office campuses and office parks.
1997	Kulkarni and McNally (1997)	US	Two way ANOVA analysis carried out on data from 524 households in 20 different urban forms controlling for household income.	Trips per household, Mode split of trips by purpose.	No significant relationships found.
1997	Moudon et al (1997)	US	Descriptive analysis of the volume of pedestrian traffic measured in 12 different neighbourhoods matched in terms of density, income and other socio-economics.	Volume of pedestrian traffic	Volume of pedestrian traffic is higher in urban neighbourhoods compared to suburban.
1997	Kitamura et al (1997)	US	Regression analysis carried out on data from approximately 1,400 persons in five neighbourhoods matched by income, controlling for	Trips per person, Walking and cycling trips per person, Public transport share of	Walking and cycling trips are more frequent closer to parks. Walk/bike share of trips is higher closer to a parks and at high densities. Public transport

			household size, car ownership, income and other socio-economic variables.	trips, Walk/bike share of trips, Two other variables.	share of trips is greater closer to parks.
1997	Cervero and Kockelman (1997)	US	Logit and regression analysis carried out on 2,850 trips from 868 households in the San Francisco Bay Area, controlling for household size, car ownership, income and other socio-economic variables.	Vehicle miles travelled per household, Vehicle miles travelled per household for home based non work trips, Probability of choosing modes other than car for non-work trips, Two other travel behaviour variables. Factor analysis used to aggregate urban form metric into the "three Ds" of Density, Diversity and	Total vehicle miles travelled is lower at locations of higher regional accessibility. Vehicle miles travelled for non work trips is lower where the intensity of diversity factor or vertical mix is greater. Use of modes other than car is more likely in neighbourhoods with more intense development. Vehicle miles travelled is lower for non-work trips where the proportion of four-way intersections is higher or proportion of blocks that are quadrilaterals is lower.

				Design. Socio-demographic variables, Vehicle ownership and Public transport service intensity.	
1997	Kockelman (1997)	US	Logit and regression analysis carried out on data from a survey of over 9,000 households controlling for household size, car ownership, income and other socio-economic variables.	Vehicle miles travelled per household, Vehicle miles travelled per household for home based non work trips, Probability of choosing walk or bike for a trip, One other mode choice variable.	Total vehicle miles travelled is lower at locations of higher regional accessibility or a higher degree of land use mixing. Vehicle miles travelled for non work trips is lower at regions of high regional accessibility, higher degree of land us mixing and more balanced mix of different uses. Use of walk and bicycle is more likely in locations of higher regional accessibility and more balanced mix of land uses. Use of modes other than car is more likely where the proportion of parcels with paid, off-

					street parking or paid on-street parking is higher.
1997	Loutzenheiser (1997)	US	Logit analysis carried out on 11,553 trips one half a mile around rapid public transport station controlling for household income, car availability and other socio-economic factors.	Probability of walking to station.	Walking to station is more likely where retail uses predominate around stations. Walking is less likely as the length of arterial roads around the station increases
1997	Ross and Dunning (1997)	US	Descriptive analysis of travel behaviour from a nationwide survey not controlling for any socio-economic or other factors.	Trips per person, Trip length, Public transport mode share, Walk/bicycle mode share, Vehicle miles travelled per person, Other travel behaviour measures.	Vehicle miles travelled appeared to be lower in locations of higher density. Trips appeared to be shorter in locations of higher population and residential density. Walk mode share is greater at higher population and residential density. Public transport mode share is greatest at the highest population and residential densities.

1997	Douglas et al (1997)	US	Study to analyse the link between an index derived from retail employment within one mile and local intersections within 1/2 mile of residences with travel behaviour.	Trips per person, Car trips per person, Public transport trips per person, Walk trips per person, Vehicle miles travelled per person.	Car trips are less frequent with higher retail and intersection indices. Public transport trips are more frequent in areas of higher indices. Vehicle miles travelled is lower in areas with higher indices.
1998	Boarnet and Sarmiento (1998)	US	Ordered Probit model using travel diary data from 769 residents of southern California collected in 1993.	Number of non-work car trips, Socio-demographic variables, Car ownership, Commute distance measure, Population density, Street pattern, Retail employment density, Service employment density,	No urban form variables are significantly associated with the number of non-work car trips.

				4 non-transport related neighbourhood attributes for residential preference modelling.	
1998	Crane and Crepeau (1998)	US	Regression analysis (ordered logit) using travel diary data from a 1986 survey of San Diego, California. Initial survey carried out over the phone followed by paper travel diaries sent to households, 2,754 of which responded.	Socio-economics, Street pattern defined as Connected, Cul-de-sac or A mixture of the two, Travel diary data on Trip mode, Times, Frequency, Purpose and Destination; Distance to central business district,	Street pattern has no statistical association with car or pedestrian travel. Percentage of undeveloped or vacant land is negatively associated with the number of non-work car trips. Distance to the central business district is positively associated with the number of car trips. Proportion of commercial land use is positively associated with non work trip generation.

				Land use mix.	
1998	Handy et al (1998)	US	Analysis carried out on survey data collected from selected Austin, Texas neighbourhoods. Controlling for income, gender, age, employment status, children under 5 in the home.	Number of walking trips for strolling and for shopping.	Perceived safety, shade coverage (hot climate), and the frequency and desirability of seeing people while walking were significant in the shopping trips analysis in the expected directions.
1998	Miller and Ibrahim (1998)	Canada	Disaggregate regression analysis not accounting for any socio-economic data based on data collected in the 1986 Transportation Tomorrow Survey around Toronto, Ontario, Canada.	Vehicle kilometres travelled for home based, Work trips per worker, Car ownership, Jobs/population balance, Population density, Distance to urban centre.	Distance to the central business district and distance to the nearest high density employment centre were significantly positively associated with vehicle miles travelled for home based, work trips per worker.

1998	Kasturi et al (1998)	US	ANOVA and other regression analysis carried out on disaggregate dataset controlling for household size, vehicle ownership, income and other socio-economic variables.	Trips per household, Vehicle miles travelled per household.	Trip frequency is higher in areas of high accessibility to jobs. Vehicle miles travelled is lower in areas of high accessibility to jobs or high accessibility to households.
1999	Buch and Hickman (1999)	US	Descriptive analysis of data from 17 light rail stations not controlling for any socio-economic variables.	Average daily ridership per station.	Public transport ridership appeared to be associated with areas of high employment density.
1999	Srinivasan and Ferreira (1999)	US	Study looking at how travel behaviour compares to 4 composite measures of urban form.	Transit accessibility factor, Pedestrian convenience factor, Commercial residential mix factor, Car accessibility factor for non-work trips.	Use of non car modes is more likely in suburbs with greater mixing of commercial residential uses. Use of public transport is less likely in outer suburbs of higher public transport accessibility. Use of public transport is more likely in home to work corridors with good public transport access. Use of walk mode is more likely in home to work corridors with good pedestrian

					convenience.
2000	Criterion Planners Engineers (2000)	US	Descriptive analysis of data from 29 households in "new-urbanist" developments compared to the regional average. No socio-economic controls.	Trips per household, Trip time per purpose, Public transport share of work trips, Walk share of work trips, Public transport share of non-work trips, Walk share of non-work trips, Others.	Trip frequencies were lower in new urbanist developments. Trip times for shopping and other trips were shorter for new urbanist developments. Walk share of non-work trips is higher for new urbanist developments.
2000	Frank et al (2000)	US	Partial correlation analysis carried out on data from 1,700 households, controlling for household size, income and number of vehicles.	Vehicle trips per household, Vehicle miles travelled per household, Vehicle hours travelled per household.	Vehicle trip frequency is lower in areas of higher household density and high employment density at the workplace. Vehicle miles travelled is lower in areas of high household density and high employment density at both the home

					and work location. Vehicle hours travelled is lower in areas of high household density and higher employment density at both the home and work location. Vehicle miles travelled is lower in areas with smaller census blocks. Vehicle hours travelled is lower in areas with smaller census blocks.
2000	Pushkar et al (2000)	Canada	Regression analysis carried out on data from 115,000 households aggregated into 795 traffic analysis zones controlling for household size, income and car ownership.	Average vehicle kilometres travelled per household, Average public transport passenger kilometres travelled per household.	Vehicle kilometres travelled is lower at locations with higher employment accessibility and more land use mixing. Public transport passenger kilometres travelled are higher at locations with fewer jobs and fewer grocery stores within 1km. Vehicle kilometres travelled is lower in locations with curvilinear roads, and more intersections per kilometres, and higher in locations with "rural" road networks and more

					road kilometres per household.
2001	Greenwald and Boarnet (2001)	US	Ordered probit regression model of cross sectional data from a sample of Portland Travel diary from 1994.	Socio-demographics, Trip frequencies, Trip speeds and distances, Activity type, Composite pedestrian environment factor, Street pattern, Population density.	Population density measured at the neighbourhood level is positively associated with the likelihood that a trip will be carried out by walking.
2001	Kitamura et al (2001)	US/Japan	In effect 2 studies. One of data from Southern California using 1,898 responses to a 1993 panel survey. Accessibility's association to car ownership and car use was explored using an ordered probit model and to car use using OLS regression. The other study	Prism based accessibility measures, Car and public transport accessibility indices, Activity engagement, Time availability, Car ownership and type, Car vehicle miles	Time availability is a stronger determinant of activity engagement than opportunity in large highly developed metropolises. In the Californian study, those with no public transport provision have higher car ownership. In the Japanese study,

			involved a structural equations model of residential location, socio-economics, car ownership and trip making using data from employed household heads randomly drawn from the 1990 Kei-Han-Shin travel survey.	travelled, Residential density, Retail employment density and Socio-demographic variables.	those in areas with both higher public transport and car accessibility owned fewer cars, but higher car accessibility lead to more car trips while higher public transport accessibility suppresses car use. The structural equations model however showed that given car ownership and use, accessibility has no direct influence on the number of trips, trip chains, or total travel time expended.
2002	Cervero (2002)	US	Binomial and multinomial logit models of mode choice based on 5,167 trips surveyed as part of a 1994 household travel survey in Montgomery Country, Maryland, US.	Urban form defined as three Ds: Density, Diversity and Design. Mode choice by Trip purpose, Socio-demographic	Higher densities and land use mixes were associated with higher public transport use and lower drive alone car travel. The influences of design factors was more modest but in the directions expected. No account made of self selection or time order.

				attributes. Travel times and costs were computed for each trip by mode.	
2003	Ewing et al (2003)	US	Aggregate OLS regression analysis based on census and other data from 83 metropolitan areas of the US with a focus on detailed measures of sprawl.	Multiple dimension characterisation of sprawl including Street pattern, Density, Land use mix and Degree of centralisation. Travel behaviour measured as Vehicles per household, Percentage of commuters using public transport, Percentage of	Density is negatively associated with average vehicle ownership, vehicle miles travelled per capita, traffic fatality rate and is positively associated with alternative shares of commute travel.

				commuters walking to work and Mean journey time to work. Other urban form, travel behaviour and other metrics.	
2003	Rajamani et al (2003)	US	Multinomial logit model of mode choice fitted to data on 2,500 individual home based trips from the Portland Metropolitan Area Activity Survey in 1995.	Socio-demographic characteristics, Trip times and costs, Land use mix diversity measures, Residential density, Accessibility, Street pattern configuration and Mode choice.	Greater mix of land uses appears to be associated with increased proportion of walking trips. Non-work trip mode choice is positively associated with accessibility level by that mode. Higher density was also associated with lower single occupant car trips and increased use of public transport although density is correlated with mix.

2004	Rodriguez and Joo (2004)	US	Utility model (multinomial conditional logit) of discrete mode choice using data from a 1997 survey of 509 students' and staff travel at the University of North Carolina.	Normal mode of travel to university, Home location, Demographics, Travel times by mode, Presence of walking and cycling paths, Sidewalk availability, Local topography, Residential population density, Vehicle ownership, Public transport provision.	Topography and walking/cycling path provision are associated with a higher propensity to walk and cycle. Population density was not significant measured at the residential block level.
2005	Handy et al (2005)	US	Regression analysis of cross sectional and quasi-longitudinal data collected in 2003 from eight neighbourhoods in Northern California weighted towards those who had recently moved home.	Commute trips, Non-work trips, Walking trips, Car ownership, Estimated weekly mileage,	The cross sectional analysis shows that no urban form variables are significant predictors of vehicle miles driven after attitudes and preferences were accounted for. The quasi-longitudinal analysis showed that change in driving

			Cross sectional analysis of vehicle miles driven and urban form. Longitudinal analysis of reported change in vehicle miles driven and change in urban form.	Reported change in vehicle miles travelled, Accessibility measures, Public transport, walking and cycling infrastructure measures, Safety, Neighbourhood typology defined as traditional or recent suburbia, Other neighbourhood characteristics, Socio-demographics and Attitudinal group.	was associated however with changes in urban form measures or proxies for them such as accessibility.
2005	Khattak and Rodriguez (2005)	US	Regression analysis combining location choice and travel behaviour on data collected from one sustainable/neo-traditional neighbourhood and one more	Various neighbourhood characteristics for residential preference model, Household size,	No difference in total trips made, however, share of alternative modes is higher in neo-traditional neighbourhoods.

			suburban neighbourhood matched in terms of socio-economics etcetera.	Vehicle ownership, Type of neighbourhood (neo-traditional or suburban), Number of trips, Distance of trips.	
2005	Zhang (2005)	US	Nested Logit model of car dependence and car use and how this relates to urban form variables using disaggregate trip diary data sets from three different US cities.	Mode choice given the car dependency of the respondent. Socio-demographic control variables, Population density, Home distance to work.	Distance to work is positively associated with car dependency. Population density is negatively associated with car dependency.
2008	Forsyth et al (2008)	US	Analysis of walking behaviour and activity levels of 715 participants in 36 environmentally diverse areas in the Twin Cities in Minnesota using survey, 7-day activity diary and accelerometer.	Walking: Distances Times, Frequencies By activity.	Walking for specific purposes such as leisure or travel was significantly associated with physical characteristics of the environment. However, total physical activity is similar for similar people in different places.

				Socio-economics, Street pattern, Public transport provision, Land use mix, Urban form perception measures.	
2008	Chatman (2008)	US	Regression analysis based on data from 3003/2004 survey of San Francisco – Oakland – San Jose area (1000 respondents) with focus on household living close to a rail station. Survey was carried out over the telephone and gathered information on activities undertaken over a 24hr period.	Dependent Variables: Auto Speed Non-work Activities Vehicle Miles Travelled. Independent Variables Built Form Density Activity Density (local desirable non-work activities) Network Load Density Others and control	Residential network load density is negatively associated with speed of driving and highly correlated with non-work travel. Activity Density and Built Form Density are not as significantly related suggesting denser development with reduced car provision are required together in order to influence travel behaviour.

				variables	
2009	Bhat et al (2009)	US	Nested logit model to reflect what the paper proposes is a joint decision on vehicle ownership, type and distance travelled using data from the 2000 Bay Area Travel Survey	Dependent Variables: Number of vehicles Type and vintage of vehicle Annual mileage Independent Variables: Household income Age Gender Ethnicity Presence of children Household size Number of employed individuals	Higher income households and those with more employed people prefer newer vintage vehicles and are less likely to use non-motorised forms of transport. Households in urban areas or high density commercial/industrial areas are less likely to own a large vehicle type. Households in areas with higher bike land densities are more likely to use non motorised forms of transport and those located in areas with a higher street block density are more likely to prefer compact vehicles.

				Presence of senior adults Population density Employment density Land use mix Bikeway/highway and street block density	The age, gender and ethnicity also related to vehicle holdings and usage decisions.
2009	Lee et al (2009)	US	Trobit model of relationships between urban form, household activities, and time allocation using cross sectional data from the SMARTRAQ 2001-2002 household activity based survey in the Atlanta region of Georgia, USA.	Various urban form and socio-demographic measures only summarily described in the paper. Measures of activity participation.	Increased concentration and accessibility to shops and services associated with more time spent of discretionary activities. Increased density associated with less time spent on maintenance activities during weekdays and less time spent on discretionary activities at the weekend.
2009	Zahran et al (2009)	US	Logistic and binomial regression analyses on the numbers of people commuting to work by foot and by	Numbers walking and cycling to work per county.	Temperate summers, low humidity and topographic variation are natural characteristics that increase numbers

			bike in each county in the US. Cross sectional aggregate data based largely on census.	Population and population density of each county Dist to work. Measures of natural amenity and green space access. Educational level, value of home and ethnicity. Measures of civic attitudes to environmental issues. Urban form metrics including measures of connectivity, proximity, sprawl	commuting by foot/bike. Lower densities, longer journeys to work, higher air pollution levels, lower incomes and lower levels of civic infrastructure are related to lower levels of walking and cycling to work.
2010	Xing et al (2010)	US	Regression analysis of disaggregate cross-sectional data relating to self reported cycling frequency. Data collected from 6 neighbourhoods in	Socio-demographic variables included age, income and educational level.	Age positively associated with weekly miles of recreational cycling but not transportation cycling. Attitudes correlate with distances cycled as

			6 small US cities matched on size, weather, topography and presence of college with 12.6% response rate.	Attitudinal variables to record views towards cycling and driving. Perceived distances to various destinations, perceived safety of cycling and perceived provision of local cycling infrastructure.	expected. Perceived safety positively associated with distances cycled. Perceived distances to destinations negatively associated with distances cycled.
2010	Pinjari and Bhat (2010)	US	Development and application of Multiple Discrete-Continuous Nested Extreme Value (MDCNEV) model of discretionary time use (activity timing and activity time use) using data from the 2000 BATS.	Out of home, non-worker, discretionary time use and timing. Socio-demographics of individuals, Household Composition Vehicle Ownership Disability	Larger household size is associated with greater non-worker participation in out of home maintenance activities. Single person non-worker households are associated with greater participation in out of home socialising and meals during evenings. Plus numerous other significant associations between socio-demographics and activity participation and timings.

Appendix B Record of European Based Research

The following table provides a summarised description of all European based studies not otherwise referred to in the main body of this thesis.

