Using GIS to Visualise and Evaluate Student Travel Behaviour

Md. Kamruzzaman[1], Julian Hine, Banihan Gunay, Neale Blair

School of the Built Environment, University of Ulster, Jordanstown Campus, Shore Road, Newtownabbey, County Antrim, BT37 0QB, Northern Ireland, UK.

Abstract
Using GIS to evaluate travel behaviour is an important technique to increase our understanding of the relationship between accessibility and transport demand. In this paper, the activity space concept was used to identify the nature of participation in activities (or lack of it) amongst a group of students using a 2 day travel-activity diary. Three different indicators such as the number of unique locations visited, average daily distance travelled, and average daily activity duration were used to measure the size of activity spaces. These indicators reflect levels of accessibility, personal mobility, and the extent of participation respectively. Multiple regression analyses were used to assess the impacts of students socio-economic status and the spatial characteristics of home location. Although no differences were found in the levels of accessibility and the extent of participation measures, home location with respect to a demand responsive transport (DRT) service was found to be the most important determinant of their mobility patterns. Despite being able to travel longer distances, students who live outside of the DRT service area were found to be temporally excluded from some opportunities. Student activity spaces were also visualised within a GIS environment and a spatial analysis was conducted to underpin the evaluation of the performance of the DRT. This approach was also used to identify the activity spaces of individuals that are geographically excluded from the service. Evaluation of these results indicated that although the service currently covers areas of high demand, 90% of the activity spaces remained un-served by the DRT service. Using this data six new routes were designed to meet the coverage goal of public transport based on a measure of network impedance based on inverse activity density. Following assessment of public transport service coverage, the study was extended using a Spatial Multi Criteria Evaluation (SMCE) technique to assess the effect of service provision on patronage.

Keywords
Participation; Accessibility; Mobility; Activity Spaces; Route Planning; Spatial Multi Criteria Evaluation (SMCE)

[1] Corresponding author. Tel.: +44 (0)28 90209315; fax: +44 (0)28 90366826. E-mail addresses: Kamruzzaman-M@email.ulster.ac.uk (Md. Kamruzzaman), jp.hine@ulster.ac.uk (Julian Hine), b.guany@ulster.ac.uk (Banihan Gunay), n.blair@ulster.ac.uk (Neale Blair)

1. Introduction

Improving access to opportunities or the provision of adequate mobility options are key policy responses to the problem of low participation rates in activities and transport disadvantage (Casas, 2007; Cass et al., 2005; Church et al., 2000; Currie et al., 2009; Hine and Mitchell, 2003; Knowles, 2006; SEU, 2003). Accessibility and mobility have been conceptualised as the ‘ease of reaching’ and the ‘ease of moving’ respectively in this discussion (Moseley, 1979; Preston and Rajé, 2007). This means that either proximate land uses (closeness of opportunities e.g. schools, hospitals) or the provision of transport means (e.g. accessible public transport) will enable individuals to participate in their desired activities.

To this end accessibility planning has been developed as a key policy tool to reduce social exclusion and improve access to particular goods and services within many local transport plans in the UK (Cass et al., 2005; Currie and Stanley, 2008; Farrington and Farrington, 2005). In addition, different GIS based accessibility planning tools have been developed to underpin accessibility planning including CAPITAL (Church et al., 2000), ACCESSION (2006), and AMELIA (Mackett et al., 2008). These tools have been used to identify areas where the accessibility is poor (Currie and Stanley, 2008; Lucas, 2006). Transport policy interventions aimed at improving mobility have also been developed. This has included the development of service routes, community transport, and demand responsive approaches to travel (Brake et al., 2004; DRD, 2002; Gray et al., 2006; Mageean and Nelson, 2003). Primarily the policy responses have been aimed at fostering the integration of transport disadvantaged groups (DfT, 2008; Knowles, 2006).

Disaggregate measures are desirable yet most of the operational measures used to identify transport disadvantaged are zone based (Hine and Grieco, 2003). These measures include zonal accessibility measures and zonal multiple deprivation measures (see for example, Church et al., 2000; DCLG, 2008; DfT, 2006; NISRA, 2005b). Therefore, these measures ignore the use of accessibility as a measure of the degree of closeness to opportunities which is a relative concept and can be differentiated amongst individuals and different groups (Farrington, 2007). This notion is equally applicable in terms of measuring access to both opportunities (e.g. hospital) and transport (e.g. train station, bus stop, car ownership) (Stanley and Stanley, 2004). Casas (2007) has mentioned that traditional accessibility measures are not suitable for identifying the experience of certain groups, such as the disabled, where local clusters are not the norm and where exclusion is not necessarily based on a lack of access to the transport system. Rather, for the disabled, difficulties are more in terms of mobility. This suggests adopting a disaggregated socio-economic approach to measure accessibility (Hine and Grieco, 2003; Preston and Rajé, 2007). Hanson and Schwab (1995) have mentioned that socio-economic disaggregation will enable policy makers to craft appropriate transport policies in order to increase the mobility of a particular group compared to aggregate measures that are more suitable for large-scale, place oriented policies.

