
THE INFLUENCE OF URBAN SPATIAL STRUCTURE ON COMMUTING AND MODAL CHOICE: EVIDENCE FROM THE GREATER DUBLIN AREA

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Abstract

This paper examines the influence of urban spatial structure (USS) on commuting and modal choice. It focuses in particular on the impact of different spatial structure types on commuting patterns and car dependency. This account encompasses the current status of debate regarding the relationship between land-use and transport as well as using evidence from the Greater Dublin Area (GDA) to analyse and discuss these issues. There is significant disagreement regarding the ability of land-use measures to promote sustainable travel and this paper seeks to clarify key questions in this regard. In order to explore this subject, the main types of urban spatial structure are broadly defined and appropriate study areas within the GDA are selected to replicate the conditions found in monocentric development, 'urban village' polycentric development and low-density sprawl. Through the utilisation of GIS techniques, these study areas are identified by categorising CSO 'small areas' according to their residential density, jobs/housing balance and the level of public transport provision. The use of CSO POWSCAR (2011) data allows for analysis of differences in commuting characteristics across different spatial structure types and the evidence to suggest that land-use is a significant factor in determining travel behaviour. Areas of particular interest are variables such as trip duration, modal split and car ownership levels. Finally, the paper builds upon this analysis by discussing the role of land-use factors in the promotion of sustainable travel and outlines the need for further research that encompasses other factors such as socio-economic characteristics as well as attitudes and preferences.

1. Introduction

The predominant development trend observed across urban areas in the developed world in recent decades has been one of increasing employment and residential decentralisation in a transition towards more polycentric urban spatial structures [1]. This has had significant impacts on urban travel patterns and the modal choice decisions, with research suggesting that decentralisation has encouraged more complex commuting and higher levels of car dependency [2, 3]. Clearly, this presents a significant challenge regarding efforts to create more sustainable transport systems and a range of land-use based planning responses have been proposed as possible solutions [4]. Yet, the ability of land-use measures in isolation, without encompassing other critical factors, to promote modal shift has been questioned and it is suggested that other methods should be considered if substantial change is to be achieved [5]. The key objectives of this paper are to: outline current research regarding the influence of urban spatial structure on commuting, utilise evidence from the Greater Dublin Area (GDA) to assess key assertions made in the literature and make recommendations for the direction of future research.

2. Methodology

In order to outline the influence of urban spatial structure on commuting, a literature review provided an overview the current status of debate regarding research in this area. An appropriate methodological approach was developed to investigate this issue using CSO POWSCAR (2011) data which provides the most detailed information available on Irish commuting patterns. The study does not consider other types of trips both due to a lack of available data but also because commuting trips are the most relevant type of travel for this study as USS has its greatest influence in determining trips between homes and workplaces [6, 7]. Also, arguably commuting mode is likely to suggest people's primary mode for other trips as well because of 'trip-chaining' that takes place with additional trips using the same mode around peak periods [7]. Through the use of GIS and SPSS packages, a series of CSO 'small areas' in the GDA were identified that would broadly replicate the conditions found across the three main types of USS identified in *Section 3* and defined in *Section 5.1*. The details of the data preparation and study area selection process are discussed further in *Section 5.2*. Following this, SPSS and Excel were utilised to complete comparative analysis and reach indicative conclusions on the relative influence of land-use factors on commuting behaviour. The key aim of this quantitative section was to gather evidence to ascertain if arguments identified in the literature regarding the effect of different spatial structure types

on commuting patterns were broadly accurate. While these conclusions could not be considered to be conclusive, they provided a certain amount of clarity and allow for a series of areas for future study to be identified.

3. Urban Spatial Structure and Commuting

The urban spatial structure of modern cities has evolved over time as transport and technology have advanced [8, 9, 10]. The first industrial cities were highly centralised around trade points in monocentric development until the introduction of motorised transport and telecommunications weakened population and employment ties to CBD areas [8, 11]. North American and European cities are now evolving towards more polycentric forms of development where there are multiple distinct employment and population centres across the urban region [12, 11]. This transition has had numerous negative impacts regarding the sustainability of urban travel [13]. Essentially commuting has changed from being largely radial, which could be easily catered for through public transport routes, to being dispersed across urban regions as decentralised residences access decentralised employment [14, 15]. This has generally resulted in more complex trip patterns, higher car use and less efficient public transport services [3, 2, 16].

Different types of development can encourage varying levels of sustainable travel and planners have sought to use this influence to reduce car use [3]. The main strategic planning responses have focused on the implementation of land-use measures that should theoretically create areas which make public transport more attractive to residents [1, 17, 18]. Such strategies are based on evidence that indicates that higher density developments, which utilise mixed-use measures, are associated with less car use [5, 19]. These approaches centre on the idea of creating sustainable 'urban village' sub-centres at the outskirts of cities (Figure 1) that would be almost self-sufficient for employment and minimise unsustainable travel by bringing residents closer to destinations and providing public transport access for non-local trips [15, 20, 19]. These planning solutions, or other similar policy approaches, have seen widespread adoption by policy makers in Europe even though some authors would question the accuracy of the supporting evidence that proves their effectiveness [21]. This urban spatial structure and the other main types present in modern urban development are outlined in Table 1 for comparison.