Table B1. Record of European Based Research

Year	Study	Location of study	Description	Key Measures	Results
2000	Snellen (2000)	Netherlands	Multinomial Logit analysis of mode choice with respect to urban form and street pattern metrics using activity diary data collected from 17 neighbourhoods in 9 medium sized Dutch cities carried out in 1997.	Socio-demographics, Density, Availability of services, Urban form (typology), Road network typology at city and neighbourhood level, Mode choice and Distance travelled.	Population density is only significantly associated with sports/club trips with medium density areas favouring non-motorised modes. Distance to the location chosen was significant as expected, with longer distance journeys associated with higher car use. No affect of urban form (typology) on mode choice. Street pattern was significantly associated with mode choice with grid patterns being more favourable to non-motorised

					transport.
2001	Meurs and Haaijer (2001)	Netherlands	Regression analysis of various mobility measures against urban form metrics and control variables using panel data from the Dutch Time Use Survey conducted in 1990 and in 1999, allowing for longitudinal and cross sectional analysis.	Home characteristics, Street characteristics, Distance to public transport provision, Traffic calming, Neighbourhood green planting, Accessibility of shopping facilities, Urban, suburban, village or rural setting, Number of trips by mode and purpose.	Residential environment characteristics together are significantly associated with the total number of trips especially for shopping trips although the effect of separate characteristics is fairly small both cross-sectionally and longitudinally.
2001	Schwanen et al (2001)	Netherlands	Analysis of how monocentric or polycentric urban structures affects mode choice and travel distance for various journey	Van der Laan (1998) method of describing polycentricity, Personal/household	Mixed results for urban system's influence on mode choice and distance travelled. Generally, deconcentration and

			purposes in the Netherlands based on data collected from the 1998 Netherlands National Travel Survey.	attributes, Residential environments, Level of urbanisation, Trip purpose, Distance, Mode and Length.	development of polycentric urban forms seem to be associated with more use of the private car for all purposes. It is arguable that the method for defining urban system is itself a function of travel behaviour.
2001	Snellen et al (2001).	Netherlands	Regression analysis of travel behaviour performance indicators with respect to urban form and street pattern metrics using activity diary data collected from 17 neighbourhoods in 8 medium sized Dutch cities.	Travel behaviour performance indicators: average travel times, average total travel distance, travel time rations (by mode), Urban form defined as polycentric, lobe, poly-nuclear and	Urban form and network type measured at the city and neighbourhood level are not associated with activity/travel performance indicators, except for people living in lobe cities who travel significantly longer distances by public transport.

				grid. Transportation network defined as ring, radial and grid.	
2002	Dieleman et al (2002)	Netherlands	Multinomial logit model and other regression analysis of mode choice and distance travelled based on data collected from the 1998 Netherlands National Travel Survey, exploring the associations with urban form metrics.	Mode Choice, Distance travelled by purpose, Household structure, Socio-demographics, Car ownership, Regional setting, City size, Urban or suburban location.	Attributes of the residential environment have a clear, strong influence on modal choice and distance travelled as expected. The metrics used makes it hard to draw any conclusions about the specific urban form measures such as density and mix that are significant. Car ownership is the most important variable for explaining mode choice.

2002	Schwanen et al (2002)	Netherlands	Multivariate regression analysis of data from 1998 Netherlands National Travel Survey investigating the association between urban form metrics and travel time.	Travel time by purpose and mode, Socio-demographic factors, Car ownership. Urban form classification based on city size, residential density, land use mix and urban structure.	Residential context influence daily travel time whereas the effects of car ownership are only indirect. Travel time for car drivers tends to rise with the degree of urbanisation of the residential environment. Car travel times in the polycentric regions are higher than in the mono-centric regions.
2002	Snellen et al (2002)	Netherlands	Multilevel regression analysis on data from activity diary surveys in various neighbourhoods throughout urban Holland, investigating associations between urban form attributes and travel behaviour.	Urban form typology categorisation, Transport network typology, Employment location, Distance to city centre, Distance to rail station, Distance to subcentre,	Urban form and network type have only a modest, yet present, effect on mode-choice decisions for frequently conducted activities.

				Density. Working, shopping leisure and escort travel times, modes, locations. Socio-demographics.	
2003	Schlich and Axhausen (2003)	Switzerland	Regression and descriptive analysis of data collected from a 12 week leisure travel diary for 71 persons.	Dwelling type, Dwelling size, Availability of external space, Residential context, Occupancy duration, Residential activities, Socio-demographics.	People with a garden/balcony carried out fewer leisure trips. People in city centres carried spend more leisure time away from their home. Other variables such as owning a dog, income age etc were also significant.
2003	Simma and Axhausen (2003)	Austria	Structural equations modelling 1992 Upper Austrian travel survey.	Gravity based accessibility measures, Car ownership,	Car ownership strongly influences mode choice, this then has an impact on distance

				Mode choice and Distance travelled.	travelled. Car owners make fewer trips on foot and more/longer trips by car. Accessible local services leads to more localised travel behaviour, distance to district capital is associated with longer distances travelled and more public transport use for commuting. Work place accessibility is associated with an increase in trips made by public transport, retail accessibility is associated with a decrease in trips made by car or on foot. Gender, work status other socio-demographics also significant.

2003	Timmermans et al (2003)	Trans-national	Comparative study using regression analysis of the activity arrangement/travel behaviour of residents in four different cities based on activity and travel diary data from Portland (USA), Midlands (UK), Fukuoka (Japan), Canadian metropolitan areas and South Rotterdam region (Netherlands).	Trip and tour frequencies by mode. Urban form defined as urban, suburban or countryside with good or bad public transport facilities. Socioeconomics	Travel patterns are largely independent from spatial setting, except for extreme cases after differences between the cities have been accounted for.
2004	Schwanen et al (2004)	Netherlands	Exploration of spatial development policies in Holland over the last 40 years. Empirical analysis (descriptive and regression) of the effect of these planning policies using data from the 1998 Netherlands National Travel Survey / travel diary.	Degree of urbanisation and measure of urban structure (polycentricity). Mode choice, Travel distance and Travel time.	Policy of concentrated decentralisation has probably stimulated the use of public transport but not walking and cycling.

2005	Naess (2005)	Copenhagen, Denmark	Multivariate regression analysis on a sample of 1932 residents (33% response rate) 485 of whom had moved house in the preceding five years. Activity diary survey included.	Travel distance, Mode split, Distance to urban rail station, Population and employment density, Distance to central Copenhagen, Distance to sub-centre, Transport attitudes, Car ownership, Driver's license, Overnight absences, Socio-demographics.	Living in a dense area close to the central Copenhagen area is associated with less travel, a lower share of car driving and more trips by foot or bike. Some evidence of compensation with more leisure travel for residents of denser, central areas.
2008	Milakis (2008)	Athens, Greece	Disaggregate multivariate regression analysis of 29, 358 households in the Athens area.	Residential Density, Jobs-employment balance, Land use balance, Distance from centre, Road space per person,	Residential density is the most important measure of urban form which influences travel behaviour. Residential density may increase the use of public transport at the expense of the

				Income, Household size, Car ownership Public transport accessibility Modal Split Mean journey length by car, Per capita energy consumption by car.	car up to a threshold of 200 persons per hectare.
2009	Verhtsel and Vamelslander (2009)	Flanders and Brussels, Belgium	Exploratory discussion around disaggregate census data for 1.2 million Flemish commuters.	Distance travelled to work by mode Proximity to public transport services Urban area categorised in terms of functional area and density.	People living close to railway stations, public transport interchanges, and in urban areas with high economic density travel less distance, especially by car.

Appendix C. Review of Urban Form Metrics

The issue of how urban form is to be measured is of obvious importance in to any investigation into relationships between urban form and travel behaviour.

This review explains and summarises the measures of urban form that have been measured in studies relating to how urban form influences travel behaviour and other issues and draws on similar reviews such as that by Krizek (2003). This review focuses on the more objective quantitative measures of urban form used as opposed to the many studies already mentioned which have manually assigned a given area to an urban form typology such as traditional, suburban etcetera.

Density

The most commonly used measure of urban form in travel behaviour and other research is density. This can, however, be measured in a number of different ways, which can give hugely different densities for the same location (Forsyth, 2003). Some studies have looked at how density at a neighbourhood level affects travel behaviour, whereas others have looked at this over a wider city or town level. It is possible that density at different scales affects different aspects of travel behaviour such as the journey to work or leisure travel.

Forsyth (2003) gives a good overview of some of the standard ways in which density can be measured, focussing on residential densities and is, in itself, based on previous work carried out on the subject. The measures outlined are:

- Site Density – Number of dwellings divided by the total area of the site.
- Block Density – Number of dwellings divided by the block area measured to the kerb line.
- Net Residential Density – Number of dwellings divided by the total land area devoted to residential facilities.
- Gross Residential Density – Number of dwellings divided by the land area.

- Net Neighbourhood Residential Building Type Density – Number of dwellings of a particular type in a neighbourhood divided by the land area associated with that type.
- Net Neighbourhood Density – Number of dwellings in the neighbourhood divided by the base land area of the neighbourhood calculated to exclude citywide uses in the neighbourhood.
- Gross Neighbourhood Density – Number of dwellings divided by the total neighbourhood area.
- City Density – Number of dwellings divided by the total developed area of the entire city.
- Metropolitan Density – Number of dwellings divided by the total metropolitan area including undeveloped parts within.
- Net Residential Density at City or Metropolitan Level – Number of dwellings divided by the total built up area within the city of metropolitan area.

These measures of density can also be calculated in terms of the number of people (resident, working, and so on) as opposed to the number of dwellings. In addition to density, it is also possible to use measures of building intensity, which relates to density at a more detailed level as follows:

- Floor Area Ratio – Built floor area divided by the site area.
- Building Site Coverage – Area of the ground floor footprint of the building divided by the site area.
- Building Block Coverage – Total area of building footprints divided by the block area.
- Impervious Surface Site Coverage – Area of ground floor footprints, plus paved parking areas, drives, footways etcetera divided by the site area.
- Impervious Surface Block Coverage – As above but based on the block area.
- Front Kerb Setback for Site – Distance from the building façade to the edge of property line.
- Front Kerb Block Setback – Average distance from the façade of a building to the edge of property line for the block.

- Side-to-Side Distance Between Buildings – distance between buildings averaged across a block.
- Front-to-Back Distance Between Buildings – distance between the back facades of buildings averaged over a block.

These measures describe density/intensity at a number of different geographies and, although some have not been specifically developed for use in investigating interactions between travel/transport and urban form may be useful measures.

The paper by Song (2002) uses the following basic measures of density for example:

- Lot Size – Median lot size of single-family dwelling units per neighbourhood,
- Floor Space – Median floor space of single-family dwelling units per neighbourhood,
- Single Family Residential Dwelling Unit Density – Number of single-family dwelling units divided by the residential area of the neighbourhood.

Further details of these measures are given by Song and Knaap (2004).

The paper by Ewing et al (2003) introduces the weighted measure of density to account for the high or low densities in the areas around the study areas (sphere of influence) but does not go into detail on how such a sphere of influence is determined. This is presumably to try and take into account of the fact that the study area might be relatively low density but close to high-density areas, which could still have a bearing on behaviour.

Cervero (2002) considers density at the origin of trips (the home) and density at the destination of trips (work place) as being key variables to be tested. This is to try and ascertain whether the origin (usually residential areas) and destination densities are important in explaining travel behaviour as opposed to just the origins on their own, which have normally been considered in urban form travel behaviour research. Similarly, Chatman (2003) found that employment density was significantly related to lower vehicle miles travelled for commuting of the employees in the areas studied suggesting that measures of density at the destination ends of journeys should also be considered.

Longley and Mesev (2002) introduce the concept of measuring density profiles between any two points in an urban system. This could theoretically be applied to density along a public transport route or a specific journey-to-work origin and destination for example.

Land Use Mix

Some measures of land use mix are intrinsic in some of the measures of density previously mentioned. A low net neighbourhood density implies a large proportion of at least one other land use be it industrial, agricultural etcetera. There are many ways of defining and categorising land use, which need to be considered before the mix of such uses can also be considered.

The Office of the Deputy Prime Minister (ODPM) use the following categorisations of land use to describe land use within the UK (ODPM. 2006):

ORDER		Group	
U010	AGRICULTURE AND FISHERIES	U011	Agriculture
		U012	Fisheries
U020	FORESTRY	U021	Managed forest
		U022	Un-managed forest
U030	MINERALS	U031	Mineral workings and quarries
U040	RECREATION AND LEISURE	U041	Outdoor amenity and open spaces
		U042	Amusement and show places
		U043	Libraries, museums and galleries
		U044	Sports facilities and grounds
		U045	Holiday parks and camps
		U046	Allotments and city farms
U050	TRANSPORT	U051	Transport tracks and ways
		U052	Transport terminals and interchanges
		U053	Car parks
		U054	Vehicle storage
		U055	Goods and freight terminals
		U056	Waterways
U060	UTILITIES AND INFRASTRUCTURE	U061	Energy production and distribution
		U062	Water storage and treatment
		U063	Refuse disposal
		U064	Cemeteries and crematoria
		U065	Post and telecommunications

U070	RESIDENTIAL	U071	Dwellings
		U072	Hotels, boarding and guest houses
		U073	Residential institutions
U080	COMMUNITY SERVICES	U081	Medical and health care services
		U082	Places of worship
		U083	Education
		U084	Community services
U090	RETAIL	U091	Shops
		U092	Financial and professional services
		U093	Restaurants and cafes
		U094	Public houses and bars
U100	INDUSTRY AND BUSINESS	U101	Manufacturing
		U102	Offices
		U103	Storage
		U104	Wholesale distribution
U110	VACANT AND DERELICT	U111	Vacant
		U112	Derelict
U120	DEFENCE	U121	Defence
U130	UNUSED LAND	U131	Unused land

Table C1. Land Use Categorisation.

The ODPM also oversee the Use Class Order system for development control, which classifies land use in England and Wales (Use Class Order England and Wales, 1987). Scotland has a slightly different Use Class system to England and Wales (OQPS, 1997). Local authorities are responsible for determining into which of these land use categories each piece of land falls. This system is currently being reviewed by the Department for Communities and Local Government in England and Wales.

Two key terms used when spatially describing land use mix along with other urban form variables are **scale**; the area over which the mix is to be measured and **grain**; the resolution of the data. For a UK example, if the land-use mix of the whole of Glasgow were to be recorded based on data at a census output level, then the scale would be Glasgow City boundary and the grain would be census output area level.

Rajamani et al (2003) in the US divided land use up into four categories and then assigns a land use index to each neighbourhood where by zero equals only one land use present up to one, which equals a quarter of each land use present.

The paper Hess et al (2001) describes some of the previous work undertaken in measuring and quantifying land use mix and patterns and suggests new methods for doing so. The paper outlines the two key ways in which land use mix has previously been measured and suggests that these alone can not accurately describe the detail of land use mix required when analysing the impact on household travel behaviour. The two methods reviewed by the paper are firstly an **entropy index** (Frank and Pivo, 1994), which does not distinguish between different types of land use but instead gives a level of how mixed an area is generally; according to the paper, in the past this has often been calculated at too large a grain (often US census tract). The other measure outlined is the **Dissimilarity Index** (Cervero and Kockelman, 1997), which assigns a predominant land use to each grain of 1 hectare and then compares this to the predominant land uses of the neighbouring grains to derive a Dissimilarity Indices. The paper suggests that both of these methods of measuring land use mix are too crude and proposes a new methodology for measuring land use mix. This new measure firstly considers **complementary land uses**. These are different land uses where the travel interactions between the two are significant such as residential and office use. A mix of land uses between agriculture and office use for example is thought to be irrelevant in transportation terms. For this reason, the study aggregated areas of land into three functionally complementary groups of land uses.

- Medium Density Residential/ Retail/ Services/ Schools
- Retail/ Services
- School/ Sites

These areas were then converted to a raster image and analysed using the Fragstats software (McGarigal et al, 2002) to describe the mixture and shape of land uses. This gave a high number of descriptive measures of land use mix including patch shape, interspersion, juxtaposition etcetera.

The paper by Song (2002) uses the following measures of land use mix:

- Mix = Acres of commercial, industrial and public land in the neighbourhood divided by the number of dwelling units.

This is obviously highly dependent on the definition of a neighbourhood, which does not appear to be given.

There are then two indices of diversity, which are relatively complex calculations of the proportions of different land uses in the neighbourhoods but would not give an indication of how these different areas of land use are arranged within the neighbourhood itself.

The paper produced by Ewing et al (2003) present six measures of land use mix as summarised below:

- % of residents within a half a block of their home
- % of residents with satisfactory neighbourhood shopping within 1 mile
- % of residents with a public elementary school within 1 mile.
- Job-resident balance
- Population serving job-resident balance
- Population serving job mix

The latter three variables aim to describe the mix of jobs in the area and how these compare to the skills of the resident population.

Cervero (2002) considered land use diversity at the trip origin and trip destination separately. For the origin, land use diversity is defined as retail employment and population ratio relative to the countywide ratio, and for the destination, an entropy index is assigned based on numbers of households, retail employment, office employment and other employment. The concept of vertical land use mix is introduced by Cervero in his work with Kockelman (Cervero and Kockelman, 1997); this is the proportion of buildings with different land uses on different levels.

A definition of how entropy, homogeneity and contrast of land use mix can be measured is given in the review by Srinivasan (2002), which describes the mathematical form of these methods in great detail.

There are a number of ways of describing land use mix and on the whole, the methodologies differ little from study to study. It is more the categorisation of land use and the scale and grain of measurement that appears to be the key decision in terms of measuring land use mix in urban-form travel-behaviour research. The problem of defining mix and choosing the scale and grain can be shown in the example below. The shaded areas represent residential areas in the grid below. If the whole grid is selected as being the grain of measurement, it will give a very different level of mix than if the whole grid is divided into four and assigned a measure of mix. The example below also highlights a problem in trying to describe shape. The residential area in the bottom left of the grid forms a well defined block whereas the residential area on the right hand side of the grid appears to form an "S shape", which might for example be aligned along a highway. How the shape of different land uses in an area might influences people's travel behaviour has not been extensively researched to date.