In addition to socio-economic disaggregation, research has also highlighted the need to incorporate disaggregation of the spatial (e.g. land use) and temporal dimensions (e.g. opening hours) of accessibility measures (Cass et al., 2005; DfT, 2006; Hine and Grieco, 2003). This reflects more clearly the mismatch between available opportunities and transport availability. These issues suggest the need to adopt a people-based method to the evaluation of accessibility in contrast to the place-based approach to measuring accessibility. A people-based method views an individual in space and time as the centre of socio-economic phenomena unlike a place-based method that represents transportation and urban form as a function of the aggregate spatial unit (Miller, 2005).

Accessibility has also been consumed as a function of both the existence of opportunity and the availability of transport to reach the opportunity (DfT, 2006; Hurni, 2006). As a result, policies have been developed to provide transport services to meet specialised needs of particular users (e.g. school buses) where local opportunities are inadequate and also where conventional transport is not profitable (e.g. in rural areas) (DfT and GMPTE, 2004; Gray et al., 2006). Public transports as a result has arguably been historically divided around two policy goals: maximising patronage and maximizing coverage (Walker, 2008). The patronage goal seeks to maximize benefit whereas the coverage goal is concerned with providing equal mobility opportunities to all citizen to ensure participation despite low patronage (Mageean and Nelson, 2003; Zografos et al., 2008). Public transport services that run to meet the coverage goal are usually referred to as demand responsive transport (DRT). Walker (2008) has demonstrated a method of trading-off resources to meet each goal involving stakeholders. Stanley and Lucas (2008) have noted that the omission of social benefits derived from investment in these types of transport scheme is a major oversight and leads to an under-valuation of the benefits associated with public transport schemes. They have also highlighted the need for improved evaluation models to include all the benefits of transport on the disadvantaged groups.

The objectives of this paper are therefore: firstly, to identify the nature (e.g. social, spatial, temporal) of activity participation (or lack of it) using a disaggregated measure of accessibility in the case of a variable opportunity to a public transport (DRT); secondly; to develop a spatial decision support framework to extend the DRT opportunities using the activity participation data and to demonstrate the trade-off between the coverage and patronage policy goal for a viable DRT service. Section 1.1 discusses different measures of accessibility and finds that operationalisation of the concept of activity spaces is a way forward to include socio-economic, spatial, and temporal disaggregation to evaluate accessibility. Section 1.2 goes on to the review of different options to make a DRT service commercially viable in operational terms. This section finds that although different operational aspects (e.g. choosing a right vehicle type) of a DRT service have received attention, research has highlighted the need for an effective route planning. Section 1.3 reviews different methods of transport route planning and identifies the research needs to incorporate activity density as an input to formulate transport routes. Section 2 discusses the methodology that was adopted in this research to reach the research objectives. Section 3 portrays the results of this research. In Section 4, discussions are directed on the basis of findings and objectives; and consequently conclusions are made.

1.1 Disaggregate measure of accessibility

Although, traditionally, different transport models have been used to derive accessibility measures to identify patterns of transport disadvantage and social exclusion, very few of them are capable of capturing the required level of disaggregation discussed earlier. The traditional 4-stage transport model provides very little information about the extent of individual participation in different activities, while disaggregate discrete choice models (such as the multinomial logit and the nested logit) tend to measure the welfare impact of transport policy. The Department for Transport has argued that these models are less valid for low income groups for whom changes in transport policy may have direct welfare effects (DfT, 2006). On the other hand, activity based approaches analyse disaggregated travel data and participation levels in different activities but have been highly focused on multivariate analysis thereby largely ignoring the spatial and temporal dimension of participation and accessibility (Kwan, 2000).