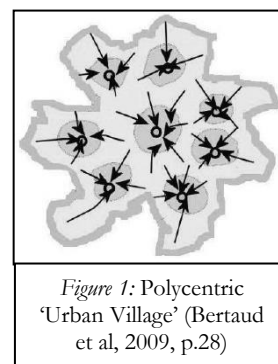


Figure 1: Polycentric 'Urban Village' (Bertaud et al, 2009, p.28)

Type	Spatial Layout	Travel Characteristics	Example	Ref.
Monocentric City	The "monocentric model has a clear declining density gradient from the city centre outwards" with centralised economic activity	Strong radial movement that favours public transport provision with limited need for the private car	Historic Dublin	[17, 11, 22]
Mono-Polycentric City	The centre remains the main area of economic activity but increasing decentralisation of employment has weakened the dominance of the CBD	Strong radial travel to central areas and public transport usage high for these trips but suburban travel primarily by private car	London	[11, 22]
Polycentric City (Urban Village)	"Intra-urban patterns of clustering of population and economic activity" composed of independent multiple centres	Majority live near employment and travel locally with high proportion of sustainable modes	Seoul, Korea	[15, 17, 11]
Polycentric City (Random Movement/ Urban Sprawl)	Sub-centres present but no dominant centre with employment and services distributed uniformly	"Each sub-centre generates trips from all over the built-up area of the city" and thus "trips tend to show a wide dispersion of origin and destinations"	Perth, Australia	[15, 17, 23]

4. Land-Use Measures and Sustainable Travel

Theoretically, it was expected that the creation of such sustainable sub-centres would occur as residents located near local employment centres to minimise their commuting costs [12]. However generally this has not been the case, with Bertaud [15, 17] suggesting that the labour market fragmentation that would be required to achieve this would run contrary to continued economic growth while also stating that it is unrealistic to assume that planners can match workplace and residential locations into the same centres in practice [17]. Yet, planning research and policy continues to forward this approach as a favourable solution to issues of car dependency as some 'urban village' developments have been recorded to

show a positive influence in promoting sustainable travel [13, 24, 25, 26]. While this may be the case, there is still great contention regarding whether it is the influence of land-use factors in these developments that actually promotes greater sustainable travel or whether other factors are at work [5]. Reference [27] raises the importance of socio-demographic characteristics in this regard but one of the most intensely debated topics is the possible role of residential 'self-selection' (RSS) in determining modal split characteristics [13, 12]. Some authors propose that the positive results observed in 'urban village' developments may reflect residents choosing to live in areas that facilitate their preferred mode rather than demonstrating a trend of modal shift that could be achieved across the entire population [5].

This idea of using of land-use measures to reduce car use has been increasingly explored in recent decades and intense debate continues regarding the effectiveness of mixed-use and density for this purpose [19]. The use of mixed-use development is widely regarded, when combined with quality public transport links, to lead to more sustainable local trips as residents can access services without the use of the private car [28, 29]. Parallel to this, the use of compact high density development is considered to compliment this approach by contributing to reduced car ownership as residential densities increase [30, 31]. Higher densities are also suggested to lead to increased patronage, with a 10% increase in density resulting in a 5% increase in passenger numbers [31, 30]. However, some studies question these results and warn that land-use measures may be less effective than once thought, with Bento et al [1] stating that a 10% increase in density may only reduce driving by 1%. Also, there is the possibility that the positive results observed, instead reflect the influence of other factors such as socio-economics [27, 13] and attitudinal variables [5, 32]. Yet, proponents of the 'urban village' approach continue to claim that the association between land-use characteristics is causal and can lead to significant reductions in car-use [19].

As can be clearly observed, a multitude of studies have attempted to understand the link between land-use factors and modal choice decisions. The majority either try to prove or disprove the relative influence of land-use factors in order to establish causality but the extent of this relationship has not yet been fully quantified [33]. A vast array of often contradictory evidence is presented in this field and clear conclusions cannot yet be reached. For instance, one author will suggest that commuting travel behaviour is primarily explained by residential self-selection [34] while another study [35] will state that the type of development is a more significant factor [19]. In light of this divergence across research, the following sections will seek to clarify the extent that land-use appears to affect commuting characteristics across different land-use types in the Greater Dublin Area.

5. Evidence of Land-Use Influence on Commuting

Due to the ambiguity in the literature regarding the influence of urban spatial structure on commuting [13], it is important to reach independent conclusions on whether land-use factors can act as a defining influence on modal split and commuting patterns. This section utilises the Census (2011) and the CSO's POWSCAR (2011) dataset which provides origin-destination data and the travel characteristics of commuters in Ireland. The study area definitions are described in *Section 5.1*, data preparation and study area selection in *Section 5.2* and results in *Section 5.3*.