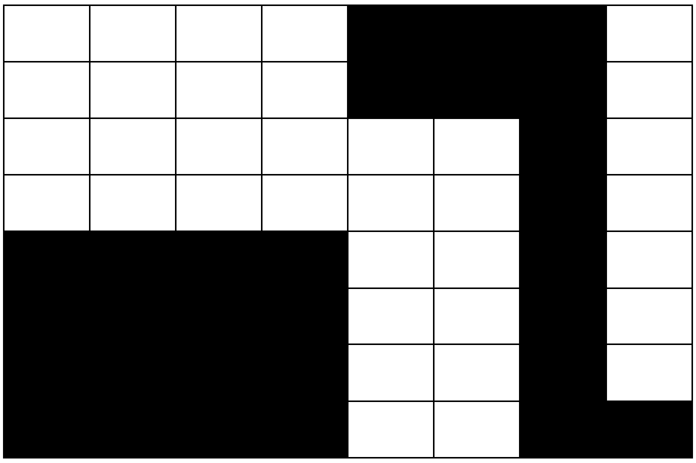
Figure C1. Large Scale Measure of Shape

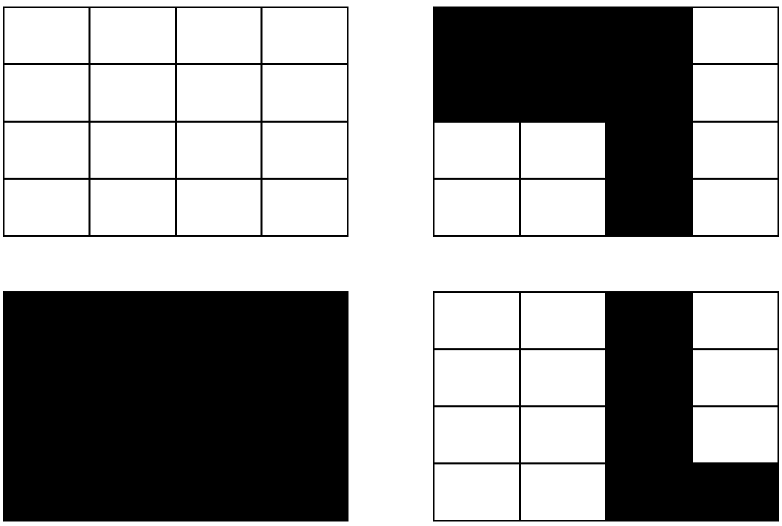
Figure C2. Smaller Scale Measure of Shape

Given these difficulties in measuring the mix of land uses, it is not surprising that many studies have instead used some ratio of jobs to residential population as a proxy for the mixture of employment to housing land uses (eg. Zhao, 2009; Cervero, 1989; Peng, 1997).

Polycentricity

Another way of measuring the spatial arrangement of an area is presented by Van Der Laan (1998). This study looks at the commuting patterns of the inhabitants in order to define the structure of a city or a region. As such, this measure of urban form is actually a measure of behaviour as opposed to built form itself. These commuting patterns enable the area to be defined in terms of how monocentric or polycentric it is. This is done by assigning two measures of nodality, N_1 and N_2 where, N_1 is the number of people commuting into the city centre from the suburbs divided by the total number of people commuting into the whole study area from within the study area and N_2 is the number of people commuting out of the city centre to the suburbs divided by the total number of people commuting out of the study area. If the value of N1 is low it indicates a more dispersed system with people commuting from one suburban peripheral area to another whereas high values of N1 indicate a monocentric system with a high proportion of people commuting from the suburban and peripheral areas to the city centre. If N2 is high then this indicates a decentralised system with people commuting out of the city centre into the suburban and peripheral areas. A combination of N1 and N2 values for a study area enables more comparisons between the relative polycentricity of the study area to be made. The study then considers whether or not the west of Holland acts as one polycentric region using a similar methodology by looking at inter-commuting between the urban areas in the west of Holland. This however does not appear to be an entirely quantitative exercise and interpretation is based on visual inspection of the results. If there is a significant exchange of commuting between two urban areas then they are considered to act as one system. The Office of the Deputy Prime Minister also produced a scoping study on polycentricity (ODPM, 2003). This report again defines a polycentric region as having significant two-way commuting between the built up areas. The report then goes on to discuss the relative pros and cons of polycentricity and describes current policy. There is no quantifiable definition of polycentricity in the report but instead includes a discussion of some of the regions within the European union, which are considered to be polycentric and how these would be further developed.

In Scotland research has been undertaken on polycentricity in terms of how it is defined (Parr, 2004) and also whether or not the central belt of Scotland can be described as a Polycentric Urban Region (PUR) and what the benefits of such might be (Turok and Bailey, 2004). From these two papers it is clear that there is no consensus on how polycentricity should be measured and what any benefits arising from such urban forms might be.

Ewing et al (2003), consider the degree of centralisation as a function of population density and employment levels and how these relate to distance from the central business district with high densities close to the CBD describing a more traditional centralised city.

Snellen et al (2002) have sought to define a city's structure based on the spatial layout and transport network. In this work, the urban form of the city is categorised as being one of the following:

- Concentric City
- Lobe City
- Linear Polynuclear City
- Concentric Polynuclear City
- Linear City
- Grid City

There are a number of ways of describing the spatial form of a city or regional area. Many of these methods are however subjective and rely on the individual to interpret how centralised the road network pattern is, or interpreting the profile of densities from the central business district. Other measures such as polycentricity measures are often themselves functions of travel behaviour and as such statistically unsound to be used as independent predictors of travel behaviour in any subsequent modelling.

Street Design

There have been a number of studies looking at how street design influences people's travel behaviour with a number of different measures of street design. Again the geography over which this is measured is a particularly important factor. Snellen et al (2002) for example, sought to define street layout at a number of different scales as falling into one of the following categories:

City Level

- Linear Network
- Radial Network
- Ring Network
- Grid Network
- Shifted Grid Network

Neighbourhood Level

- Ring
- Loop
- Radial
- Axial
- Grid
- Tangential

Local Street Network Level

- Loop/Tree
- Loop
- Loop/Grid
- Grid
- Tree

This categorisation is carried out based on visual inspection of the street networks.

Srinivasan (2002) gives a good overview of a number of different ways people have tried to quantify and measure street design including:

- Road density
- Proportion of four way (or more) junctions
- Proportion of three way junctions
- Proportion of cul-de-sac or dead end streets

These are more quantifiable and remove the subjective element from the definition. See also Cervero and Kockelman (1997) who also include highway width as a measure of street design.

Handy et al (2002) consider the concept of street scale in terms of its influence on travel behaviour. Street scale is defined as being the 3-dimensional space along a street as bounded by the buildings.

A continuation or progression from these basic measures of street pattern is a small but growing field of research into describing the patterns of networks, particularly road networks. The best know of these techniques is probably Space Syntax (Hillier and Hanson, 1998).

Using the Space Syntax theory, the idea of describing settlements in terms of the spaces bounded by the buildings, i.e. the roads and public open spaces, is discussed. This “space” can then be broken down into a number of constituent parts referred to as a “convex map”. The space can also be represented as an “axial map”.

If the convex or axial space is directly accessible by the buildings, the space is said to be, “constituted by the buildings”. If the space is adjacent to but not directly permeable to the buildings, it is said to be, “unconstituted”.

Thus the systems of axial and convex space can be discussed in terms of the following:

- Their internal configurations,
- In relation to each other,
- In relation to the buildings which define the system, and
- In relation to the world outside that system.

It is suggested that settlements arranged axially refer to global organisation through the system, whereas settlements organised convexly are organised from the point of view of those who are already statically present in the system. While the reasoning behind this theory may be obvious empirical evidence backing this theory up is not presented.

All space can also be described as below:

- Symmetry – where the relation from point a to point b is the same as point b to point a.
- Asymmetry – where the relation from point a to point b is not the same as point b to point a.
- Distributed – where more than 1 non-intersecting route from point a to point b exists.
- Non-distributed – where only 1 non-intersecting route from point a to point b exists.

"These values indicate the degree of unitary or diffused control of that space. That is, the extent to which it participates in a system of ringy routes and the degree of integration or segregation of that space with respect to the whole system."

The Space Syntax Ovation software analyses some of these measures and for any given network can produce the following measures for each axial line in the network:

- Integartion_Rad_n – Reciprocal of relativised RA
- Inegtration_Rad_x – Reciprocal of relativised Rax
- Connectivity – The number of immediate neighbours of each axial line
- Control – A measure of the degree of dominance to the immediate neighbours in terms of local movements. A function of the number of neighbours an axial line has and the connectivity of each neighbour.
- RA – Global integration (concept of centrality)
- Rax – Local integration over radius x
- X,Y,X2,Y2 – Start and end co-ordinates for each axial line.
- Kx – Measure of the size of the "scoped" local area.

The measures outlined in (Hillier and Hanson, 1998) in order to describe a network have the benefit of being relatively objective, although it appears that some subjective judgement may need to be made on the boundary of the study area in the first place and also in the construction of the axial maps.

The measures that the Space Syntax software uses, draw on these measures listed and as such is again a fairly objective way of describing a network. The description is purely a way of objectively describing a network and the constituent parts of it. It does not appear to give the user any information on whether, or how, any one of these measures influences the functioning of a settlement. If, for example, a particular axial line in a network scores a very high measure of "connectivity", this says nothing about what is happening in the network in reality or how people will behave in that area. It may be, for example, that the axial line is purely a very long line and hence has many immediate neighbours. It may also be little used and not important to the functioning of the settlement in real life.

Other techniques such as that developed by Porta et al (2006), which in itself refers to other work, uses five measures to try and describe the pattern of a network in detail.

These five measures are collectively referred to as a Multiple Centrality Assessment (MCA) as shown below.

Being Central as Being Near the Others

$$C_i^D = \frac{\sum_{j \in G} a_{ij}}{N-1} = \frac{k_i}{N-1} \qquad (1)$$

$$C_i^C = \frac{N-1}{\sum_{\substack{j \in G \\ i \neq j}} d_{ij}} \qquad (2)$$

Being Central as being Between the Others

$$C_i^B = \frac{1}{(N-1)(N-2)} \cdot \sum_{\substack{j,k \in G \\ J \neq k \neq i}} \frac{n_{jk}(i)}{n_{jk}} \qquad (3)$$

Being Central as Being Straight to the Others

$$C_i^S = \frac{\sum_{\substack{j \in G \\ j \neq i}} \frac{d_{ij}^{Eucl}}{d_{ij}}}{N-1} \qquad (4)$$

Being Central as Being Critical for All the Others

$$C_i^I = \frac{\Delta E}{E} = \frac{E(G) - E(G')}{E(G)},$$

$$(5)$$

$$E(G) = \frac{\sum_{\substack{i,j \in G \\ i \neq j}} \frac{d_{ij}^{Eucl}}{d_{ij}}}{N(N-1)}$$

Where

G is a valued graph of N nodes and K edges (links). G' is the network with N nodes and K-k_i edges, obtained by removing from G the edges incident at node i. a_{ij} is equal to 1 when there is an edge (link) between I and j and 0 otherwise. d_{ij} is the shortest path length between i and j. d_{ij}^{Eucl} is the Euclidean distance between i and j.	N = Total number of nodes n_{jk} = The number of shortest paths between j and k $n_{jk}(i)$ = The number of shortest paths between j and k that contain node i. C_i^D = Degree Centrality C_i^C = Closeness Centrality C_i^B = Betweenness Centrality C_i^S = Straightness Centrality C_i^I = Information Centrality

It is proposed that these five metrics can be used to determine a measure of the centrality of any part of any network including the road network. Centrality is calculated for each street in the network.

By plotting graphs of cumulative numbers of streets against centrality, it is suggested that differences emerge, which can be used to differentiate between planned cities and self-organised ones.

The description of urban form is a key part of this study. In addition to many other measures of urban form such as measures of density and land use mix, it may be useful to have measures of settlement patterns. One straight-forward way of doing this is to try to pigeon hole the patterns into predefined typologies based on human inspection. This is however very subjective and the categorical nature of the measure makes it statistically weak.

Both Space Syntax and the primal approach outlined above offer ways of describing settlement patterns in a more objective way and possibly as numeric variables instead of categorical. It is, however, not possible to use either Space Syntax or the "Primal" approach to make any conclusions about one settlement structure compared to another. For example, it is not possible to use either method to determine true “accessibility” measures of any settlement network or part of it. Moreover, these measures may well be highly correlated with other urban form metrics discussed in this section. It is worthwhile again noting that the likely use to policy makers of any results from this study rely on the metrics of urban form being applicable in terms of policy. In this respect the more complex metrics of urban spatial form used, the less likely they are to be of assistance to policy makers. Specifications of a centrality measure or connectivity as discussed here would be difficult for planners to use.

Other commonly used metrics for measuring the overall function of the city relate to how different characteristics of the population are spatially arranged. For example, measures of how segregated the population is by income or how clustered commercial land uses are. There are a number of well-developed and often complex ways of measuring such factors; some of which are outlined here.

Gini coefficients (Gini, 1912) are measures of inequalities. It is not related to any specific geography and is in essence a measure of spread of any given variable and could be applied to an urban form measure. The Gini co-efficient is usually used to describe income inequalities for particular areas such as countries, cities etcetera. The co-efficient ranges from 0 to 1; 0 being perfect equality and 1 being perfect inequality. One key problem though is that it may sometimes be difficult to give meaning to any differences in equality between two different populations due to the differences in sizes for these populations. For example, the US has a higher Gini co-efficient for income inequality than almost all EU nations, but obviously has a much larger population than any individual EU nation. If a Gini score is calculated for the EU as a whole, it is evident that there are greater income inequalities in the EU as a whole than there are in the US. Thus Gini Co-efficients are highly dependent on the geographies over which they are measured.

Another metric used to describe spatial arrangements is the Moran’s coefficient (Moran, 1950) is a measure of clustering or dispersion of any continuous variable. The coefficient I, lies between –1 and +1 where a score of +1 would refer to maximum clustering, -1 to perfect dispersion and 0 as randomly distributed.

Different Gini scores or Moran's coefficients could be derived for different characteristics of the population including:

- Density
- Income
- Car ownership
- and any other variable of interest available from the census.

These co-efficients could then be compared with behaviour to ascertain if there is an association with these wider urban form measures.

Housing Type

There has been relatively little research into household type and how this influences travel behaviour. The research that has been carried out tends to use this as a proxy for residential density. Filion (1999) categorises housing type into the following three categories:

- Detached Dwellings,
- Apartment Buildings including tenements and conversions,
- Other.

Burton (2002) however describes the following classification of housing type:

- Higher density dwellings (flats, tenements, terraces, conversions),
- Lower density dwellings (detached and semi detached),
- Small dwellings (1 to 3 rooms),
- Large dwellings (4 plus rooms).

The detail of housing type and its influence on travel behaviour has perhaps been overlooked in favour of measures of residential density.

Other Measures

A number of studies have considered the effect that owning a garden, patio or veranda such as Bagley et al (2002), Schlich and Axhausen (2003) and others. This measure had been investigated with particular reference to leisure trips such as trips to public parks and open space.

The paper by Handy et al (2002) tries to quantify some softer measures of urban form including the number of locations of graffiti per square mile and percent of ground in shade at noon.

Appendix D. Summary of Urban Form Measures

Table D1. Density Urban Form Measures

Measure	Definition	Geography						
		Region	City	Sector	Ward	Neighbourhood	Street	Plot
Site Density	Nº of dwellings or people/ total site area		☑	☑	☑	☑	☑	
Block Density	Nº of dwellings or people/ block area measured to kerb line				☑	☑		
Net Residential Density	Nº of dwellings or people/ total land area devoted to residential facilities		☑	☑	☑	☑		
Gross Residential Density	Nº of dwellings or people/ land area		☑	☑	☑	☑	☑	☑
Net Neighbourhood Residential Building Type Density	Nº of dwellings of a particular type in a neighbourhood/ the land area associated with that type					☑		

Net Neighbourhood Density	Nº of dwellings or people in the neighbourhood/ the base land area of the neighbourhood excluding citywide uses in the neighbourhood.					☑		
Gross Neighbourhood Density	Nº of dwellings or people/ by the total neighbourhood area					☑		
City Density	Nº of dwellings or people/ total developed area of the entire city		☑					
Metropolitan Density	Nº of dwellings or people/ total metropolitan area including undeveloped parts within	☑	☑					
Net Residential Density at City or Metropolitan Level	Number of dwellings or people/ total built up area within the city of metropolitan area.	☑	☑					
Floor Area Ratio	Built floor area/ site area							☑
Building Site Coverage	Total area of building footprints/ by the block area							☑

Impervious Surface Site Coverage	Built or paved area/ total site area							☑
Impervious Surface Block Area	Built or paved area/ total block area							☑
Front Kerb Site Setback	Dist from façade to the edge of property line						☑	☑
Front Kerb Block Setback	Block average site setback					☑		
Side to Side Building Distance	Distance between buildings averaged across a block						☑	☑
Front to Back Building Distance	Distance between the rear of one building and rear of the building backing onto it averaged over a block					☑	☑	☑
Lot Size	Median lot size of a single family dwelling unit (SFDU) per neighbourhood					☑		
Floor Space	Median floor space of an SFDU per neighbourhood					☑		
Dwelling Density	Number of SFDUs divided by the residential area of the neighbourhood.					☑		

Weighted Density	A weighting given to the density to reflect its distance away from the study area.					☑	☑	
Origin Density	Density at the origin of the journey				☑	☑	☑	☑
Destination Density	Density at the destination of the journey				☑	☑	☑	☑
Density Profile	Profile of density between any two points in an urban area	☑	☑	☑	☑			

Table D2. Household Type Measures

Measure	Definition	Geography						
		Region	City	Sector	Ward	Neighbourhood	Street	Plot
Proportion of Higher Density Dwellings	% of total housing stock made up of higher density dwellings (flats, tenements, terraces, conversions)		☑	☑	☑	☑	☑	
Proportion of Lower Density Dwellings	% of total housing stock made up of lower density dwellings (detached and semi detached dwellings)		☑	☑	☑	☑	☑	
Proportion of Small Dwellings	% of total housing stock made up from small dwellings (1-3 rooms)		☑	☑	☑	☑	☑	
Proportion of Large Dwellings	% of total housing stock made up from large dwellings (4 rooms+)		☑	☑	☑	☑	☑	
Housing Type	% of total housing stock made up from detached dwellings,% of apartment buildings including flats, tenements and conversions, % of other		☑	☑	☑	☑	☑	

Table D3. Land Use Mix Measures.