Measures of accessibility that have been derived from the above transport models can broadly be classified into potential accessibility and actual accessibility. Potential accessibility measures the opportunities that could be reached whereas actual accessibility measures the opportunities that are actually reached (Becker and Gerike, 2008; Verron, 2008). Measures of potential accessibility (e.g. gravity measure, isochrones measure, space-time/individual accessibility measure) lack the ability to measure an individual's levels of participation in different activities, whereas infrastructure related accessibility measures focused on the characteristics of infrastructure and have not been focused on the measurement of the individual trip characteristics (Geurs and Wee, 2004). Classical gravity/isochrones measures are zone based and neglect the variations across individuals in transport experience (Dong et al., 2006), while utility based measures are based on random utility theory which assume that people participate in activities that have the highest utility. McDonagh (2006) has argued that people often make decisions, not based on utility, but on personal preferences and present circumstances. The time-space geography approach, originally proposed by Hägerstrand (1970) and the potential path area (PPA) concepts have been operationalised, on the other hand, to measure individual accessibility (Kwan, 1999; Kwan and Weber, 2008; Miller, 1991). PPA determines the potential opportunities that are accessible for an individual. This measure takes into account an individual's characteristics (e.g. personal mobility – speed of travel), spatial characteristics (e.g. disaggregated land uses – opportunities available), and temporal features (e.g. availability of time to participate in discretionary activities between two pegs). However, this paper argues that people do not necessarily participate in discretionary activities only in between fixed activities on the one hand. On the other hand, existence of an opportunity within a PPA does not necessarily mean that an individual has participated in that opportunity.

In this context, the operationalisation of the activity space concept proposed by Golledge and Stimson (1997) is a possible way forward. Activity spaces are defined as the subset of all locations within which an individual has direct contact as a result of his/her day-to-day activities. These activities include: firstly, movement within and near the home; secondly, movement to and from regular activity locations, such as journeys to work, to shop, to socialize, and so on; and thirdly, movement in and around the locations where these activities occur. This approach therefore measures an individual's actual mobility (movement) and actual accessibility (participated opportunities – shop, social, work etc.) and can also be used to identify lack of participation in particular opportunities or activities. Miller (2005) has mentioned that the concept of activity spaces is a people-based method. Activity spaces are also dynamic; they change with an individual's exposure to travel opportunities (mobility) as well as exposure to opportunities (accessibility) that can improve his/her quality of life (Casas, 2007; Cass et al., 2005).

The use of the activity space concept to analyse travel behaviour has a long tradition though its application to investigate the issues of participation in activities is a relatively recent development (see for instance, Horton and Reynolds, 1971; Wolpert, 1965). Different dimensional indicators of the size of activity spaces such as area based measures (e.g. standard distance circle, standard deviational ellipse, minimum convex polygon) (Buliung and Kanaroglou, 2006; Newsome et al., 1998; Schönfelder and Axhausen, 2003), distance based measures (e.g. shortest path distance) (Buliung and Kanaroglou, 2006; Rollinson, 1991; Schönfelder and Axhausen, 2003), count based measures (e.g. number of unique activity locations visited, frequency of visite) (Rollinson, 1991; Schönfelder and Axhausen, 2003; Wyllie and Smith, 1996), and duration based measures (e.g. travel time, activity duration) (Kawase, 1999; Newsome et al., 1998) have all been used to derive travel patterns. Recent researches such as Schönfelder and Axhausen (2003), Miller (2006), McCray and Brais (2007), Casas (2007) have quantified the size of activity spaces and explored the issues of travel-activity participation of different groups.

Schönfelder and Axhausen (2003) and Newsome et al. (1998) have used different area based measures of the size of activity spaces and found no significant difference between different groups examined. However, the other indicators (e.g. activity duration) used by Newsome et al. (1998) shows significant differences between different socio-economic (e.g. age, race) as well as spatial (e.g. hometype: downtown, central city, suburb) groups of travellers. McCray and Brais (2007) have found that home distance from transit route is an important determinant to the size of activity spaces (area – standard distance circle of visited locations) for the low-income women in Quebec city. Buliung and Kanaroglou (2006) have investigated all the three area based measures and found significant differences of the size of activity spaces between urban and suburban population. This work has also used total daily household kilometres travelled (DHKT) as an indicator of the size of household activity spaces. Using a regression analysis Buliung and Kanaroglou (2006) have found that household structure (number of employed householders) is a significant contributor to this model.

Casas (2007) has blended the concept of activity spaces and potential accessibility to examine the opportunities available for activity participation. He has calculated distances from home to all destinations using a single weekday travel diary of individuals in Western New York. The longest distance has been used as an indicator of personal mobility that delimits the size of actual activity spaces for an individual. He has adopted a cumulative opportunity measure and counted the total number of opportunities available for an individual within the area generated using the longest travel distance centred around home (potential accessibility) placed over the network. This work has found a significant difference of opportunities available for participation between disabled and non-disabled individuals.