5.1. Study Area Selection: Defining USS Types for the GDA

The Greater Dublin Area represents a metropolitan region that has experienced rapid employment suburbanisation and residential sprawl in recent decades and is a topical European location in which to conduct this research [36]. Similar to Reference [36], the GDA is defined as the four administrative counties of Dublin City, South Dublin, Dun Laoghaire-Rathdown and Fingal for the purposes of this study. The data used is at the smallest scale provided within geographic boundaries in the Irish census, classified by the CSO as 'small areas' (SA) which operate at a level of detail of around 100+ households. The study area selection process seeks to identify a series of SA's in the GDA which broadly replicate the conditions found in the three main types of USS defined in the literature (*Table 1*). Based on these definitions, the three main USS types of monocentric, urban village and sprawl were categorised as having the following land-use characteristics (*Table 2* with expanded definitions in *Appendix 1 and 3*). The 'random movement' model was intentionally excluded from the study classifications as this is largely only found in North American urban areas [17]. Also, due to the lack of data on existing, rather than zoned, land-use types in the GDA,

jobs/housing balance was used as a proxy for the influence of mixed-use development as this is arguable a very similar measure [37].

Table 2: Study Area Selection: Development Criteria

Spatial Structure	Level of Public Transport Availability	Density of Development	Jobs/Housing Balance
Monocentric/Core	High	High	Imbalanced (Jobs+)
Polycentric (Urban Village)	Medium/High	Medium	Balanced
Polycentric (Sprawl)	Low	Low	Imbalanced (Housing+)

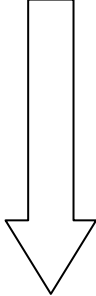
These characteristics were defined in the following way:

- Level of public transport availability:** As the vast majority of public transport access in the GDA is provided through bus services, this was the major consideration of categorisation and all Luas/rail services were by default assigned to the 'high' level of availability due to their peak frequency levels. Bus routes were defined according to their majority frequency during the 7am-8am peak commuting time, rather than 8am-9am, to assess the level of service that outer commuters would have in reaching the CBD for the start of the average working day. The frequency levels of each type of public transport availability are defined in *Appendix 1*, along with a list of excluded routes. In line with standard practice, a catchment buffer of 400m was applied to all bus stops and an 800m buffer to all light/heavy rail routes as accurate stop data was not available for these modes. The monocentric and sprawl areas are only located in their respective high or low areas of public transport availability as described *Table 2*. While it was intended that the urban village category would also only include SA's located within medium level public transport buffers, in reality few of these existed without overlapping with other buffers and so SAs were selected to have at least medium level access and higher. The total catchment of all these buffers is shown in *Appendix 4*.
- Density of development:** Density levels often cited in USS literature were generally out of scale with the Irish context and so broad categorisations of low, medium and high density development in the GDA were created by using Irish policy guidelines [38]. All densities are defined as housing units per hectare (UPH) and this was calculated by dividing total housing stock by the number of hectares contained within each boundary. Originally, a tighter definition of urban villages was defined (*Appendix 2*) but due to the limited number of SA's contained in this bracket (5 in total), this definition was broadened to 20-40 UPH to ensure a respectable sample size (*Appendix 3*).
- Jobs/housing balance:** Due to the lack of data available regarding the number of jobs present within each SA, this had to be calculated using POWSCAR (2011) data. The destination of commuting trips to each SA was used to denote the number of jobs located within each area so that jobs/housing balance could be calculated. There were originally over 2.7 million commuting destinations (Inc. students) located across Ireland but once the four counties of Dublin were selected and mobile workers, those who worked at home, those in home schooling and blank entries were removed, the dataset composed of 776,019 entries. Following this, all school/student trips were removed to ensure that the remaining commuting destinations were only of employed workers, totalling 513,566 employment destinations across the GDA. From this, jobs/housing balance could be calculated by using the total housing stock figures for each SA. Originally, the jobs/housing balance definition for urban villages was 1.3-1.7 (*Appendix 2*) but this was later revised to a broader classification of 1-2 jobs per person (*Appendix 3*) due to the lack of suitable SA's available.

5.2. Study Area Selection: Identification Process and Data Extraction

In total there are 4806 different small areas located in the GDA and once the three layers described in *Section 5.1* had been created, this number of SA's could be filtered down to identify the USS types outlined in *Table 2*. The selection of SA's according to density and

jobs/housing balance was completed according to GIS attribute data while SA's located in different levels of public transport availability were identified by the location of their centroid within the required buffer type. It should be noted that the sprawl category was identified by SA's within the 'low' category of public transport availability, which did not overlap with medium/high public transport buffer areas, in order to accurately reflect sprawl conditions. The breakdown of the SA filtering process is provided in *Table 3* with each set of numbers showing the amount of SA's that fulfilled different land-use requirements as they accumulated:

	USS Type	Selection Type	Number of Small Areas	Total SA's
	Monocentric	Density	1,136	50
		J/H Balance	50	
		Public Transport Availability	50	
	Urban Village	Density	1906	45
		J/H Balance	47	
		Public Transport Availability	45	
	Sprawl	Density	1764	130
		J/H Balance	1397	
		Public Transport Availability	130	

This resulted in the following number of SA's that fulfilled the USS definitions of the study:

- *Monocentric*: 50 small areas (*Appendix 5*) predominantly located in central locations except for scattered suburban concentrations.
- *Urban Village*: 45 small areas (*Appendix 7*) largely located in central, outer CBD areas, along with some suburban locations.
- *Sprawl*: 130 small areas (*Appendix 8*) predominantly located in suburban areas far removed from the CBD.