Measure	Definition	Geography						
		Region	City	Sector	Ward	Neighbourhood	Street	Plot
Dissimilarity Index	Predominant land use assigned to each grain and compared to the predominant land uses of the neighbouring grains		☑	☑	☑	☑		
Functionally Complementary Land Uses	Land use groups of functionally complementary land uses: medium density residential/ retail/ services/ schools, retail/services, schools sites		☑	☑	☑	☑		
Mix	Area of commercial, industrial and public land in the neighbourhood/ the number of dwelling units					☑		
Mix	Land use put into four categories and each area given an index where 0 = one use only and 1 = perfect mix of all four categories			☑	☑	☑		
Residential Business Mix	% of residents with business of institution land uses within half a block of their home				☑	☑		

Residential Retail Mix	% of residents with satisfactory shopping within 1 mile of their home.				☑	☑		
Residential Education Mix	% of residents with a public elementary school within 1 mile of their home				☑	☑		
Job Resident Balance	Nº of jobs in the area compared to number of residents			☑	☑	☑		
Population serving job-resident balance/ entropy	Nº of jobs in the area in each sector compared to the number of residents in each area working in those sectors			☑	☑	☑		
Diversity Index	Proportions of each land use in an area		☑	☑	☑	☑		
Origin Diversity	Retail employment and population relative to countywide ratio		☑	☑	☑	☑		
Destination Diversity	Entropy index based on no of households, retail employment, office employment and other employment		☑	☑	☑	☑		
Vertical Mixed Use	Proportion of buildings with different land uses over different levels.				☑	☑	☑	☑

Table D4. Polycentricity Measures

Measure	Definition	Geography						
		Region	City	Sector	Ward	Neighbourhood	Street	Plot
Dispersion	No of people commuting from suburbs to city centre/ number of people commuting from the suburbs to the suburbs compared to the number of people commuting out of the city centre to the suburbs/number of people commuting from the suburbs to the suburbs		☑					
Polycentric Regions	Significant level of exchange commuting between two urban areas	☑						
Centralisation	Population densities relative to distance from the central business district				☑	☑		
Typology of Urban Form	Morphological urban form based on the shape of the developed city categorised as Concentric, lobe, linear polynuclear, concentric polynuclear, linear, grid	☑	☑					
Typology of	Linear network, radial network, ring network, grid	☑	☑					

Transportation Networks at City Level	network, shifted grid network							

Table D5 Street Design Measures

Measure	Definition	Geography						
		Region	**City**	**Sector**	**Ward**	**Neighbourhood**	**Street**	**Plot**
Typology of Transportation Network at the Neighbourhood Level	Ring, loop, radial, axial, grid, tangential			☑	☑	☑		
Local Street Network Type	Loop/tree, loop, loop/grid, tree					☑	☑	
Traffic Calming	Proportion of traffic controlled/calmed streets		☑	☑	☑	☑		
Footpath Width	Width of footpath					☑	☑	

Block Length	Distance between intersections along arterial routes			☑	☑			
Permeability	Proportion of four-way + intersections, 3 way intersections etcetera.			☑	☑			
Street Density	Road length divided by study area. Can be divided into road category		☑	☑	☑			
Street Connectivity	Number of street intersections/ study area.		☑	☑	☑			
Street Scale	3 Dimensional space along a street as bounded by buildings						☑	

Table D6. Other Urban Form Measures

Measure	Definition	Geography						
		Region	City	Sector	Ward	Neighbourhood	Street	Plot
Year Of Development	Year the neighbourhood was first developed	☑	☑	☑	☑	☑	☑	☑
Street Lighting	Proportion of streets lit			☑	☑			
Distance From Urban Centre	Point to point distance from study area to CBD				☑	☑	☑	☑
Access to Garden or Private Open Space	Proportion of dwellings with own garden, terrace or patio				☑	☑		

Appendix E. Urban Form Data Sources

Urban Form Data Sources

The following categories summarise the main data sources available for describing urban form.

Valuations Data

Address point detailed information is also available from the Valuation Office Agency Scotland (SAA, 2008) on the uses of all commercial addresses in Scotland and also rateable values of residential addresses. Through the valuation office, it is possible to ascertain commercial and residential properties by searching under a post code in the case of Scotland. The commercial properties also include a description of use. The detail and categorisation of the use needs to be confirmed. It may well be possible for a database of addresses to be supplied directly so avoiding us entering all the postcodes into the website search engine.

The detailed Valuation Roll can also be purchased directly from local authorities. The Valuation Roll for Glasgow for example includes much more detailed information about the use of each commercial address than is held centrally by the Valuation Office such as the names of both the proprietor and the owner of commercial addresses. From these and the land use description it is usually possible to determine in detail what the commercial property is used for. The formatting of the address uses and the addresses themselves are inconsistent and hence matching this data directly to GIS map is time consuming.

Structure/Development Plans

Local Planning Authorities are likely to have land use information at a more aggregate level which will possible be of use for categorising urban form over wider areas.

Local Authority Environmental Health Departments

Environmental health departments are obliged to keep records of all businesses involved with food retail. A list of such businesses has been obtained for Glasgow and includes everything from farms to food distribution companies to restaurants and even petrol stations. Local authorities have to keep records of all these businesses and where they are located so that food standards can be ensured.

Business Directories

Business directories and phone directories can give an indication of most of the commercial businesses in any given area. These databases are however not complete and require a lot of interrogating to build up a land/address use map.

Ordnance Survey Products

There is a considerable amount of land use/cover information available from the Ordnance Survey (Ordnance Survey, 2008). Address point data includes descriptions of some key properties such as schools, post offices, public houses, sports venues etcetera. The topographic layer from the OS includes descriptions of land cover but these are unlikely to go into the detail required for the project. Aerial photography provided by the OS could also be particularly useful in describing "green" land cover.

Census/ NOMIS

The Census holds information on households so may be of use in measuring urban form at a household level. At a wider level information on resident and also daytime populations may be useful in terms measuring urban form.

NOMIS (2008), "houses an extensive range of government statistical information on the UK labour market including Employment, Unemployment, Earnings, Labour Force Survey and Jobcentre Plus vacancies." The data is built up from a number of sources. The main source of data is the Census but there is also data from the following sources:

- Annual Business Inquiry
- Claimant Count
- Jobcentre Plus Vacancies
- Labour Force Survey
- New Earnings Survey
- Population Estimates/NHSCR Migrations
- VAT Registrations & Stocks

These data sources include amongst other things, information on employment levels by type of industry for geographic areas. This information is available at a census area statistic level (CAS) or a post code sector level. The data may be particularly useful in determining the mix of an area in terms of employment by type and maybe a more useful measure than for example relying on floor areas for different types of commercial businesses.

Appendix F. Household Survey

A. Your Accommodation

First we would like to ask you some questions about your current address and your address at the end of 2002

A1. What type of accommodation does your household occupy at this address?

A whole house or bungalow that is:

- ❑ Detached
- ❑ Semi-detached
- ❑ Terraced (including end-terrace)

A flat, maisonette or apartment that is:

- ❑ In a tenement
- ❑ In a purpose-built block of flats (including '4-in-a-block')
- ❑ Part of a converted or shared house (including bed-sits)
- ❑ In a commercial building (for example, in an office building)

A2. What is the lowest floor level of your household's living accommodation?

- ❑ Basement or semi-basement
- ❑ Ground floor (street level)
- ❑ First floor (floor above street level)
- ❑ Second floor
- ❑ Third or fourth floor
- ❑ Fifth floor or higher

A3. Does this accommodation have access to:

- ❑ A shared garden
- ❑ A private garden
- ❑ Neither of the above

A4. Does your household own or rent this accommodation?

- ❑ Own outright
- ❑ Buying with a mortgage or loan
- ❑ Pay part rent and part mortgage (shared ownership)
- ❑ Rent (includes rent paid by housing benefits)
- ❑ Live here rent free

A5. How long have you lived at this address?

Years ☐ **Months** ☐

A6. Do you expect to move from this address in the next few years?

- ❑ No
- ❑ Yes

<u>If Yes</u>, what is the main reason you expect to move?

- ❑ Changing tenure (e.g. from renting to owning)
- ❑ Accommodation reasons
- ❑ Area reasons
- ❑ Job reasons
- ❑ Personal reasons
- ❑ Other

A7. Suppose you (and your spouse/partner if applicable) were to buy a new home - which price range would you consider?

- ❑ less than £50,000
- ❑ £50,000 to £100,000
- ❑ £100,000 to £150,000
- ❑ £150,000 to £200,000
- ❑ £200,000 to £250,000
- ❑ £250,000 to £350,000
- ❑ more than £350,000

A8. Thinking back to the end of 2002, what was your main address at that time?

- ❑ Current address
- ❑ Or elsewhere, please specify address below:

First line of address	
Town/City	
Postcode	

<u>If elsewhere</u>, what type of accommodation did you occupy?

- ❑ Detached house
- ❑ Semi-detached house
- ❑ Terraced house
- ❑ Flat, maisonette or apartment

B. Preferred Housing and Neighbourhood Characteristics

For this question, assume you were interested in moving to a new place to live

B1. Please indicate how important each of the following housing and neighbourhood characteristics would be in your choice of new place to live.

	Extremely unimportant	Unimportant	Important	Extremely important
Local shops and other amenities within easy walking distance	☐	☐	☐	☐
Safe neighbourhood for children to play outdoors	☐	☐	☐	☐
A detached house	☐	☐	☐	☐
Parks with amenities (e.g. playground/ sports fields)	☐	☐	☐	☐
Short drive to main road network	☐	☐	☐	☐
Safe cycle routes which extend beyond neighbourhood	☐	☐	☐	☐
Adequate off-street parking (garage or driveway)	☐	☐	☐	☐
Close to work	☐	☐	☐	☐
Within catchment area of good local school(s)	☐	☐	☐	☐
Close to city centre	☐	☐	☐	☐
Private garden	☐	☐	☐	☐
Parks with many natural features (e.g. trees, bushes, long grass)	☐	☐	☐	☐
Mixture of different housing types in neighbourhood	☐	☐	☐	☐
Close to family and/or friends	☐	☐	☐	☐
Frequent public transport services within easy walking distance	☐	☐	☐	☐

C. Car Ownership and Travel

The following questions relate to car ownership and travel

C1. How many cars or vans are currently owned or available for use by your household?

- ❑ None
- ❑ One
- ❑ Two
- ❑ Three or more

C2. Please provide details of any cars or vans, which are owned by your household or are available for personal use.

If your household has more than three vehicles, please provide details of the three that are most frequently used.

	Vehicle 1	Vehicle 2	Vehicle 3
Type of vehicle (e.g. car, van)			
Manufacturer (e.g. Ford)			
Model (e.g. Focus)			
Approximate age of vehicle (years or date)			
Engine size (e.g. 1.6 litres or 1600cc)			
Type of fuel (e.g. petrol)			
Ownership (e.g. privately owned, leased, company car)			
Estimated annual mileage			
When was this vehicle acquired for your household's use?			
Including yourself, how many members of your household are entitled to drive this vehicle?			
Where do you normally park this vehicle at home (e.g. on the road, in the drive/garage)?			

C3. Thinking back to the end of 2002, how many cars or vans were owned or available for use by your household at that time?

- ❑ None
- ❑ One
- ❑ Two
- ❑ Three or more

C4. Do you currently have a full driving license for a car?

- ❑ No
- ❑ Yes

<u>If yes</u>, in what year did you obtain your full driving license? ________

C5. Including yourself, how many other members of your household have full driving licences for a car?

C6. Generally speaking, how often do you undertake the following activities?

	Daily	Once or twice a week	Once or twice a month	Less than once a month	Never
Visit friends & relatives					
Take children to / from school					
Supermarket shopping					
Non-food shopping					
Evenings out					
Visit parks to enjoy nature (e.g. birds/ trees)					
Take children to leisure activities					
Leisure activities (playing sport, visiting tourist attractions)					

C7. When you undertake the following activities, how often do you use a car, either as a driver or passenger?

	Always	Often	Rarely	Never
Visit friends & relatives				
Take children to / from school				
Supermarket shopping				
Non-food shopping				
Evenings out				
Visit parks to enjoy nature (e.g. birds/ trees)				
Take children to leisure activities				
Leisure activities (playing sport, visiting tourist attractions)				

C8. In the last 3 months, how many round-trip journeys by any mode of more than 200 miles have you undertaken within the United Kingdom (e.g. Glasgow to Carlisle and back, Edinburgh to Aberdeen and back)?

Please INCLUDE all trips whether or not you stayed away from home overnight.

But EXCLUDE all trips undertaken in the course of your employment.

- ❑ None
- ❑ One or two
- ❑ Three or four
- ❑ Five or more

C9. In the last 12 months, how many trips by any mode outside the United Kingdom have you undertaken?

Please EXCLUDE all trips undertaken in the course of your employment.

- ❑ None
- ❑ One
- ❑ Two
- ❑ Three or more

C10. Compared to the end of 2002, how much do you use a car as driver or passenger at the moment? (Exclude taxis)

A lot less	A little less	About the same	A little more	A lot more

C11. Please indicate how much your agree with each of the following statements

	Strongly agree	Tend to agree	Neither agree nor disagree	Tend to disagree	Disagree strongly		Unsure		Not applicable
I intend to reduce the amount that I use the car during the next six months									
I would only travel by bus if I had no other way of getting there									
I feel morally obliged to reduce my car use									
I feel a responsibility to reduce my car use									
I feel responsible for problems caused by car use									
I am trying to use the car less									
Reducing my car use would cause me inconvenience									
I could not use public transport any more than do at the moment									
Driving is much more practical than using other modes of transport									
Reducing my car use would be easy									
I could reduce my car use if I wanted to									
Most people who are important to me think that I should reduce my car use									
Most people who are important to me are trying to reduce their car use									
Travelling by bus is mainly for people who can't afford anything better									
Reducing my car use would have a positive effect on the environment									
Travelling by car can be stressful at times									
I find driving enjoyable									
When I go out I just get in the car rather than thinking about how I am going to travel									
Reducing my car use would not make any difference to congestion because most other people will not reduce theirs									
The way I travel is not just practical; it says something about who I am									
Reducing my car use would make me feel good									

D. Employment

Some questions about your employment and travel to work

D1. Which of the following best describes your current employment status?

- ❑ Employed, full-time (more than 30 hours per week)
- ❑ Employed, part-time (less than 30 hours per week)
- ❑ Self-employed/freelance
- ❑ Unemployed/seeking work
- ❑ Retired
- ❑ Looking after family/home
- ❑ Full-time student at college/university
- ❑ Long-term sick/disabled
- ❑ Other

If you are NOT currently working full or part-time please go to Question D9.

D2. Please give the full title by which your current job is known (including rank or grade if you have one).

D3. What address do you travel to for your main job?

(Answer for the place where you spend most time for work. If you report to a depot write in depot address)

- ❑ Work mainly from home
- ❑ No fixed place
- ❑ Work on offshore platform
- ❑ The address below:

Employer's name	
First line of address	
Town/City	
Postcode	

D4. Does your current employer offer you parking as part of your main job?

- ❑ No
- ❑ Yes - free parking
- ❑ Yes - parking which I have to pay for

D5. How do you currently travel to your main place of work?

(Tick one box for the longest part, by distance, of your usual journey to work)

- ❑ Underground
- ❑ Train
- ❑ Bus, minibus or coach (public or private)
- ❑ Driving a car or van
- ❑ Passenger in car or van your household owns or is available for personal use
- ❑ Passenger in car or van owned by someone else
- ❑ Motorcycle, scooter or moped
- ❑ Bicycle
- ❑ Walk
- ❑ Other

D6. If you usually drive a car or van to work, where do you park?

- ❑ Commercial car park – I pay for
- ❑ On street - free
- ❑ On street - I pay for
- ❑ Employer provided car park - I pay for
- ❑ Employer provided car park – free
- ❑ Another car park - free
- ❑ Other

D7. If you usually take public transport (i.e. underground, train or bus) to work, how do you normally travel from your home to the bus stop or station?

- ❑ Walk
- ❑ Driving a car or van
- ❑ Passenger in car or van
- ❑ Motorcycle, scooter or moped
- ❑ Bicycle

D8. Does your employer currently have a Workplace (or Green) Travel Plan that you aware of?

- ❑ No
- ❑ Yes

<u>If yes</u>, in what year was the Travel Plan introduced?

D9. Thinking back to the end of 2002, which of the following best describes your employment status at that time?

- ❑ Employed, full-time (more than 30 hours per week)
- ❑ Employed, part-time (less than 30 hours per week)
- ❑ Self-employed/freelance
- ❑ Unemployed/seeking work
- ❑ Retired
- ❑ Looking after family/home
- ❑ Full-time student at college/university
- ❑ Long-term sick/disabled
- ❑ Other

If you were NOT working full or part-time at the end of 2002 please go to Section E – Employment Status of Your Spouse of Partner.

D10. What address did you travel to for your main job at the end of 2002?

(Answer for the place where you spent most time for work. If you reported to a depot write in depot address)

- ❑ Current work address
- ❑ Worked mainly from home
- ❑ No fixed place
- ❑ Worked on offshore platform
- ❑ Or, the address below:

Employer's name	
First line of address	
Town/City	
Postcode	

D11. Did your employer offer you parking as part of your main job at the end of 2002?

- ❑ No
- ❑ Yes – free parking
- ❑ Yes – parking which I had to pay for

D12. How did you travel to your main place of work at the end of 2002?

(Tick one box for the longest part, by distance, of your usual journey to work)

- ❑ Underground
- ❑ Train
- ❑ Bus, minibus or coach (public or private)
- ❑ Driving a car or van
- ❑ Passenger in car or van your household owned or had available for personal use
- ❑ Passenger in car or van owned by someone else
- ❑ Motorcycle, scooter or moped
- ❑ Bicycle
- ❑ Walk
- ❑ Other

D13. If you usually drove a car or van to your place of work at the end of 2002, where did you park your vehicle?

- ❑ Commercial car park – I paid for
- ❑ On street - free
- ❑ On street - I paid for
- ❑ Employer provided car park - I paid for
- ❑ Employer provided car park – free
- ❑ Another car park - free
- ❑ Other

E. Employment Status of your Spouse or Partner

Please answer the following questions if you are currently living as a married / cohabiting couple. Otherwise please go to Section F – Personal and Household Information

E1. Which of the following best describes your spouse / partner's current employment status?

- ❑ Employed, full-time (more than 30 hours per week)
- ❑ Employed part-time (less than 30 hours per week)
- ❑ Self-employed/freelance
- ❑ Unemployed/seeking work
- ❑ Retired
- ❑ Looking after family/home
- ❑ Full-time student at college/university
- ❑ Long-term sick/disabled
- ❑ Other

If your spouse / partner is NOT currently working full or part-time please go to Section F – Personal and Household Information

E2. What address does your spouse / partner travel to for their main job?

(Answer for the place where they spend most time for work. If they report to a depot write in depot address)

- ❑ Work mainly from home
- ❑ No fixed place
- ❑ Work on offshore platform
- ❑ Or the address below:

Employer's name	
First line of address	
Town/City	
Postcode	

<u>and</u> has your spouse / partner's main place of work changed since the end of 2002?

- ❑ No
- ❑ Yes

E3. How does he/she currently travel to main place of work?

(Tick one box only for the longest part, by distance, of their usual journey to work)

- ❑ Underground
- ❑ Train
- ❑ Bus, minibus or coach (public or private)
- ❑ Driving car or van
- ❑ Passenger in car or van your household owns or is available for personal use
- ❑ Passenger in car or van owned by someone else
- ❑ Motorcycle, scooter or moped
- ❑ Bicycle
- ❑ Walk
- ❑ Other

<u>and</u> has your spouse / partner's mode of travel to work changed since the end of 2002?

- ❑ No
- ❑ Yes

E4. If your spouse/partner usually drives a car or van to work, where do they park?

- ❑ Commercial car park – they pay for
- ❑ On street - free
- ❑ On street - they pay for
- ❑ Employer provided car park - they pay for
- ❑ Employer provided car park – free
- ❑ Another car park - free
- ❑ Other

E5. If your spouse / partner usually takes public transport (i.e. underground, train or bus) to work, how does they normally travel from home to get to the bus stop or station?