However, the movements between the activities have been approximated using the shortest path approach in the above studies. Therefore, a modelling technique is required that would be able to trace all the movements (mentioned above) and participation in activities of individuals in real geographic space that would be able to: firstly, measure the individuals' level of actual mobility and actual accessibility to illustrate the differences between different groups; and secondly, identify the nature (e.g. socially, spatially, temporally) of participation (or lack of it) in different activities between the groups; thirdly, examine whether the individual's activity spaces are accessible by the current public transport services; and fourthly, formulate and evaluate transport policy options to facilitate decision making for an inclusive society.

1.2 DRT for an inclusive society

Traditionally in the UK, DRT services have been identified as a way to ensure participation in activities of particular groups (DETR, 2000; DfT and GMPTE, 2004). Often these services are heavily subsidised and little effort has been made to assess for their commercial viability (Brake et al., 2004). The Department for Transport (DfT) and Greater Manchester Passenger Transport Executive (GMPTE) commissioned a research team to determine the market potential for DRT systems in the UK. This work has identified that a DRT can perform at any of the following four financial levels: a) commercially viable DRT: services that are either profitable, or operate within a commercial context (e.g. temporary losses are accepted as a service is built up or a loss-making service is compensated by its positive financial effects on a service network as a whole); b) acceptable subsidy DRT: where

DRT requires only the same (or less) subsidy than other comparable tendered services (a subsidy of £2 per trip or less appears to be the crucial threshold); c) justifiable higher subsidy DRT: where a subsidy above that comparable to tendered services can be justified. This may be due to the operational area (e.g. deep rural areas cost more anyway), that DRT is replacing inherently even more expensive transport, or because it is yielding significant cross-sector benefits; and d) financially unsustainable DRT: for demonstration and trial projects or other services whose losses remain very high (DfT and GMPTE, 2004, p.15).

Few commercially profitable DRT schemes operate in the UK and research has highlighted the need to find a way to effectively introduce and market DRT services. Planning, organising and operating a viable DRT is a complex decision making process that involves the specification of the types of services to be provided, identification of the relevant stakeholders and their roles, and determination of cost and revenue structures (Zografos et al., 2008). DRT operations are varied in structure and type and can feature any combination of characteristics in their design (Table 1). Zografos et al. (2008) have developed a framework to design a business model for DRT using a multi criteria evaluation (MCE) method. Using this framework, they have identified the most preferable vehicle type for a DRT service targeting elderly and disabled people in Helsinki. Though a DRT service is currently operating in Helsinki for these groups, Zografos et al. (2008) have not identified how the service could meet the transport needs of other groups where participation in particular activities is to be encouraged (e.g. education). They have also concluded that 'the final decision requires further economic and financial feasibility analysis based on a more detailed description of the operational features of the intended flexible transport services (e.g. route planning policy)' (Zografos et al., 2008 p.793).

1.3 Transport route planning

Operationalisation of the concept of activity spaces requires detailed (ex-ante) disaggregate travel data. This data must also show the socio-economic characteristics, locations and the movements between activities undertaken by individuals. Therefore, an effective tool is required to explore this data (Higgs and White, 1997; Kwan and Weber, 2008). The development and use of geographical information system (GIS) is a way in which this problem can be overcome (Dykes, 1996; Gahegan, 2000). However, the use of GIS is at an early stage of development in understanding the transport routing problem, although it has been extensively used to solve routing problems in utility infrastructure (e.g. pipeline routing, transmission line routing, telecommunication network) (Keshkamat et al., 2009). Current practices of transport evaluation in the UK are multi criterion (MCE) based (Sayers et al., 2003), this seeks to incorporate non-spatial criteria and their weights to evaluate alternative options. Yet, GIS can handle spatial criteria unlike MCE. The development of spatial multi criteria evaluation (SMCE) is a way in which this problem can be addressed. SMCE is a combination of the MCE method and spatial analysis (GIS) which bridges the gap between GIS and MCE (Malczewski, 1999; Zarkesh, 2005; Zucca et al., 2008).

Network analysis is considered to be the most powerful method in GIS for developing a route planning process which takes into account the impedance of each segment of a road network. Impedance is a measure of the amount of cost/resistance that accrues to users as they pass through a segment (Niaraki and Kim, 2009). Although in network analysis, a one dimensional variable such as distance/time is used to determine road segment impedance, recent route planning models have attempted to integrate multi dimensional factors using SMCE. In addition to the transport efficiency criteria (e.g. network coverage, route length); these models have combined socio-economic variables as well to assess network impedance. For instance, Grossardt et al. (2001) have generated a composite cost surface combining the priority of stakeholders for different criteria domains e.g. social, environmental and economic. This cost surface has been used to generate a least cost path between an origin and a destination. The resultant path is a least cost route with no control over its length.