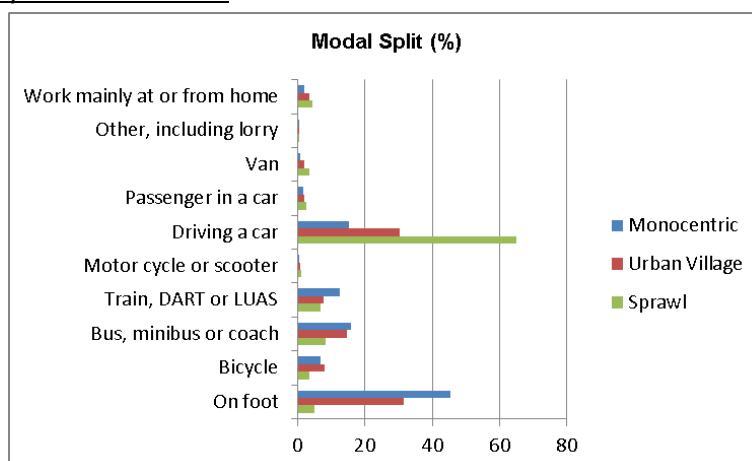
It should be noted that the original urban village definition resulted in too few study areas and was later revised as mentioned in *Section 5.1*, the locations of these original urban village SA's can be observed in *Appendix 6*. In order to collate the results of the study area selection process, a database of residents in the GDA who were commuters for employment trips, and not students or school children, had to be extracted from the POWSCAR (2011) dataset. This resulted in a total population of 526, 058 commuters, from which, the following samples were extracted for analysis:

- *Monocentric*: Sample of 5,782 commuting residents
- *Urban village*: Sample of 4,183 commuting residents
- *Sprawl*: Sample of 14,795 commuting residents

5.3. Results and Analysis

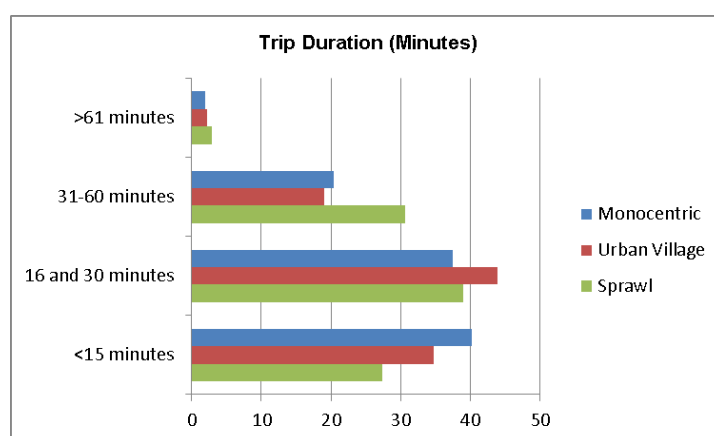
In order to form indicative conclusions on the role of land-use factors across different spatial structure types, the variables of; modal split characteristics, trip duration and car ownership levels were utilised. These variables allowed for the levels of the sustainable travel present in each USS category to be broadly outlined for later discussion. The following results were calculated from the sample datasets with the exclusion of blank or non-relevant responses:

5.3.1. Modal Split Characteristics



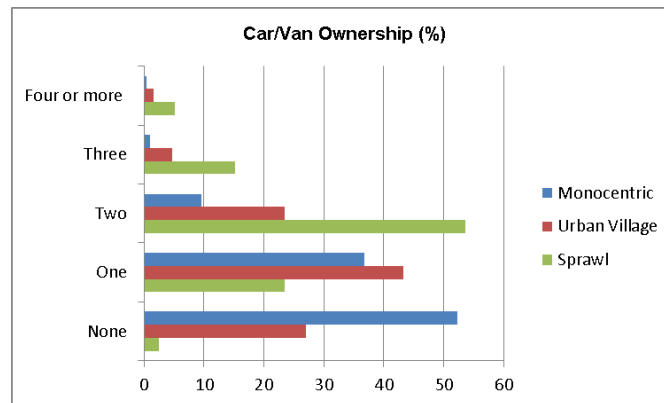
In line with what has been suggested in the literature [5, 19], there were significantly higher levels of travel by sustainable modes in monocentric (80%) and urban village (61.5%) developments when compared to sprawl areas (23.3%). This indicates a clear influence of land-use factors in reducing car dependency which can be clearly observed through the high levels of car drivers in low density, single use areas (65%) when compared to high density, employment centres (15.3%). The most dramatic modal differences regarded walking where high levels (45%) were identified in monocentric areas when compared to the almost non-existent levels (4.9%) of sprawl areas. Interestingly, different USS types did not result in a significant variation in public transport usage across the small areas under study.