- ❑ Walk
- ❑ Driving a car or van
- ❑ Passenger in a car or van
- ❑ Motor cycle, scooter or moped
- ❑ Bicycle

F. Personal and Household Information

F1. Are you:

- ❑ Male
- ❑ Female

F2. Please tick your age group:

- ❑ 16 – 24 years
- ❑ 25 – 34 years
- ❑ 35 – 44 years
- ❑ 45 – 54 years
- ❑ 55 – 64 years
- ❑ 65 years or above

F3. Do you have any long standing illness, disability or infirmity that limits your activities in any way?

- ❑ No
- ❑ Yes

If yes, when did this illness, disability or infirmity first arise?

Year

and does the illness, disability or infirmity affect your ability to do any of the following? (Tick all that apply)

- ❑ Drive a car
- ❑ Use a bus
- ❑ Use a train
- ❑ Cycle
- ❑ Walk

F4. Which one of the following best describes the relationship between those normally living at this address?

- ❑ One person only
- ❑ Married / cohabiting couple only
- ❑ Married / cohabiting couple with child/ren, at least one under 16 years old
- ❑ Married / cohabiting couple with child/ren, all over 16 years old.
- ❑ Lone parent with child/ren, at least one under 16 years old.
- ❑ Lone parent with child/ren, all over 16 years old.
- ❑ Two or more adults living together as flat-mates / house-mates
- ❑ Other

F5. How many people normally live at this address?

F6. Please tick the age group of all children under 16 years old normally living at this address.

If you do not have any children please go to Question F7.

	Child 1	Child 2	Child 3	Child 4
0 – 2 years				
3 – 5 years				
6 – 10 years				
11 – 15 years				

F7. What is your household's total annual income from all sources?

Tick the box for the range into which your annual income falls. Count all income. Do not deduct taxes, National Insurance contributions, superannuation payments, health insurance payments.

- ❑ Nil
- ❑ Up to £10,399
- ❑ £10,400 - £15,599
- ❑ £15,600 - £20,799
- ❑ £20,800 - £25,999
- ❑ £26,000 - £31,199
- ❑ £31,200 - £51,999
- ❑ £52,000 or more

F8. How does your household's current income compare with household income in 2002?

Current household's income is:

- ❑ A lot less
- ❑ A little less
- ❑ About the same
- ❑ A little more
- ❑ A lot more

G. Travel Diary

Finally, we would like to ask you to complete the following travel diary

This travel diary will help us understand how and where people travel. Please use the attached sheets to record all activities (including travel) you carried out over four days, starting on Thursday 15th June and ending on the evening of Sunday 18th June.

Please think about what you did each day (e.g. travel by car, watch film at cinema). Think also about the order in which you undertook each activity.

In the first row of the column marked **'What were you doing?'** record the first activity you undertook on the day in question. We have provided a list of common activities at the foot of each page. Please enter the appropriate code or simply write in words what you were doing if you find this easier. Ignore all short walks of less than 10 minutes to a bus-stop or train station.

In the same row, record the **start** and **end time** of the activity.

If you were away from home and not travelling please also complete the column **'Where were you?'**. To make this easier we have provided a map of Glasgow and the surrounding area showing the centres of local districts. Please record the code of the nearest centre to where you were, or write the location in words. If you were outside Glasgow, simply write the name of the nearest city or town.

Please also record **'Who was with you?'** by ticking all boxes that apply.

Then, in each of the following rows repeat the process for consecutive activities.

Example:
John spends the night at home.
At 7.00am he takes the family dog for a walk to a park, returning home at 7.30am.
At 8.00am he leaves home to drive alone to work. He arrives at work in Anderston, Glasgow (location code 2) at 8.45am. He then spends the day at work.
At 5.00pm he leaves work and drives to a supermarket in Ibrox, Glasgow (location code 57). He arrives at the supermarket at 5.15pm and buys some milk and a loaf of bread.
He leaves the supermarket at 5.30pm and drives home arriving at 5.45pm.
At 7.00pm he drives his wife and two children (both of whom are under 16 years old) to the cinema to watch a film. They arrive at the cinema in the City Centre, Glasgow (location code 27) at 7.20pm
At 9.00pm they leave the cinema and drive home. They arrive home at 9.20pm. John spends the rest of the day at home.

What were you doing? (please write code for **one main** activity)	Start time	End time	Where were you? (please write code for location)	Who was with you? (please tick all that apply): Alone or with people you don't know	With your spouse/ partner	Children under 16 years old who live with you	Other household members	Other persons that you know
A1 At home	:	7:00						
F7 Walk in park	7:00	7:30		✓				
A1 At home	7:30	8:00						
T1 Drive car	8:00	8:45		✓				
D1 At work	8:45	5:00	**2** (Anderston)					✓
T1 Drive car	5:00	5:15		✓				
C2 Grocery-top	5:15	5:30	**57** (Ibrox)	✓				
T1 Drive car	5:30	5:45		✓				
A1 At home	5:45	7:00						
T1 Drive car	7:00	7:20		✓	✓	✓		
F3 Cinema	7:20	9:00	**27** (city centre)	✓	✓	✓		
T1 Drive car	9:00	9:20		✓	✓	✓		
A1 At home	9:20	:						

Thursday 15th June

What were you doing? (please write code for **one main** activity)	Start time	End time	Where were you? (please write code for location)	Who was with you? (please tick all that apply)				
				Alone or with people you don't know	With your spouse/ partner	Children under 16 years old who live with you	Other household members	Other persons that you know
	:	:						
	:	:						
	:	:						
	:	:						
	:	:						
	:	:						
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	:	:						
	:	:						
	:	:						

T - Travel		**At home**		**C - Shopping**		**F - Leisure**	
T1	Car - driving	**A1**	At home	**C1**	Groceries – main	**F1**	Play sport
T2	Car - passenger			**C2**	Groceries – top-up	**F2**	Hobby
T3	Bus			**C3**	Clothing & consumer goods	**F3**	Cinema, theatre, watch sport etc
T4	Coach			**C4**	Other shopping	**F4**	Social (pub, club, bingo, restaurant, café etc)
T5	Train	**B - Personal activities**		**D - Formal activities**		**F5**	Exercise in park (jogging, etc, excluding walking)
T6	Underground	**B1**	Medical (includes GP, hospital)	**D1**	Paid work	**F6**	Exercise not in park (jogging etc, excluding walking)
T7	Motorcycle	**B2**	Care	**D2**	Education / training	**F7**	Walking for pleasure, dog walk – in park
T8	Walking	**B3**	Escort	**D3**	Other formal activities	**F8**	Walking for pleasure, dog walk – not in in park
T9	Bicycle	**B4**	Banking, financial			**F9**	Sightseeing or tourist attractions
T10	Taxi	**B5**	Visiting friends/relatives	**E – Other**		**F10**	Holiday
T11	Other	**B6**	Other personal activity	**E1**	Other activities	**F11**	Other leisure

Friday 16th June

What were you doing? (please write code for **one main** activity)	Start time	End time	Where were you? (please write code for location)	Who was with you? (please tick all that apply) Alone or with people you don't know	With your spouse/ partner	Children under 16 years old who live with you	Other household members	Other persons that you know
	:	:						
	:	:						
	:	:						
	:	:						
	:	:						
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T - Travel		**At home**		**C - Shopping**		**F - Leisure**	
T1	Car - driving	**A1**	At home	**C1**	Groceries – main	**F1**	Play sport
T2	Car - passenger			**C2**	Groceries – top-up	**F2**	Hobby
T3	Bus			**C3**	Clothing & consumer goods	**F3**	Cinema, theatre, watch sport etc
T4	Coach			**C4**	Other shopping	**F4**	Social (pub, club, bingo, restaurant, café etc)
T5	Train	**B - Personal activities**		**D - Formal activities**		**F5**	Exercise in park (jogging, etc, excluding walking)
T6	Underground	**B1**	Medical (includes GP, hospital)	**D1**	Paid work	**F6**	Exercise not in park (jogging etc, excluding walking)
T7	Motorcycle	**B2**	Care	**D2**	Education / training	**F7**	Walking for pleasure, dog walk – in park
T8	Walking	**B3**	Escort	**D3**	Other formal activities	**F8**	Walking for pleasure, dog walk – not in in park
T9	Bicycle	**B4**	Banking, financial			**F9**	Sightseeing or tourist attractions
T10	Taxi	**B5**	Visiting friends/relatives	**E – Other**		**F10**	Holiday
T11	Other	**B6**	Other personal activity	**E1**	Other activities	**F11**	Other leisure

Saturday 17th June

What were you doing? (please write code for **one main** activity)	Start time	End time	Where were you? (please write code for location)	Who was with you? (please tick all that apply): Alone or with people you don't know	With your spouse/ partner	Children under 16 years old who live with you	Other household members	Other persons that you know
	:	:						
	:	:						
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T - Travel		**At home**		**C - Shopping**		**F - Leisure**	
T1	Car - driving	**A1**	At home	**C1**	Groceries – main	**F1**	Play sport
T2	Car - passenger			**C2**	Groceries – top-up	**F2**	Hobby
T3	Bus			**C3**	Clothing & consumer goods	**F3**	Cinema, theatre, watch sport etc
T4	Coach			**C4**	Other shopping	**F4**	Social (pub, club, bingo, restaurant, café etc)
T5	Train	**B - Personal activities**		**D - Formal activities**		**F5**	Exercise in park (jogging, etc, excluding walking)
T6	Underground	**B1**	Medical (includes GP, hospital)	**D1**	Paid work	**F6**	Exercise not in park (jogging etc, excluding walking)
T7	Motorcycle	**B2**	Care	**D2**	Education / training	**F7**	Walking for pleasure, dog walk – in park
T8	Walking	**B3**	Escort	**D3**	Other formal activities	**F8**	Walking for pleasure, dog walk – not in in park
T9	Bicycle	**B4**	Banking, financial			**F9**	Sightseeing or tourist attractions
T10	Taxi	**B5**	Visiting friends/relatives	**E – Other**		**F10**	Holiday
T11	Other	**B6**	Other personal activity	**E1**	Other activities	**F11**	Other leisure

Sunday 18th June

What were you doing? (please write code for **one main** activity)	Start time	End time	Where were you? (please write code for location)	Who was with you? (please tick all that apply)				
				Alone or with people you don't know	With your spouse/ partner	Children under 16 years old who live with you	Other household members	Other persons that you know
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T - Travel		**At home**		**C - Shopping**		**F - Leisure**	
T1	Car - driving	**A1**	At home	**C1**	Groceries – main	**F1**	Play sport
T2	Car - passenger			**C2**	Groceries – top-up	**F2**	Hobby
T3	Bus			**C3**	Clothing & consumer goods	**F3**	Cinema, theatre, watch sport etc
T4	Coach			**C4**	Other shopping	**F4**	Social (pub, club, bingo, restaurant, café etc)
T5	Train	**B - Personal activities**		**D - Formal activities**		**F5**	Exercise in park (jogging, etc, excluding walking)
T6	Underground	**B1**	Medical (includes GP, hospital)	**D1**	Paid work	**F6**	Exercise not in park (jogging etc, excluding walking)
T7	Motorcycle	**B2**	Care	**D2**	Education / training	**F7**	Walking for pleasure, dog walk – in park
T8	Walking	**B3**	Escort	**D3**	Other formal activities	**F8**	Walking for pleasure, dog walk – not in in park
T9	Bicycle	**B4**	Banking, financial			**F9**	Sightseeing or tourist attractions
T10	Taxi	**B5**	Visiting friends/relatives	**E – Other**		**F10**	Holiday
T11	Other	**B6**	Other personal activity	**E1**	Other activities	**F11**	Other leisure

T - Travel		At home		C - Shopping		F - Leisure	
T1	Car - driving	A1	At home	C1	Groceries – main	F1	Play sport
T2	Car - passenger			C2	Groceries – top-up	F2	Hobby
T3	Bus			C3	Clothing & consumer goods	F3	Cinema, theatre, watch sport etc
T4	Coach			C4	Other shopping	F4	Social (pub, club, bingo, restaurant, café etc)
T5	Train	**B - Personal activities**		**D - Formal activities**		F5	Exercise in park (jogging, etc, excluding walking)
T6	Underground	B1	Medical (includes GP, hospital)	D1	Paid work	F6	Exercise not in park (jogging etc, excluding walking)
T7	Motorcycle	B2	Care	D2	Education / training	F7	Walking for pleasure, dog walk – in park
T8	Walking	B3	Escort	D3	Other formal activities	F8	Walking for pleasure, dog walk – not in in park
T9	Bicycle	B4	Banking, financial			F9	Sightseeing or tourist attractions
T10	Taxi	B5	Visiting friends/relatives	**E – Other**		F10	Holiday
T11	Other	B6	Other personal activity	E1	Other activities	F11	Other leisure

Location Codes

Below is a list of district centres in and around Glasgow to help you complete the travel diary section of the questionnaire. If you were away from home and not travelling, please write the code of the nearest centre to where you were, or write the location in words.

District Centre	Code
Alexandra Parade	1
Anderston	2
Anniesland	3
Auchinairn	4
Baillieston West	5
Balornock	6
Bankhead South	7
Barlanark	8
Barloch	9
Barmulloch	10
Barrhead	10a
Barrowfield	11
Battlefield	12
Bishopbriggs	13
Blairdardie	14
Braehead	14a
Broomhill	15
Burgh, Eastfield and Silverbank	16
Burnhill	17
Calton/ Bridgeton	18
Cambuslang	19
Cardonald	20
Carntyne	21
Carnwadric	22
Castlehill	23
Castlemilk	24
Cathcart	25
Cessnock	26
City Centre	27
Clarkston/ Sheddens	28
Cowlairs/ Port Dundas	29
Craigton	30
Cranhill/ Queenslie	31
Crookston	32
Dalmarnock	33
Darnley	33a
Dennistoun	34
Dowanhill	35
Drumchapel	36
Drumoyne/ Shieldhall	37

District Centre	Code
Drumry	38
Dumbreck	39
Ferguslie	40
Finnieston	41
Firhill	42
Gallowgate	43
Gallowhill	44
Garrowhill	45
Giffnock	46
Glasgow Harbour	47
Glenwood	48
Gorbals	49
Govan	50
Govanhill	51
Greenfield	52
Haghill	53
Hillhead	54
Hillington	55
Hyndland	56
Ibrox	57
Kelvindale	58
Kelvingrove	59
Kelvinside/ Jordanhill	60
Keppochhill	61
Kessington	62
Kilmardinny	63
Kingspark	64
Kinning Park	65
Knightswood	66
Langside	67
Laurieston/ Tradeston	68
Mains Estate	69
Maryhill East	70
Maxwell Park	71
Mearns Village	72
Merrylee	73
Milton	74
Mosspark	75
Mount Florida	76
Muirend	77
Netherlee	78
Newlands	79
Nitshill	80

District Centre	Code
North Kelvin	81
Paisley	82
Paisley Ralston	83
Parkhead	84
Partick	85
Penilee	86
Petershill	87
Pollok	88
Pollokshaws	89
Pollokshields	90
Possil Park	91
Renfrew	92
Riddrie	93
Roystonhill/ Provanmill	94
Ruchill	95
Scotstoun	96
Shawfield and Clincarthill	97
Shawlands	98
Shettleston	99
Sighthill	100
Spittal	101
Springburn	102
Stamperland	103
Strathbungo	104
Summerston	105
Thornliebank	106
Tollcross	107
Toryglen and Oatlands	108
Vicarland and Cairns	109
Victoria Park	110
Westburn/ Newton	111
Westerton	112
Whitecraigs	113
Whiteinch	114
Williamwood	115
Woodhill West	116
Woodlands	117
Woodside	118
Wyndford	119
Yoker	120

Appendix G - Copies of Letters

THE HOUSEHOLDER
XXXXXXXXXX
XXXXXXXX
XXX XXX

Dr Neil Ferguson
Department of Civil Engineering
John Anderson Building
University of Strathclyde
Glasgow G4 0NG

GC1
5th June 06

Dear Householder,

Researchers at the University of Strathclyde are carrying out important research about your neighbourhood as part of a nationwide research project called ‘CityForm’. The research is funded by one of the UK’s Research Councils and aims to find out what is best and most sustainable about your local environment.

Your house is located within a carefully selected sample area. In the next few days we will send you a short questionnaire and travel diary. Your responses to our questions will be highly valued and are vitally important for our project. We would very much appreciate your time and effort in completing the questionnaire.

If you would rather we did not send you this questionnaire, please contact Lee Woods at 0141 548 3774 or lee.woods@strath.ac.uk so we can remove your name from our mailing list.

If you would like to know more about our research please visit the CityForm web-site at www.city-form.org for further information on our project.

Thank you in advance for your assistance.

Yours sincerely,

Neil S Ferguson

Dr Neil Ferguson

UNIVERSITY OF STRATHCLYDE

THE HOUSEHOLDER GC1
XXXXXXXXXXX
XXXXXXXXX
XXXXX

12th June 06

Dear Householder,

CityForm Questionnaire

Researchers at the University of Strathclyde are carrying out a survey to find out how people use their local area as part of a nationwide research project called 'CityForm'. The project is funded by one of the UK's Research Councils. The findings of the research will be used to improve the quality of our cities.

You house is located within a carefully selected sample area and your responses to our questions will be highly valued and are vitally important for the project. We would very much appreciate your time and effort in filling out this questionnaire.

We would like to ask you or your spouse/partner to complete the enclosed questionnaire and return it in the envelope provided. No stamp is required. This will only take a short amount of time, and your answers will be kept strictly confidential, private and anonymous. If you are unhappy answering any questions, please leave them blank.

Returned questionnaires will be entered into a prize draw in which you can win one of four £50 gift vouchers for Marks and Spencer.

Thank you in advance for you assistance.

Please tick if you do not wish to be entered into the prize draw ☐

If you have any questions regarding the questionnaire, please contact Lee Woods on 0141 548 3181 or lee.woods@strath.ac.uk. If you would like to know more about our research please visit the CityForm website at www.city-form.org for further information on our project.

Department of Civil Engineering, John Anderson Building, University of Strathclyde, Glasgow, G4 0NG.

Personal information used will be processed under the terms of the Data Protection Act. Any information you supply will be used exclusively for the purposes of the research programme and will not be passed to others or used for any other purpose. All information will be published in aggregate form so that individuals cannot be identified. The data will be held securely and disposed of when its purpose for collection is over.

CITY FORM

University of Strathclyde
Glasgow

29th June 2006

THE HOUSEHOLDER GC1
1 AIRD'S LANE,
GLASGOW.
G1 5HU

Dear Householder,

Researchers at the University of Strathclyde recently sent you a questionnaire about the way you use your local neighbourhood. This survey is part of a nationwide research project called "City Form" investigating ways in which we could improve our cities.