Keshkamat et al. (2009) have overcome the route length problem by incorporating existing road networks as the basis for generating and evaluating alternative routes. They have prepared a suitability surface combining four domains of criteria and their weights. These include: a) transport efficiency, b) ecology, c) social impact and safety, and d) economic cost and benefit. The suitability scores beneath each road segment have been extracted and inverted to form a segment impedance. They have used Equation 1 of Beyer's (2004) line raster extraction algorithm:

$$LWM = \frac{\sum_{i=1}^{n}(l_i.v_i)}{L} \qquad \text{….. Equation 1}$$

where LWM is the line weighted mean suitability score, li is the length of a line segment i that is covering a certain raster cell, vi is the suitability value of the raster cell underlying that line segment, and L is the total length of a segment of which the line segments forms part. To form the impedance of a road segment, they have inverted the LWM values by subtracting them from 1 (maximum suitability) and multiplied by the length of that segment L. The composite impedance has been used in network analysis to find the path of least impedance.

Table 1: Operational categorisation of DRT
(adapted from DfT and GMPTE, 2004; Horn, 2004; Mageean and Nelson, 2003; Robberts et al., 1999; Round and Cervero, 1996; Westerlund et al., 2000; Zografos et al., 2008)

Characteristics	Alternatives
Function	Network – enhances public transport either by providing additional services, or by replacing uneconomic services in a particular place or at certain times
	Destination-specific – closely related to network DRT but serve particular destinations (e.g. airport, employment locations)
	Interchange – provides feeder link to conventional public transport
	Substitute – where a DRT system substantially replaces conventional public transport
Scheduling	Fixed-schedule – operates in pre-defined time
	Responsive – operates only when a user need it
Stop points	End stop (Origin-Destination) points only (e.g. terminals)
	Fixed intermediate stop points (e.g. conventional bus stops)
	Pre-defined stop points (e.g. recognised meeting place)
	Non pre-defined stop points (e.g. doorstep of the user)
Route type	Fixed-route – starting from a pre-defined route
	Semi-fixed – some stop points are obligatory while others requiring deviation
	Flexible-route – stops are determined in a period just before operation
	Virtual flexible route – no fixed end or intermediate stops and no fixed schedule
Origin-Destination (O-D) relation	One-to-one – operates strictly between two points
	One-to-many – delivers passengers from multiple origins to a single destination or vice versa
	Many-to-many – transport passenger between any two reasonable accessible points in the service region
Vehicle type	Car/taxi
	Minibus
	Specially equipped minibus (e.g. ambulance)
	Coach
	Bus
Target area	All areas
	Where public transport service is lacking
	Where public transport exists, but serves only specific needs
Target market	Captive user – restricted transport choices, and in particular low levels of access to car or structurally dependent on car[2]
	Choice user – many of whom could have made the trip by car

Although the work of Keshkamat et al. (2009) is a methodological enrichment, two important issues have, however, been ignored. Firstly, the method produces the mean suitability score disregarding the presence of a constraint (non suitability cell usually denoted by zero suitability score) beneath a road segment. The suitability surface is a raster map generated by combining both factor maps and constraints. If a constraint exists underneath a road segment, that road segment should not be considered as a candidate for an alternative route. Secondly, the extracted impedance score

[2] McDonagh (2006) has clarified that structurally dependent are those individuals who have little choice but to use their cars, for example, when there is no alternative public transport.

possesses a risk of producing a rounding error. This is due to the production of a mean score in the first instance; and the multiplication of the mean score by segment length to obtain the total impedance score.

Population density has been considered an indicator for assessing coverage/patronage in most of the route planning studies (see for instance, Current et al., 1985; Current and Schilling, 1994; Keshkamat et al., 2009; Matisziw et al., 2006). Walker (2008) has mentioned that density must be understood as a combination of both population and activity density. Activity density represents the spatial intensity of the locations of workplace, home and non-employment activities. It has been used for visual comparison of the density patterns of different activities (see, Kwan, 2000). This could provide a valuable input to the route planning process if it is transformed into a network impedance value.

2. Methodology

The spatial decision support framework has been developed to facilitate decision makers in their selection of a DRT route. The Department for Regional Development (DRD) published a Regional Development Strategy (RDS) in 2001 and a Regional Transportation Strategy (RTS) in 2002 for Northern Ireland (NI) (DRD, 2001; 2002). The aim of these strategies is to develop an integrated framework for land use and transport development so that equal participation in activities is ensured from all sections of the community in the region. The RDS proposes that the spatial development will take place in the main towns and regional gateways and will act as hubs (centre of employment and services etc). These hubs will then be connected through a polycentric transport network to serve the towns as well as their rural hinterlands. The RTS proposes the provision of innovative public transport service (e.g. community transport, DRT) to ensure participation to these hubs, particularly of the rural communities. Access to education is seen as an important policy goal within this strategy.