5.3.2. Trip Duration Characteristics



The assumption in the literature is that mixed-use developments, in this case reflected through jobs/housing balance, would result in shorter trip durations for residents as they would be able to access local employment [20]. While it is clear that monocentric developments have the highest percentage of <15 minute trips, there is only a small proportional difference between this figure and the number of commuters of the same USS type that take 16-30 minute trips. Within this longer trip bracket (16-30 minutes), the urban village USS is the most prominent and this suggests that influence of jobs/housing balance in providing truly localised jobs is not occurring as expected, although this could be a result of the broader definition of jobs/housing balance that was used. However, both spatial structure types compare favourably with sprawl as regards shorter commuting trips. This can more plainly be observed through departure time results (*Appendix 9*) where residents of sprawl areas predominantly leave for work between 7-8am rather than the higher average of 8-9am trips seen in monocentric and urban village areas. Overall, this data suggests that while higher levels of jobs/housing balance do tend to result in moderately shorter average journey times than sprawl areas, the significant contrast that would be expected from the literature between these USS types is not present.

5.3.3. Car Ownership Characteristics



The consistent trend throughout the literature is that higher density development results in lower levels of car ownership, and this in combination with local employment and accessible public transport services, should encourage greatly reduced car dependency [30, 31]. The results of this study clearly suggest that this is the case with over 50% of residents of monocentric areas living without a car and only 11% of residents owning more than one car. Results for urban village developments are also favourable in this regard with 27.1% of residents living without a car and the majority of the remainder (43.3%) only owning one car. In comparison, and consistent with the literature previously cited, car ownership in sprawl areas is far higher with the majority (53.7%) owning two cars and only a mere 2.5% of residents living without a car in their household.

6. Discussion

Generally, the results extracted from the POWSCAR (2011) data suggest that the conclusions reached in the literature regarding the correlations between particular land-use types and levels of sustainable travel are broadly correct in relation to the GDA. Throughout all variables, it was clear that higher levels of residential density, local employment opportunities and public transport access resulted in proportionally higher levels of sustainable travel and large reductions in car dependency. This would suggest that the key theoretical rationales that underpin arguments in favour of developing urban village developments in outer areas to reduce car dependency are based on accurate supporting evidence [15, 20, 19]. However, the study area selection process used in this research highlighted several aspects of urban development in the GDA which would serve as reasons for caution in this regard. For instance, Bertaud [17] argues that while the urban village approach presents a technically correct solution, examples of it in reality are rare due to feasibility issues involved in the spatial matching of jobs and housing. This can be clearly observed through the original, and more accurate, definition for urban villages (*Appendix 2*) which resulted in the identification of only 5 cases in the GDA, representing less than 500 commuters (*Appendix 5*), in areas too central to be truly considered as real sub-centres.

Surprisingly, the lack of urban village areas was not an issue of density, as the required densities for all definitions could easily be reached, but rather an issue of jobs/housing balance where the values were all extremely low (*Table 3*). For example, with the revised definition for urban villages, over 1900 small areas with the required density levels (20-40 UPH) were identified but when the jobs/housing balance requirement was introduced, this figure fell to a mere 47 cases (*Table 3*). This highlighted the fact that across the GDA, there is significant polarisation between numerous higher density central areas with large concentrations of employment, consistent with the monocentric classification, and large swaths of low density residential areas largely devoid of employment in outer areas with few examples of anything in-between these two types. As the creation of such urban villages is supported in most Irish and European land-use-transport policies, these results would indicate that Burgalassi's [21] assertions that the merits of this approach are questionable or unclear and Bertaud's [17] criticisms regarding feasibility are issues worthy of further exploration. Beyond jobs/housing balance, the issue of sprawl and public transport access was another key issue. As was outlined in *Table 3*, it was clear that there was no shortage of small areas in the GDA that had extremely low densities and employment levels with 1397 study areas identified in this regard. However, this figure fell to a mere 137 small areas when

access to only basic ('low') public transport services was required. As *Appendix 10* demonstrates, large outer areas of the GDA do not have access to even basic public transport services. While it is concerning that the results outlined in *Section 5.3.3* demonstrate high levels of car dependency and very low levels of public transport patronage (15%) in sprawl areas, these results are probably quite positive compared to the larger number of areas without public transport located on the periphery of the GDA where commuting without a car simply isn't a viable option.