We would like to thank all those people who have already responded to the survey. If however, you have not yet returned your questionnaire but would still like to, your response would be very much appreciated.

If you still wish to take part in the survey please complete the travel diary section for the four days from Thursday 6th July to Sunday 9th July. Please note, these dates should replace the dates shown in the original questionnaire.

If you have not received or have mislaid the original and would still like to take part in the survey, please contact Lee Woods on 0141 548 3774 or e-mail: Lee.Woods@strath.ac.uk. If you have returned the questionnaire within the last few days, please ignore this letter.

Your answers will be kept strictly confidential, private and anonymous and will not be released to any third party. If you cannot complete the entire questionnaire but can complete part of it, we would appreciate it if you could return the partially completed version.

Should you have any queries about the questionnaire, please feel free to contact Lee Woods at 0141 548 3774 or lee.woods@strath.ac.uk. You can also visit the CityForm website at: www.city-form.com for further information on our project.

Thank you again for your help.

Neil S Ferguson

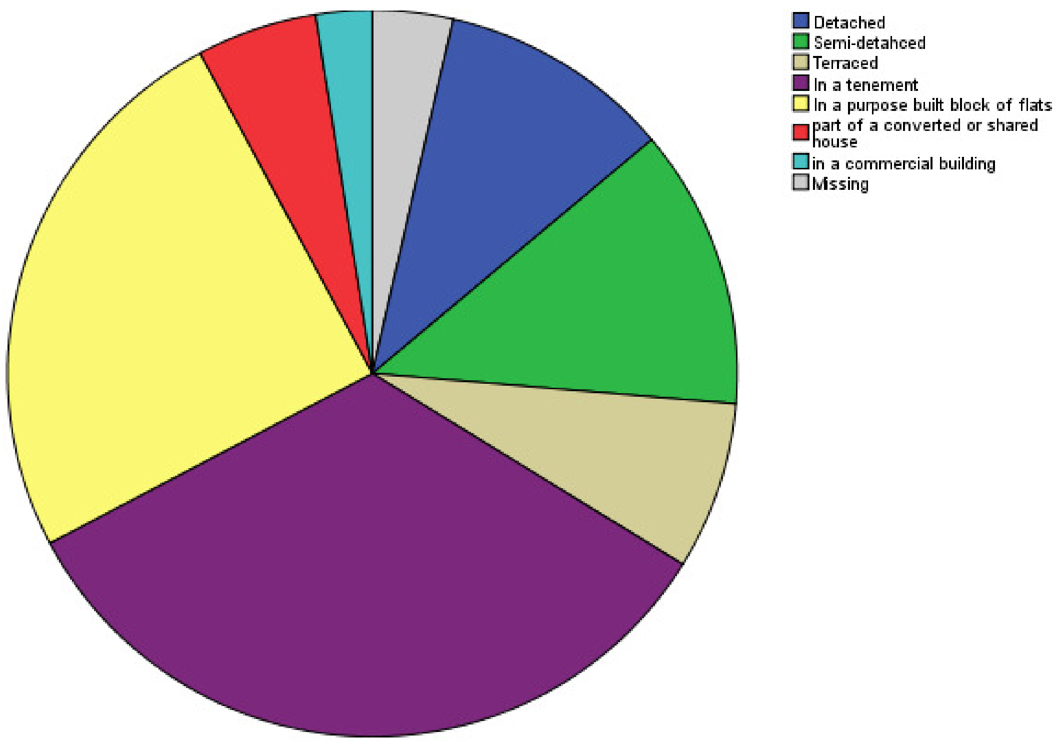
Dr Neil Ferguson - Lecturer

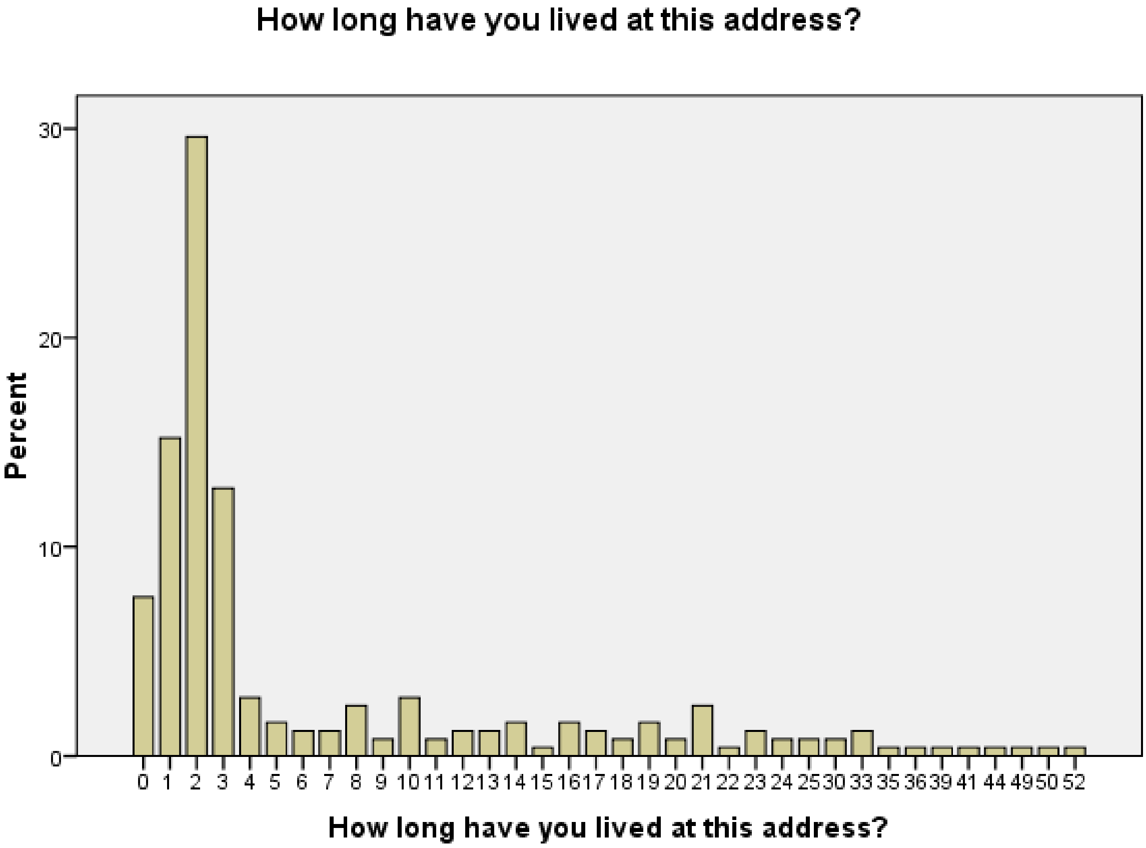
Appendix H - Descriptive Statistics

What type of accommodation does your household occupy at this address?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Detached	29	10.3	10.7	10.7
	Semi-detahced	35	12.5	12.9	23.6
	Terraced	21	7.5	7.7	31.4
	In a tenement	94	33.5	34.7	66.1
	In a purpose built block of flats	70	24.9	25.8	91.9
	Part of a converted or shared house	15	5.3	5.5	97.4
	In a commercial building	7	2.5	2.6	100.0
	Total	271	96.4	100.0	
Missing	System	10	3.6		
Total		281	100.0		

What type of accommodation does your household occupy at this address?

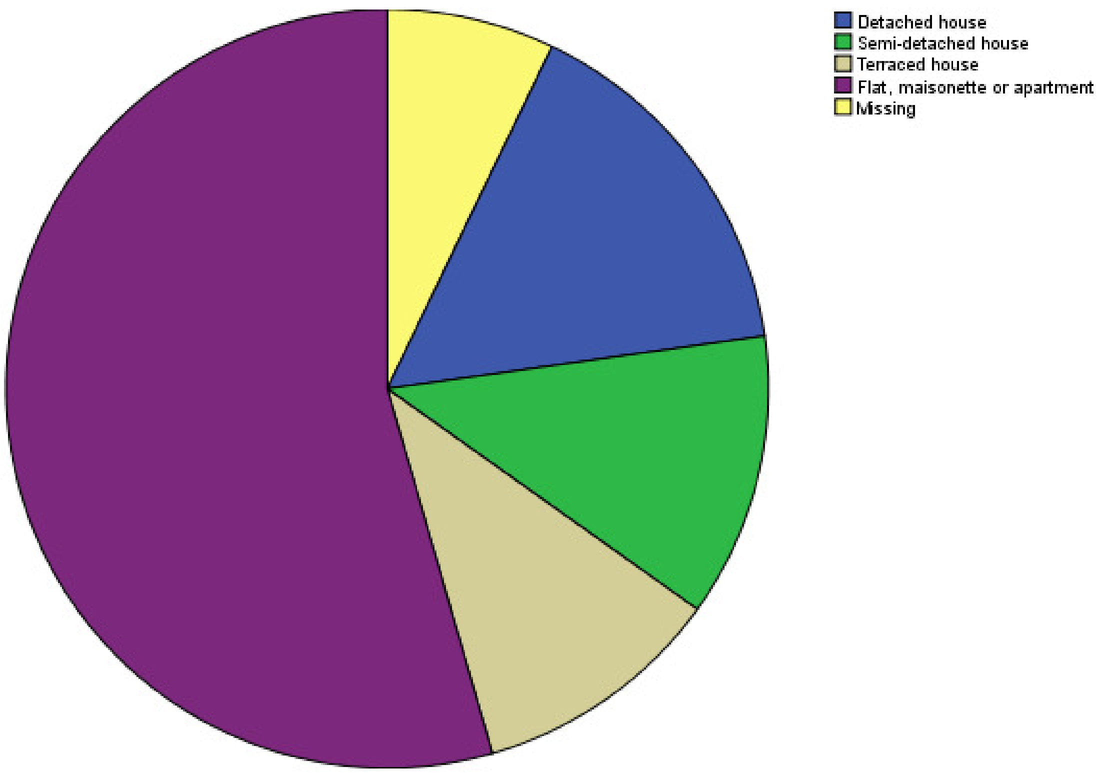



How long have you lived at this address?
30
20
10
0
Percent
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 30 33 35 36 39 41 44 49 50 52
How long have you lived at this address?

If elsewhere, what type of accommodation did you occupy

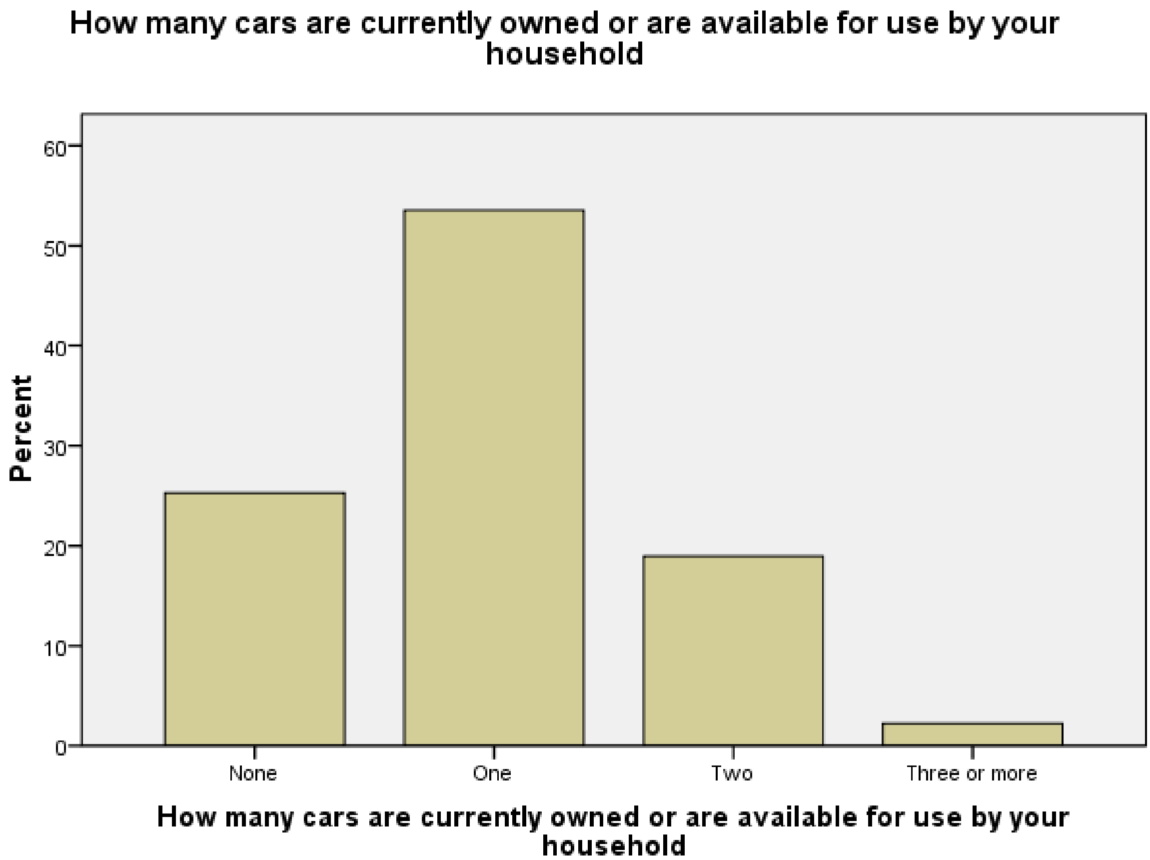
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Detached house	44	15.7	16.9	16.9
	Semi-detached house	34	12.1	13.0	29.9
	Terraced house	30	10.7	11.5	41.4
	Flat, maisonette or apartment	153	54.4	58.6	100.0
	Total	261	92.9	100.0	
Missing	System	20	7.1		
Total		281	100.0		

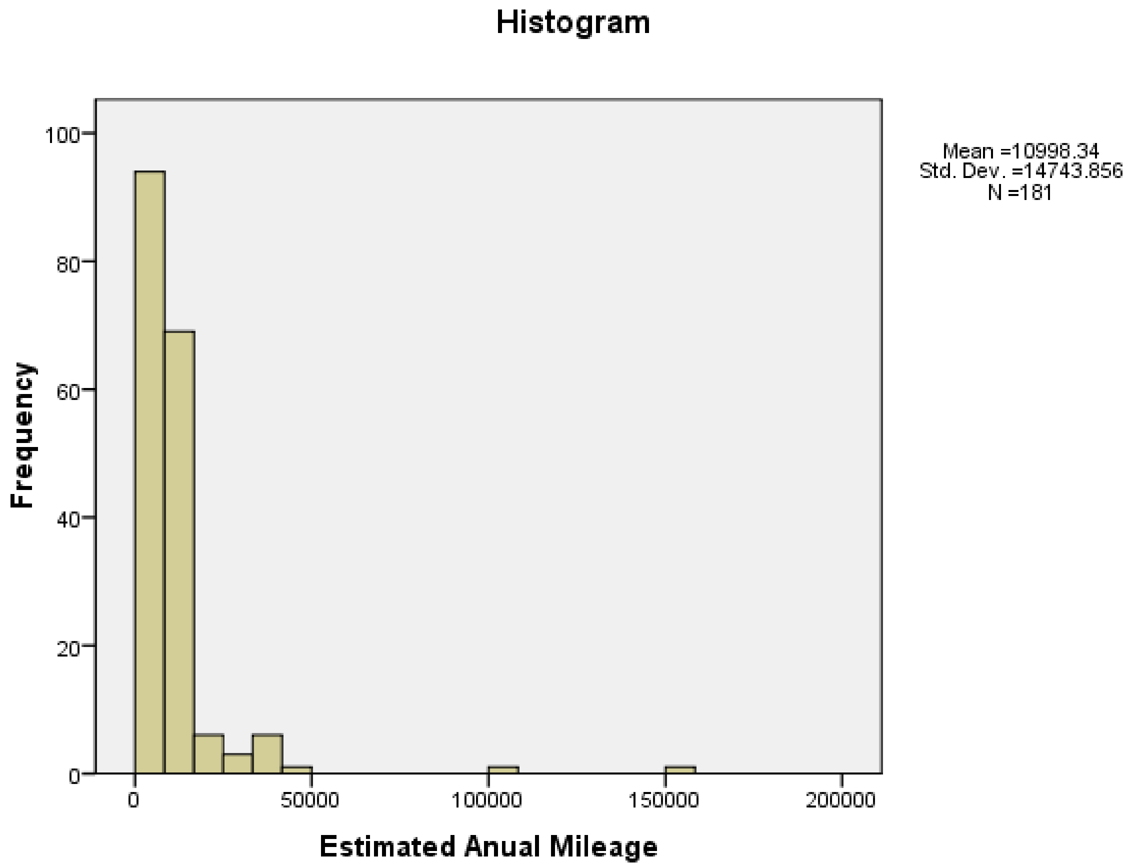
If elsewhere, what type of accommodation did you occupy



How many cars are currently owned or are available for use by your household

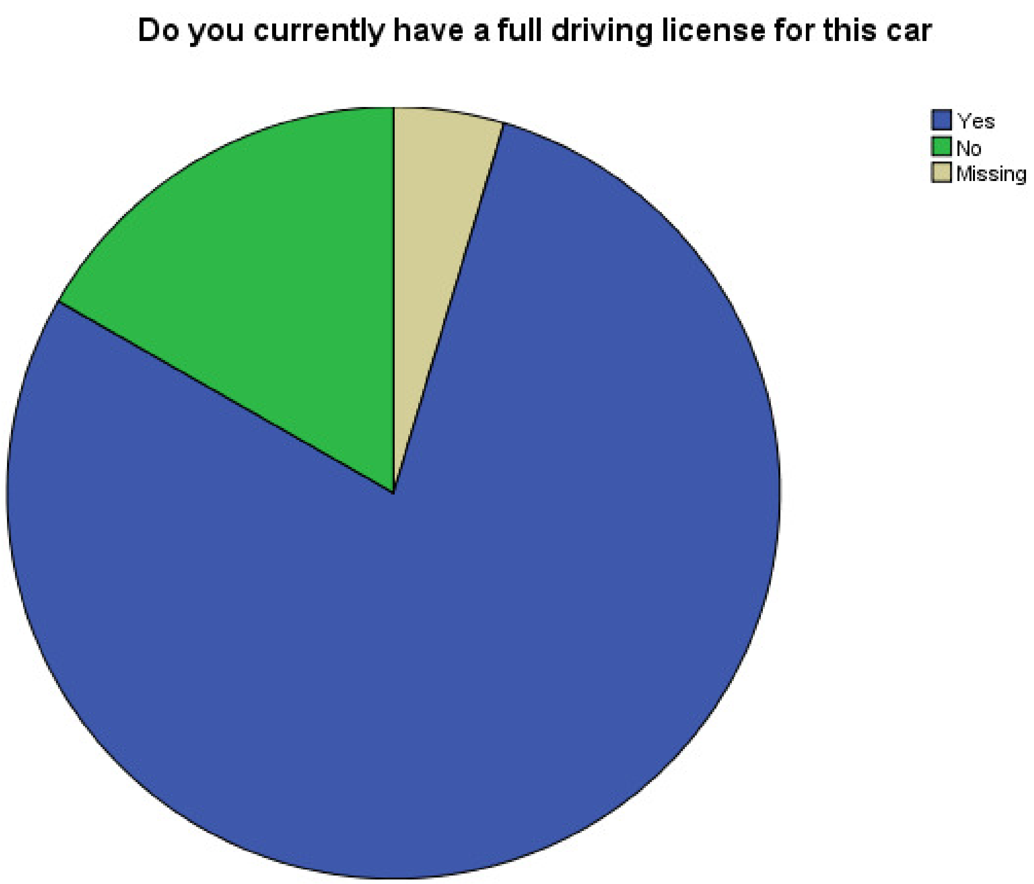
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	None	68	24.2	25.3	25.3
	One	144	51.2	53.5	78.8
	Two	51	18.1	19.0	97.8
	Three or more	6	2.1	2.2	100.0
	Total	269	95.7	100.0	
Missing	System	12	4.3		
Total		281	100.0		