At present, 154,695 students are enrolling in different higher educational courses in NI which is more than 10 percent of the total population (NISRA, 2005a). Currently, *Translink*, a transport provider (government run) in NI, is operating Ulster Bus Service no 163a (*Unilink*) for the students of the University of Ulster at the Jordanstown campus. Using the service characteristics specified in Table 1, this service can be characterised as a DRT. The service operates from September to May (undergraduate students' term time when there is a high demand) and therefore does not benefit the post graduate students during the off term period. In addition, the service is not available for the students staying in residential accommodation on campus Saturday and Sunday even during the term time. The service runs every 10-20 minutes (headway) starting from 8 am till midnight depending on demand (Translink, 2009). The route length of the service is 16 km and average trip time is 30 minutes. The service provides a link between the two universities located in Belfast Metropolitan Area (BMA) (University of Ulster and Queen's University, Belfast). Figure 1a shows the 163a service route.

2.1 Data collection

A detailed account of travel and activity during a certain period provides extensive material that would help in the analysis and visualisation of individual travel patterns (Røe, 2000). Travel and activity data have traditionally been collected through travel diary (TD) surveys; however, the problem associated with administering a TD survey is the selection of an appropriate sample size. Barber (1995) has indicated that the large scale transportation studies carried out between 1955 and 1970 used a single day travel diary. He has claimed that the characteristics of trips respondents made on a single day in these studies formed an important and stable input for the analysis into the 1990s. Bowman and Ben-Akiva (2000) have thought of activity patterns as the structure of one day activities and travel. However, a single day's diary cannot reveal the typical travel pattern of an individual and analysis of multi-day travel and activity data has been suggested (Hanson and Schwab, 1995). Bhat and Singh (2000) have suggested that the activity based approach of travel behaviour analysis focuses on sequences or patterns of activity behaviour, with the whole day or longer periods of time as the unit of analysis. Pas (1988) has pointed out that interest has grown in extending the analysis of travel-activity behaviour of individuals over some time period greater than one day and has used 5 days diaries in his research.

Buliung et al. (2008) have identified the main characteristics of well known TD surveys conducted since 1949. Examination of their work does not provide any conclusive result on sample size. The sample sizes vary from as few as 72 persons to as many as 9471 persons. Similarly the number of diary days also varies from 1 day to 6 weeks. However, a general trend which can be observed is that the sample sizes are larger for smaller number of diary days. This study used 130 TDs of students containing two days travel and activity participation. A recall TD survey method was followed. Students were requested to fill in their last two days out of home travel and activities. Since the current 163a service is operational only for the captive users, TDs have only been collected from the non-residential undergraduate students of the University of Ulster at Jordanstown. A dynamic TD form was designed and disseminated to the students using their e-mail addresses. But the rate of response was found to be inadequate for the analysis to proceed. Only three students replied with a completed form. As a result, additional diaries were completed by students on campus.