One of the main weaknesses of this study was the lack of consideration of either socio-economic or attitudinal variables which are increasingly being recognised in influencing commuting characteristics in urban areas [27, 13, 12]. Traditionally, transport planners have viewed the link between land-use and travel behaviour as a one-way causal relationship, meaning that resident's travel patterns are shaped by the area they live in [39]. But it is now generally accepted that the interactions that take place are far more complex than a simple 'cause and effect' relationship and that causality needs to be established if clear conclusions are to be reached regarding the ability of land-use factors to reduce car-use [19, 27, 18]. While urban spatial structure will always play a major role in dictating commuting patterns as it is responsible for the respective locations of jobs and workplaces, and the results of this study demonstrate the importance of its influence in this regard, a key consideration is that land-use characteristics can only influence modal choice decisions if residents choose to live in more sustainable areas in the first place [40, 18]. Thus the travel behaviour traits observed in a certain type of development could be attributed to prior 'self-selection' by residents and not due to land-use factors alone, an aspect that is often missed in empirical studies such as this that directly compare commuting patterns across different built environment types [40, 13]. This issue is of particular relevance to those seeking to improve the effectiveness of planning approaches as it may have led to overestimation of the positive benefits of land-use measures and further understanding in this area may be key to clarifying the relationship between the built environment and travel behaviour [32, 19, 41]. This is in no sense, an argument that land-use based are ineffective but rather that they need to be further understood in order to ascertain whether land-use based strategies can significantly change attitudes and achieve desired modal shift, rather than just enabling existing users [41, 32].

Finally, it seems that there are several areas with potential for future research:

- Greater analysis of the selected GDA study areas to incorporate factor analysis of socio-economic data and mapping of the individual commuting trips from different USS types to more accurately judge the effect of mixed-use measures on trip length.
- Further study of the attitudinal factors that can influence modal choices, especially in regard to the influence of 'residential self-selection' as research into this area has been quite limited [19, 32].
- Collection of travel behaviour data that incorporates respondent's preferences and socio-economic background to facilitate regression analysis of the relative influence of each factor on modal choice decisions [32].

7. Conclusion

This study has made a small contribution towards clarifying the influence of urban spatial structure on urban commuting characteristics and helped identify some of the key land-use-transport issues present in the GDA. The results of this research confirm that land-use factors are highly related to the sustainability of travel in urban areas and support many of the assertions made in the literature. However, the effectiveness of the urban village approach in response to high levels of car dependency is still questionable due to issues of feasibility and whether it is realistic to expect such developments to occur on a large scale considering current urban development characteristics. Many of these problems are related to the limited understanding of the relationship between land-use and transport, and the interactions between these factors and others such socio-economic conditions and preferences. Key to achieving more effective transport policies will be establishing causality in this regard and it is vital that research continues in an effort to achieve this. Unless this occurs, it will remain hard to quantify the benefits of land-use based planning responses and accurately assess their effectiveness in promoting modal shift. Yet, through improved research design and greater understanding, it is not overly optimistic to assume that the effectiveness of current land-use and transport plans can be improved.

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Appendices

Appendix 1: Categorisation of Bus Frequencies

Categorisation of Bus Frequency Levels		
Level	Frequency Definition	Bus Routes
High	>=10 minutes during (7am-8am) peak	1, 9,15,15B,16,25A,25B,27,27B, 29A,37, 39A, 46A, 70, 77A, 122, 123, 130, 145, 150
Medium	>=10-20 minutes during (7am-8am) peak	4,7,7b,11,13,14,15a,17a,18,32x,33,38,38a,38b,39,40,40d, 41,41c,42,43,49,75,76,79a,83,84,90,120,140,142,151
Low	>=20-30 minutes during (7am-8am) peak	17,26,27a,31,31b,41b,44,45a,47,51d,53,54a,59,61,63,65b, 66,67,68,69x,79,102,111,114,184,185,236,238,239,270
Excluded	Non-standard service (e.g. 747 airport bus) or <=30 minutes during (7am-8am) peak	7d,8,25,25x,27x,32,32b,32a,33a,40b,41x,44b,46e, 56a,65,69,76a,84a,84x,104,116,118,161,270,747

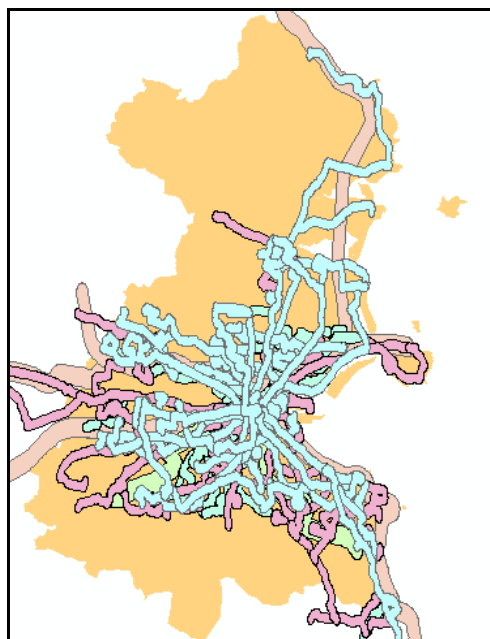
Appendix 2: Original Study Area Land-Use Characteristic Definitions