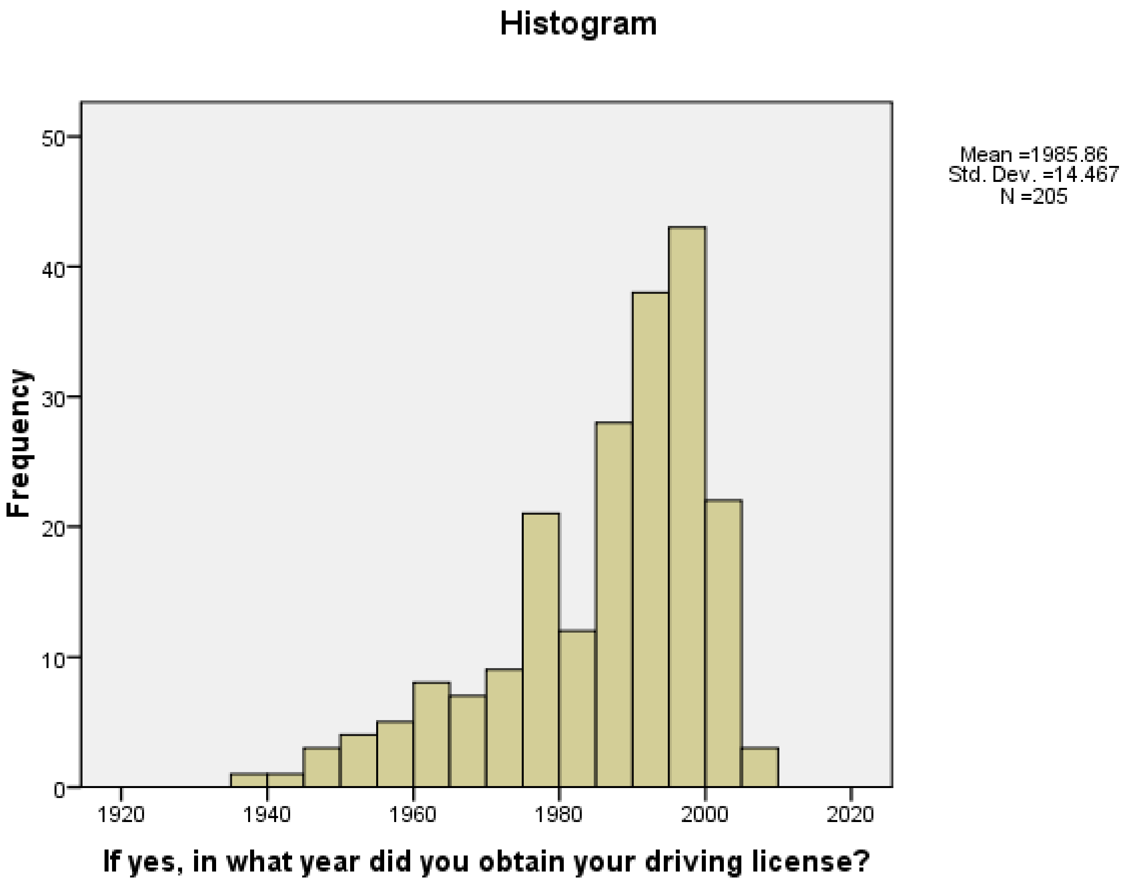



Histogram
Mean =10998.34
Std. Dev. =14743.856
N =181
Frequency
100
80
60
40
20
0
0
50000
100000
150000
200000
Estimated Anual Mileage

Do you currently have a full driving license for this car

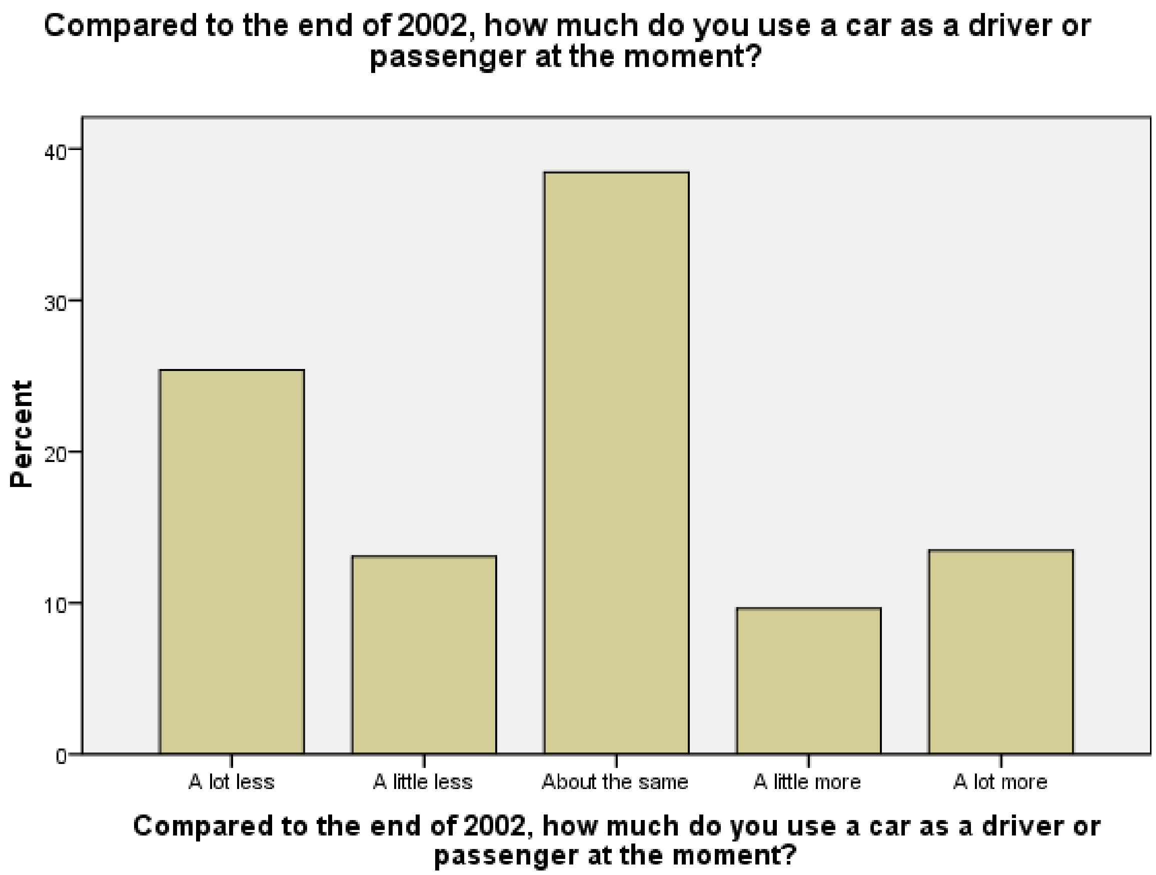
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	221	78.6	82.5	82.5
	No	47	16.7	17.5	100.0
	Total	268	95.4	100.0	
Missing	System	13	4.6		
Total		281	100.0		




Histogram
Mean =1985.86
Std. Dev. =14.467
N =205
Frequency
0
10
20
30
40
50
1920
1940
1960
1980
2000
2020
If yes, in what year did you obtain your driving license?

Compared to the end of 2002, how much do you use a car as a driver or passenger at the moment?

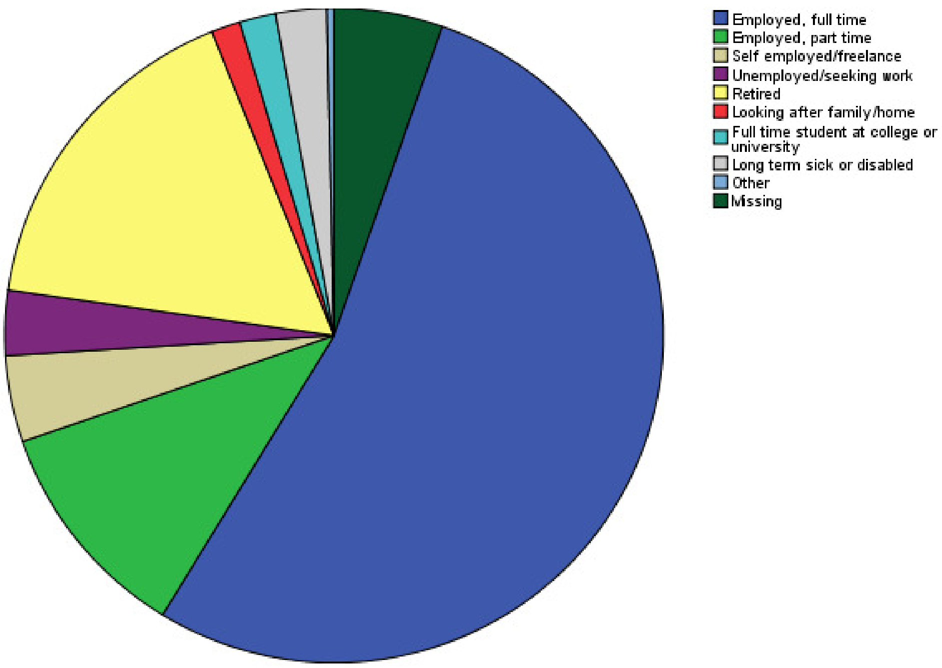
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	A lot less	66	23.5	25.4	25.4
	A little less	34	12.1	13.1	38.5
	About the same	100	35.6	38.5	76.9
	A little more	25	8.9	9.6	86.5
	A lot more	35	12.5	13.5	100.0
	Total	260	92.5	100.0	
Missing	System	21	7.5		
Total		281	100.0		



Which of the following best describes your current employment status?

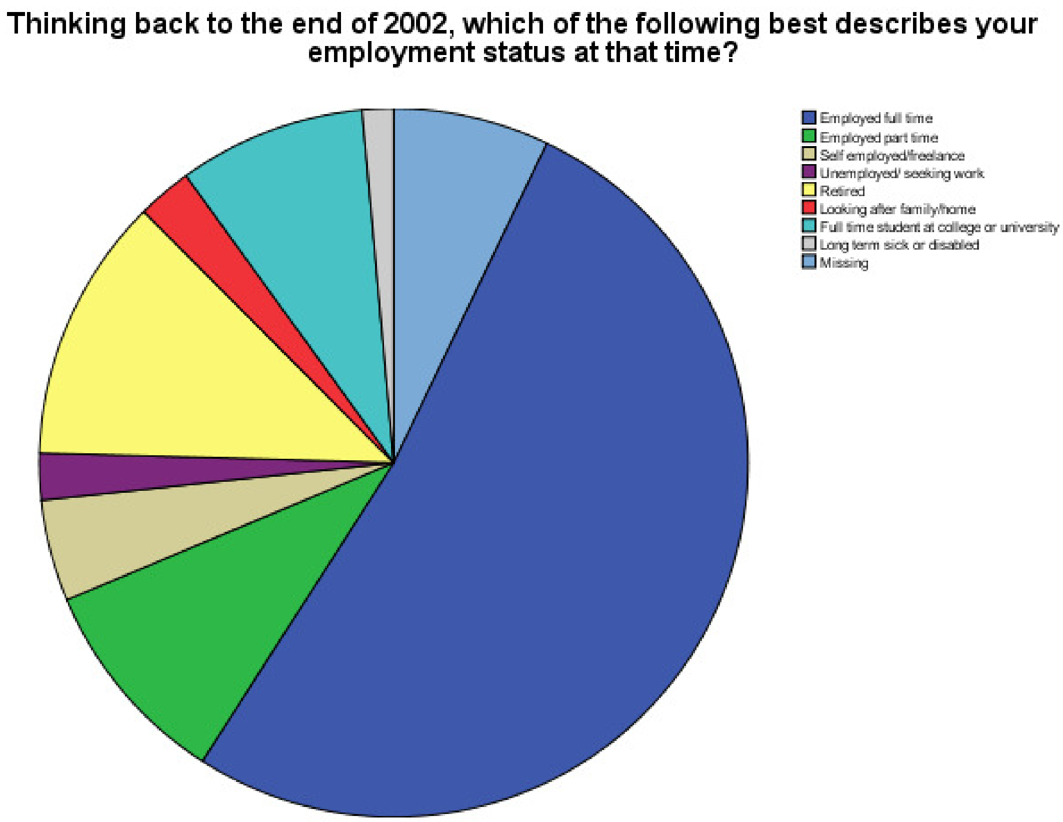
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Employed, full time	150	53.4	56.4	56.4
	Employed, part time	31	11.0	11.7	68.0
	Self employed/freelance	12	4.3	4.5	72.6
	Unemployed/seeking work	9	3.2	3.4	75.9
	Retired	47	16.7	17.7	93.6
	Looking after family/home	4	1.4	1.5	95.1
	Full time student at college or university	5	1.8	1.9	97.0
	Long term sick or disabled	7	2.5	2.6	99.6
	Other	1	.4	.4	100.0
	Total	266	94.7	100.0	
Missing	System	15	5.3		
Total		281	100.0		

Which of the following best describes your current employment status?



Thinking back to the end of 2002, which of the following best describes your employment status at that time?

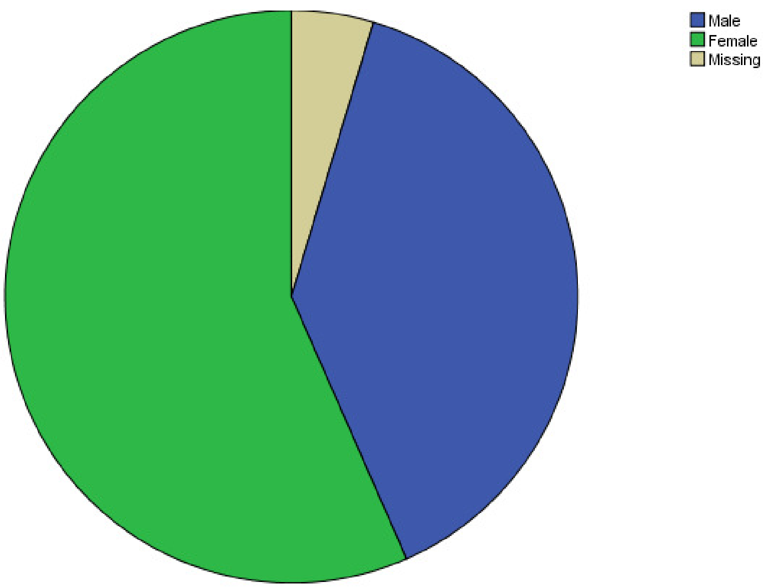
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Employed full time	146	52.0	55.9	55.9
	Employed part time	27	9.6	10.3	66.3
	Self employed/freelance	13	4.6	5.0	71.3
	Unemployed/ seeking work	6	2.1	2.3	73.6
	Retired	34	12.1	13.0	86.6
	Looking after family/home	7	2.5	2.7	89.3
	Full time student at college or university	24	8.5	9.2	98.5
	Long term sick or disabled	4	1.4	1.5	100.0
	Total	261	92.9	100.0	
Missing	System	20	7.1		
Total		281	100.0		



Are you?

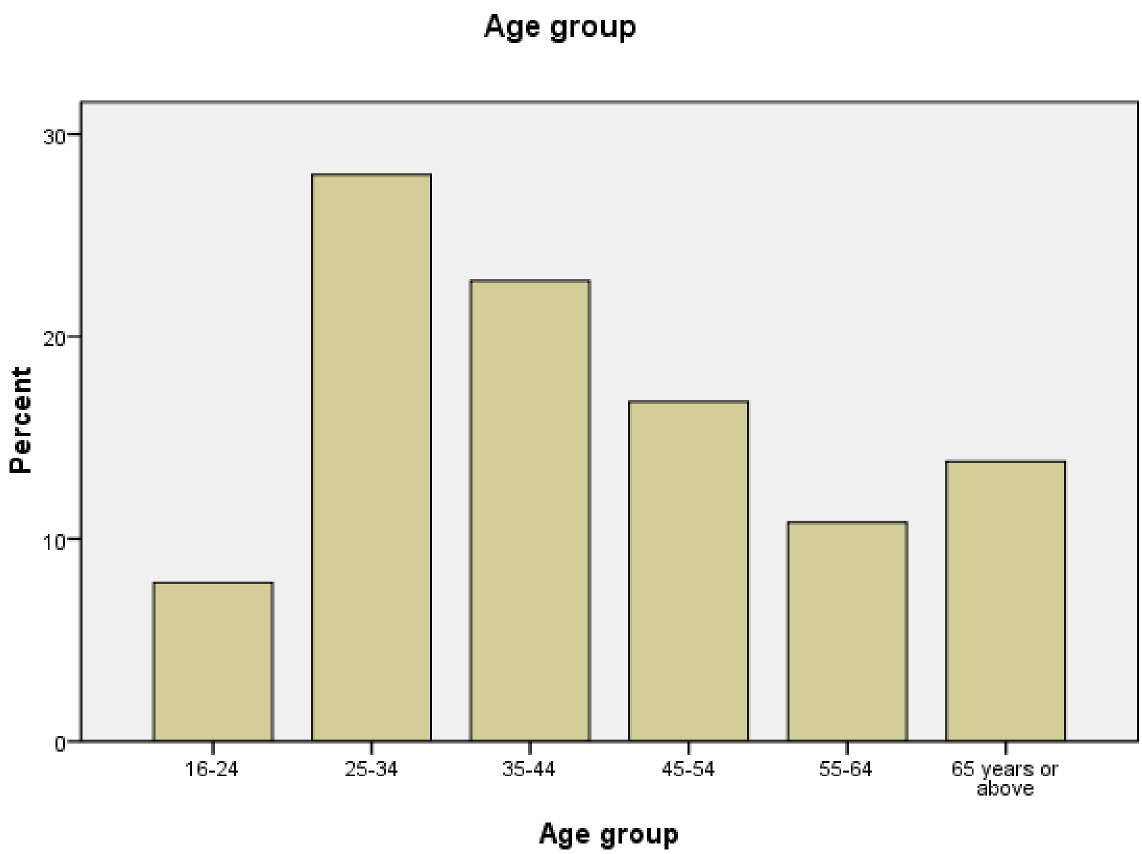
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	109	38.8	40.7	40.7
	Female	159	56.6	59.3	100.0
	Total	268	95.4	100.0	
Missing	System	13	4.6		
Total		281	100.0		

Are you?