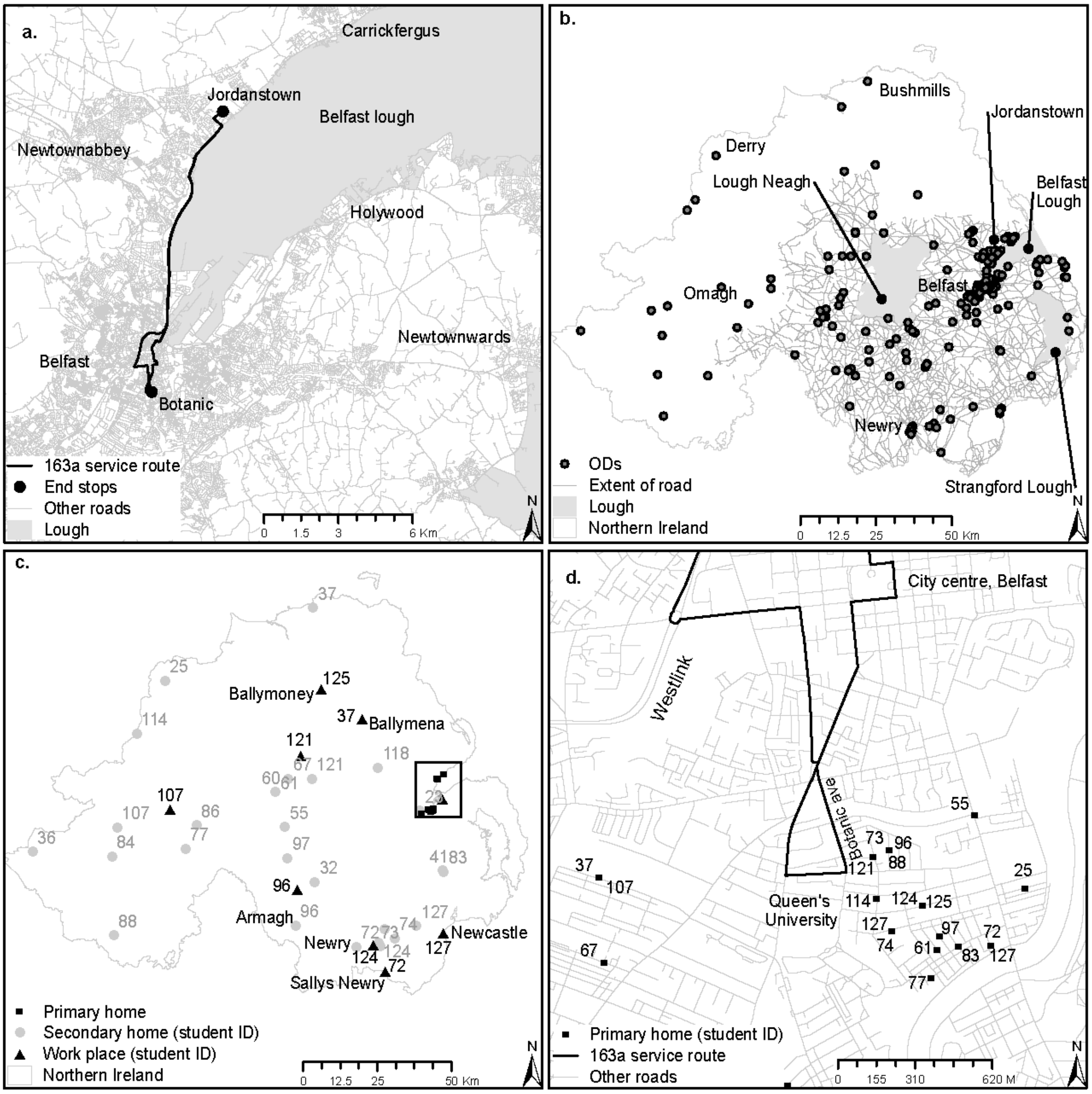


Fig. 1. a) Location of the 163a route in wider geographic context, b) Distribution of students' activity location in Northern Ireland and the extent of *road network shapefile*, c) Students are temporarily living (primary home or term time address) in Belfast (see box) to access university though their work places remain close to their secondary home, and d) Students' temporary residences are clustered around Botanic Avenue – close to the 163a route

The TD form consisted of two sections: the first section collected data on student socio-economic characteristics; and the second section consisted of travel and activity data. The socio-economic data were treated as the explanatory variables in this study. These include: car-ownership, gender, age, and income[3]. Two spatial variables were considered in addition to the above four socio-economic explanatory variables. These are: firstly, students 'home location' with respect to the 163a service (whether the students are living within its service area); and secondly, their 'lifestyle' representing the

3 Although students income data were collected using 11 classes of income ranges, these were recoded into low income and high income due to only few non-zero responses in several classes. Students whose income range was found to be less than the mean income of the collected data were recoded as low income and the remaining were recoded as high income.

characteristics (rural/urban) of their living areas. Therefore, home addresses of the students were also collected. Students home addresses were matched with the rural-urban classification of settlement in Northern Ireland to identify their nature of lifestyle (see, NISRA, 2005c). Table 2 shows the descriptive statistics of these explanatory variables. The second section consisted of data describing travel and activity participation, and was used to calculate the actual size of student activity spaces (dependent variables). The section includes data on: left at (time), left from (address), to go to (address), got there at (time), trip purpose, transport mode, and route/roads travelled through. Each trip is defined as any purposeful stop during the journey and has been entered in the TD form.