Defining Study Area Land-Use Characteristics			
Factor	Level	Definition	References
Population Density	High	40+ residential UPH (Units Per Hectare)	[38, 20]
	Medium	30-40 residential UPH	
	Low	Less than 20 residential UPH	
Jobs/Housing Balance	Over supply of jobs	1.7+	[42]
	Balanced	1.3 - 1.7 jobs per household	[43]
	Under supply of jobs	>1.3	[42]

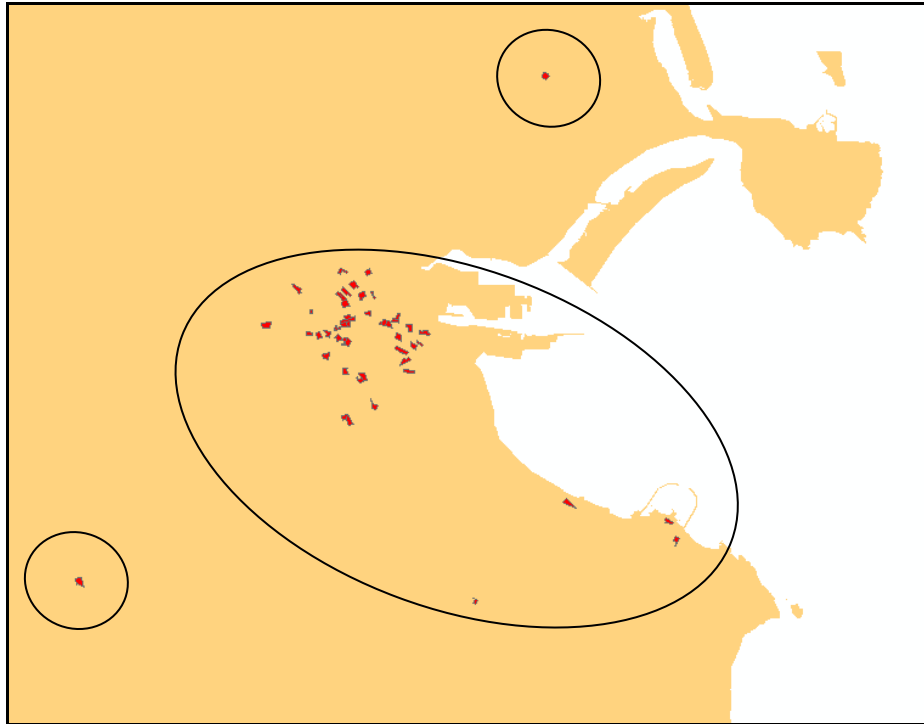
Appendix 3: Revised Study Area Land-Use Characteristic Definitions

Defining Study Area Land-Use Characteristics			
Factor	Level	Definition	References
Population Density	High	40+ residential UPH	[38, 20]
	Medium	20-40 residential UPH	
	Low	Less than 20 residential UPH	
Jobs/Housing Balance	Over supply of jobs	1.7+	[42].
	Balanced	1 - 2 jobs per household	[43]
	Under supply of jobs	>1.3	[42]

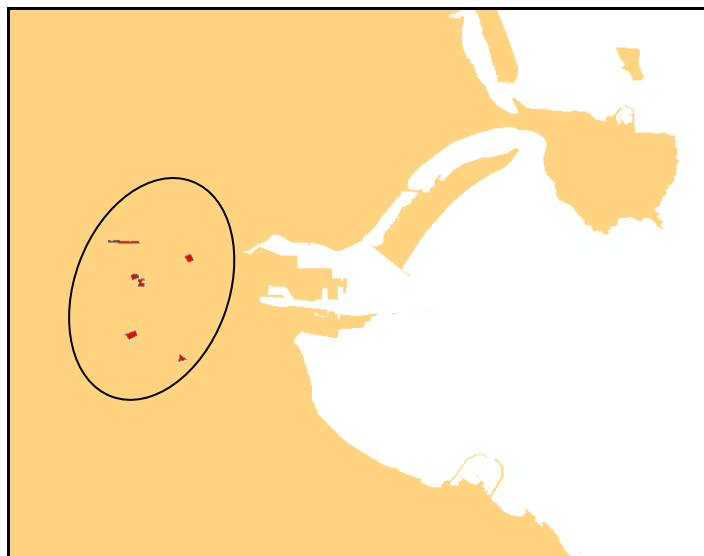
Appendix 4: Public Transport Catchment Buffers in the GDA