Age group

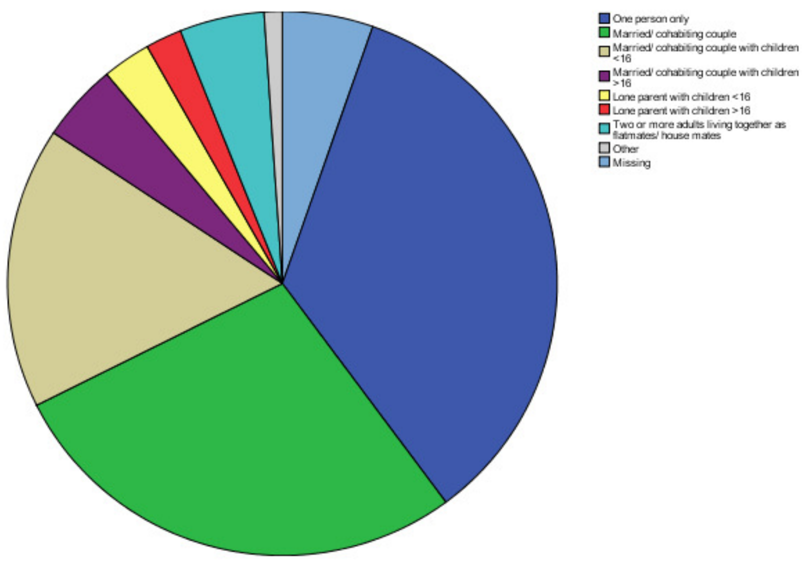
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	16-24	21	7.5	7.8	7.8
	25-34	75	26.7	28.0	35.8
	35-44	61	21.7	22.8	58.6
	45-54	45	16.0	16.8	75.4
	55-64	29	10.3	10.8	86.2
	65 years or above	37	13.2	13.8	100.0
	Total	268	95.4	100.0	
Missing	System	13	4.6		
Total		281	100.0		



Which of the following best describes the relationship between those normally living at this address?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	One person only	97	34.5	36.5	36.5
	Married/ cohabiting couple	78	27.8	29.3	65.8
	Married/ cohabiting couple with children <16	47	16.7	17.7	83.5
	Married/ cohabiting couple with children >16	13	4.6	4.9	88.3
	Lone parent with children <16	8	2.8	3.0	91.4
	Lone parent with children >16	6	2.1	2.3	93.6
	Two or more adults living together as flatmates/ house mates	14	5.0	5.3	98.9
	Other	3	1.1	1.1	100.0
	Total	266	94.7	100.0	
Missing	System	15	5.3		
Total		281	100.0		

Which of the following best describes the relationship between those normally living at this address?



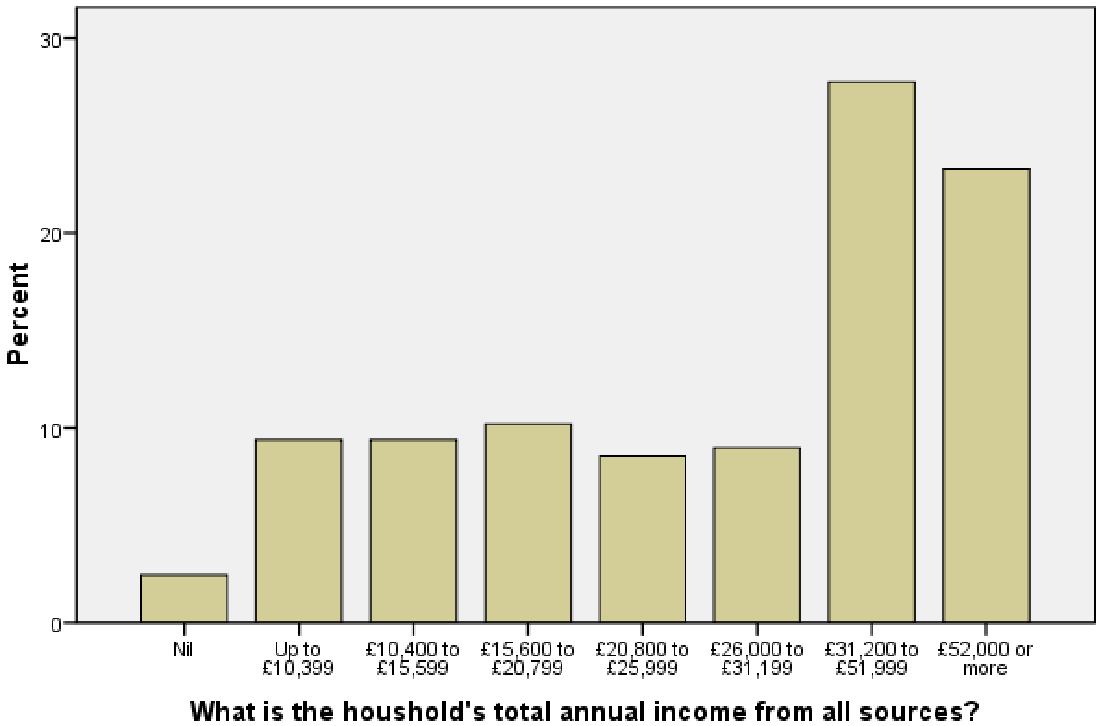
How many people normally live at this address?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	93	33.1	35.2	35.2
	2	101	35.9	38.3	73.5
	3	36	12.8	13.6	87.1
	4	24	8.5	9.1	96.2
	5	7	2.5	2.7	98.9
	6	2	.7	.8	99.6
	16	1	.4	.4	100.0
	Total	264	94.0	100.0	
Missing	System	17	6.0		
Total		281	100.0		

What is the household's total annual income from all sources?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Nil	6	2.1	2.4	2.4
	Up to £10,399	23	8.2	9.4	11.8
	£10,400 to £15,599	23	8.2	9.4	21.2
	£15,600 to £20,799	25	8.9	10.2	31.4
	£20,800 to £25,999	21	7.5	8.6	40.0
	£26,000 to £31,199	22	7.8	9.0	49.0
	£31,200 to £51,999	68	24.2	27.8	76.7
	£52,000 or more	57	20.3	23.3	100.0
	Total	245	87.2	100.0	
Missing	System	36	12.8		
Total		281	100.0		

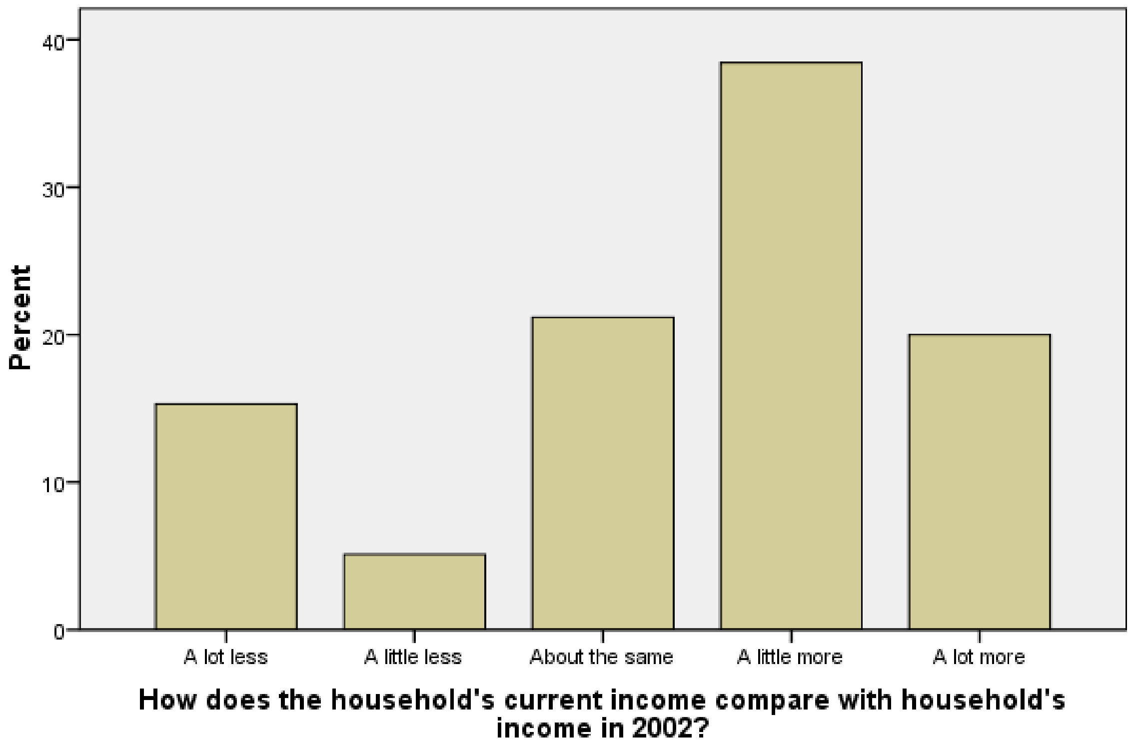
What is the houshold's total annual income from all sources?



How does the household's current income compare with household's income in 2002?

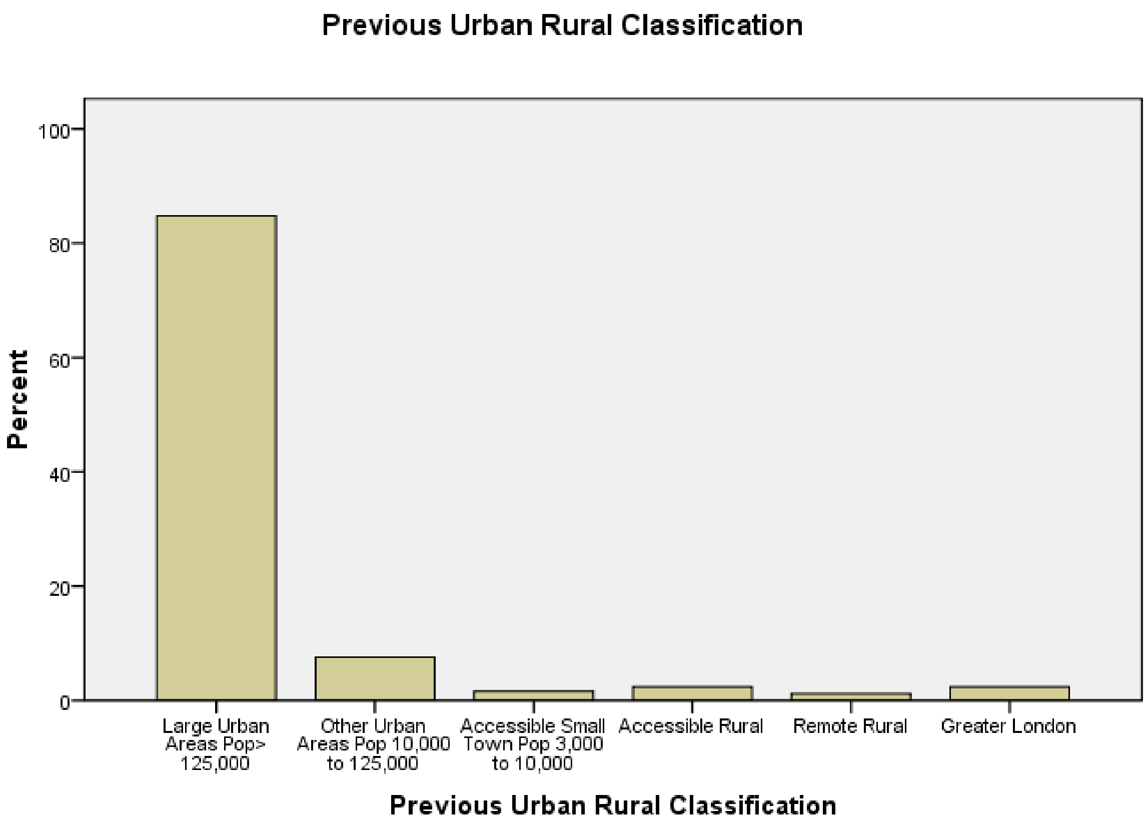
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	A lot less	39	13.9	15.3	15.3
	A little less	13	4.6	5.1	20.4
	About the same	54	19.2	21.2	41.6
	A little more	98	34.9	38.4	80.0
	A lot more	51	18.1	20.0	100.0
	Total	255	90.7	100.0	
Missing	System	26	9.3		
Total		281	100.0		

How does the household's current income compare with household's income in 2002?



Previous Urban Rural Classification

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Large Urban Areas Pop> 125,000	212	75.4	84.8	84.8
	Other Urban Areas Pop 10,000 to 125,000	19	6.8	7.6	92.4
	Accessible Small Town Pop 3,000 to 10,000	4	1.4	1.6	94.0
	Accessible Rural	6	2.1	2.4	96.4
	Remote Rural	3	1.1	1.2	97.6
	Greater London	6	2.1	2.4	100.0
	Total	250	89.0	100.0	
Missing	System	31	11.0		
Total		281	100.0		



Appendix I. Correlation Matrix

		Current Accommodation Type	Network Distance from Current Address to Current Work Place km	Current Output Area Density	Current Ward Density	Distance to Nearest Urban Centre (current)	Current Jobs:Pop Ratio	Current employment status?	Gender	Age	Household Structure	Number of residents in current household	Current household income	Change in household income	Current household car ownership	Previous household car ownership	Total Household Distance Driven	Change in car use
Current Accommodation Type	Pearson Correlation	1																
	Sig. (2-tailed)																	
	N	271																
Network Distance from Current Address to Current Work Place km	Pearson Correlation	-.072	1															
	Sig. (2-tailed)	.266																
	N	243	243															
Current Output Area Density	Pearson Correlation	.158**	-.057	1														
	Sig. (2-tailed)	.009	.376															
	N	271	243	281														
Current Ward Density	Pearson Correlation	.251**	-.080	.470**	1													
	Sig. (2-tailed)	.000	.214	.000														
	N	271	243	281	281													
Distance to Nearest Urban Centre (current)	Pearson Correlation	-.563**	-.024	-.308**	-.383**	1												
	Sig. (2-tailed)	.000	.711	.000	.000													
	N	271	243	281	281	281												
Current Jobs:Pop Ratio	Pearson Correlation	.244**	-.080	-.079	-.200**	-.387**	1											
	Sig. (2-tailed)	.000	.212	.189	.001	.000												
	N	271	243	281	281	281	281											
Current employment status?	Pearson Correlation	-.121*	-.294**	.063	-.098	.096	.003	1										
	Sig. (2-tailed)	.050	.000	.305	.109	.118	.958											
	N	265	243	266	266	266	266	266										
Gender	Pearson Correlation	.074	-.140*	.064	.017	.119	-.057	-.053	1									
	Sig. (2-tailed)	.229	.030	.295	.780	.051	.354	.396										
	N	267	241	268	268	268	268	263	268									

Age	Pearson Correlation	-.310**	-.066	-.120*	-.121*	.250**	-.218**	.495**	-.098	1								
	Sig. (2-tailed)	.000	.307	.050	.048	.000	.000	.000	.110									
	N	267	241	268	268	268	268	263	268	268								
Household Structure	Pearson Correlation	-.135*	-.017	-.045	-.102	.138*	-.096	-.037	.083	-.132*	1							
	Sig. (2-tailed)	.028	.797	.466	.098	.025	.120	.555	.178	.031								
	N	265	240	266	266	266	266	262	266	266	266							
Number of residents in current household	Pearson Correlation	-.237**	.034	-.068	-.088	.195**	-.139*	-.088	.010	-.002	.536**	1						
	Sig. (2-tailed)	.000	.600	.273	.154	.001	.024	.160	.873	.972	.000							
	N	263	237	264	264	264	264	259	264	264	262	264						
Current household income	Pearson Correlation	-.093	.265**	-.202**	-.113	-.045	-.018	-.555**	-.055	-.244**	.100	.143*	1					
	Sig. (2-tailed)	.145	.000	.001	.078	.483	.784	.000	.394	.000	.118	.027						
	N	245	224	245	245	245	245	242	245	245	244	241	245					
Change in household income	Pearson Correlation	.064	.092	.002	.021	-.044	.020	-.369**	.081	-.208**	-.060	-.071	.317**	1				
	Sig. (2-tailed)	.312	.164	.972	.739	.483	.753	.000	.195	.001	.339	.262	.000					
	N	255	231	255	255	255	255	251	255	255	253	252	241	255				
Current household car ownership	Pearson Correlation	-.248**	.246**	-.246**	-.199**	.234**	-.218**	-.300**	-.083	-.009	.101	.267**	.503**	.092	1			
	Sig. (2-tailed)	.000	.000	.000	.001	.000	.000	.000	.177	.885	.103	.000	.000	.146				
	N	268	240	269	269	269	269	263	265	265	263	262	243	253	269			
Previous household car ownership	Pearson Correlation	-.080	.157*	-.175**	-.190**	.124*	-.069	-.101	-.084	-.032	-.022	.136*	.296**	-.129*	.636**	1		
	Sig. (2-tailed)	.196	.015	.004	.002	.044	.265	.103	.176	.608	.728	.028	.000	.042	.000			
	N	265	238	266	266	266	266	261	262	262	261	259	241	250	266	266		
Total Household Distance Driven	Pearson Correlation	-.045	.145*	-.050	-.034	.012	-.087	-.148*	-.019	-.039	.028	.168**	.267**	.049	.409**	.308**	1	
	Sig. (2-tailed)	.463	.024	.402	.574	.845	.148	.015	.753	.528	.650	.006	.000	.439	.000	.000		
	N	271	243	281	281	281	281	266	268	268	266	264	245	255	269	266	281	
Change in car use	Pearson Correlation	.055	.190**	.068	.087	.006	-.138*	-.284**	-.032	-.184**	.013	.079	.187**	.214**	.193**	-.082	.107	1
	Sig. (2-tailed)	.381	.004	.274	.160	.926	.026	.000	.613	.003	.830	.208	.004	.001	.002	.193	.084	
	N	259	233	260	260	260	260	256	257	257	256	253	236	244	258	256	260	260

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table I1. Correlation Matrix