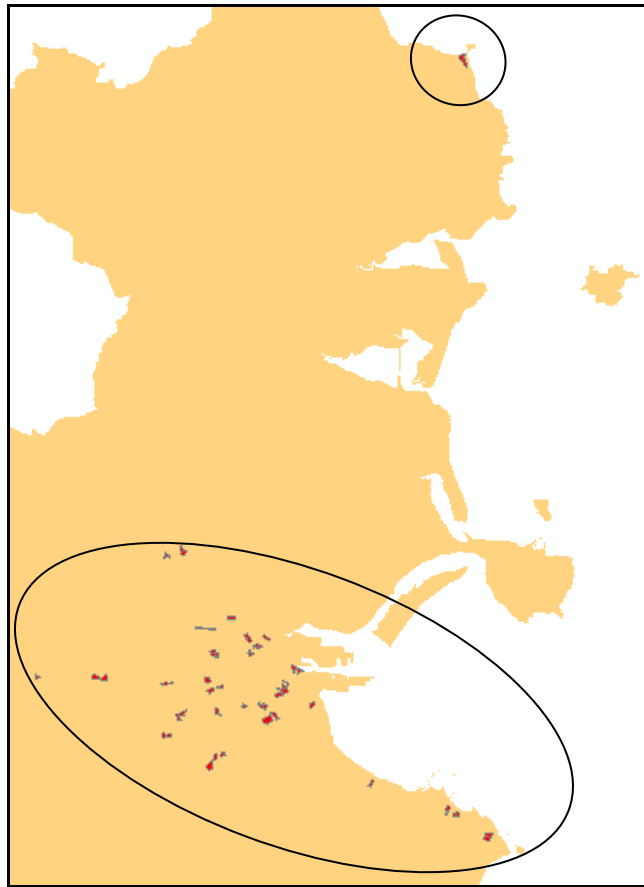
Appendix 5: Location of Monocentric USS 'Small Areas'



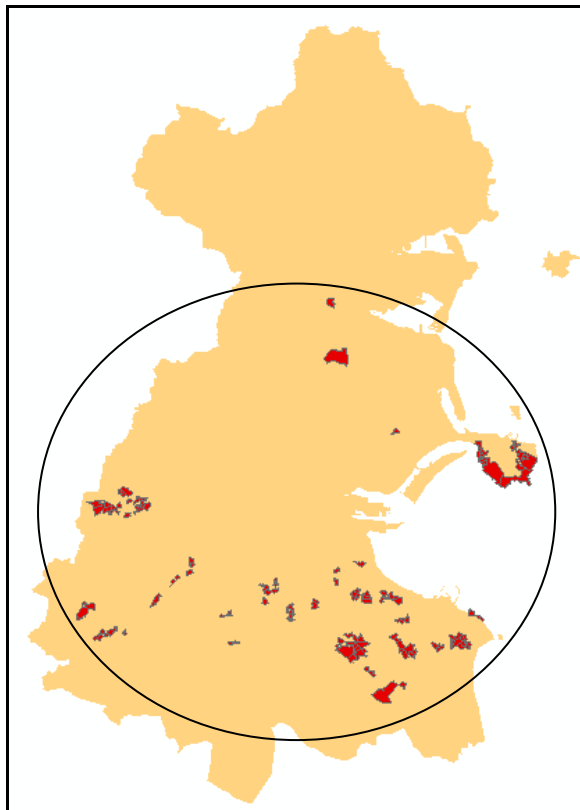
Appendix 6: Location of Urban Village USS 'Small Areas' (Original Definition)



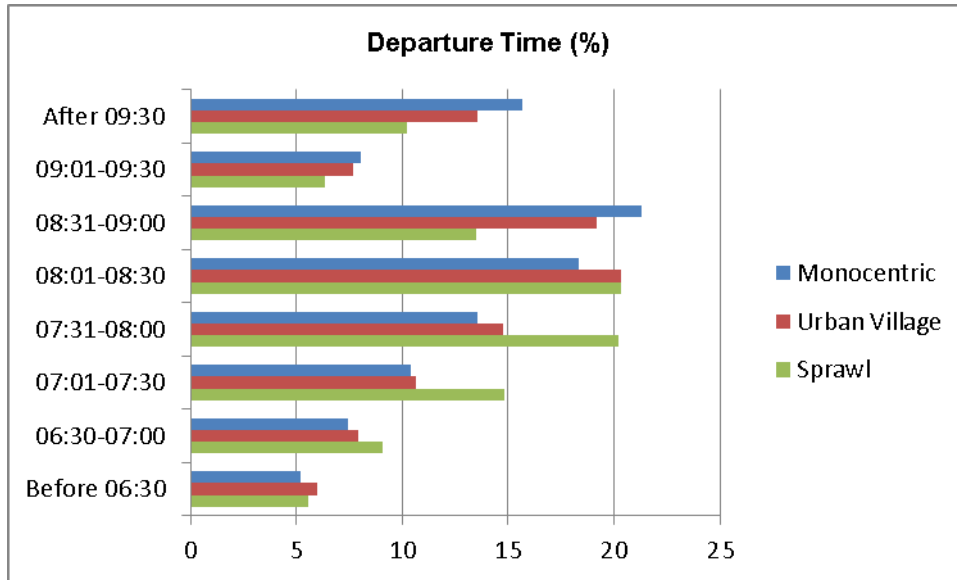
Appendix 7: Location of Urban Village USS 'Small Areas' (Revised Definition)



Appendix 8: Location of Sprawl USS 'Small Areas'



Appendix 9: Departure Time of Commuting Trips



Appendix 10: Sprawl areas (highlighted in turquoise) selected according to density and jobs/housing balance but before filtering by 'low' public transport availability buffers