Table 2: Descriptive statistics of the explanatory variables and the size of activity spaces

Variables	Category	Frequency	%	Number of unique locations visited	Average travel distance (m)/day	Average activity duration (min)/day
Sex	Male	85	68	3.39	56 058.45	378.72
	Female	42	33	4.00[a]	56 699.89	407.72
Car ownership	Yes	100	79	3.58	62 227.11[a]	394.34
	No	27	21	3.63	34 209.35	366.00
Age	Below 18 years	36	28			
	18-24 years	80	63			
	24 years and above	11	9			
Income	Low	73	57	3.60	57 852.36	426.00[a]
	High	54	43	3.57	54 132.25	337.37
Living form	Urban	91	72			
	Rural	36	28			
Home location	Within 163a catchments	56	44	3.80	32 593.94	382.93
	Away	71	56	3.42	74 945.12[a]	392.56
Average				3.59	56 270.58	388.32

[a] One way ANOVA test shows significant intra-group differences at 95% confidence level

Instructions were provided to participants with the TD form on the coding and completion of their diary forms (Table 3). The TD survey was administered in two spells: 18 TDs were collected in the first spell in January 2008; and 121 TDs were collected in the later spell in October 2008. An initial check of the reported TDs in the first spell revealed that students faced difficulty in filling in road names within the provided space. The TD form was therefore modified. 139 TDs were collected and checked. 9 TDs were found to be incomplete and were not included in the analysis.

2.2 Data processing

The verified 130 TDs contained 211 chained trips[4] and 15 non-chained trips, a total of 708 individual trips. Although 260 chains were expected over 2 days of travel and activity participation, 32 students only provided a diary covering one day because they did not leave home on the second day. The 130 students surveyed visited 237 unique activity locations[5], 1414 times over these two days (see Figure 1b). Three *database* tables were prepared from the collected TDs. These included: *socio-economic data (socio-economic* table*)*; *origin-destination (OD) data (OD* table*)*; and *trips by road data (trip by road* table*)*. A unique identity was assigned to individual students (*Person ID*), individual trips (*Trip ID*), individual activity locations (*OD ID*), and individual road segments (*Road ID*). The *OD* table contains 12 *fields*: *Trip ID, Person ID, Origin ID, Origin Name, Destination Name, Destination ID, Left at (time), Got there at (time), Trip Day, Trip Purpose, Travel Time* and *Activity Duration*. *Left at* time was subtracted from the *got there at* time to get *travel time* for each trip. A*ctivity duration* was calculated by subtracting *got there at* time of a trip from the *left at* time of the subsequent trip of the chained trips. As a result, activity duration was derived from 449 intermediate trips of the chains. Time spent at home was considered as an activity duration only for those returning home trips that

[4] Chained trip is referred here as at least two consecutive trips.

[5] These 237 locations are the street names of the visited activity and do not specifically refer to any building addresses of that street. For instance, several trips were originated or destined to different houses on the same street but represented by one location only to keep the students' identity secret. Therefore, the number could be higher if specific addresses were used.

appeared in the middle of a chain. The *trips by road* table comprises of *Trip ID* and the corresponding *Road IDs* of that trip together with *Travel Mode*. The same identity numbers of the *OD ID* and the *Road ID* were assigned to the corresponding *objects* of a *pointer address database* (*shapefile)* and to the segments of a *road network shapefile* (*polyline*) respectively.

Table 3: Lists of activity types and transport modes that were provided for a consistent TD data reporting

Trip purposes		Transport mode
Main category	Sub-category	
Study visit	Attending classes Borrowing books from the library Presenting study work Interchange to go to university Intra-change to go to university	▪ Driving car ▪ Bus ▪ Train ▪ Walk ▪ Taxi (including shared taxi) ▪ Lift (Passenger in a car)
Social	Visiting friends and family Religious Social networking/community/club	
Recreation	Amusement Exercise Sports	
Returning home	Travelling by single mode to go home Interchange to go home Intra-change to go home	
Food	Hotel and restaurant Bar	
Associated with study	To drop off To be dropped off To pick up To be picked up To get bus/taxi/train to go to university	
Work	Any type of paid work	
Shopping	Shopping grocery Shopping food Other shopping	

The spatial extent of the *pointer address shapefile* covers all the reported 237 activity locations. However, the spatial extent of the *road network shapefile* does not cover all the visited roads. Therefore the analysis in this study is confined to the spatial extent of the *road network shapefile* (Figure 1b). Out of 708 trips, 32 trips were either originated or ended to the outside of the analysis area and were not considered for further analysis[6].

The train was used as a mode of travel for 15 trips. The associated activity locations of these trips are reported in the results although the associated routes were not considered because of the nature of the current DRT under investigation. The remaining 661 (708-32-15 = 661) trips passed through 6069 road segments. These 6069 segments were visited a total of 60825 times. Out of 217 unique activity locations within the analysis, 117 activity locations[7] are the residences of the students. These include: 100 primary homes[8] and 17 secondary homes. 27 students reported that they also visited their secondary homes during the survey period (Figure 1c and Figure 1d).

---

6 Only 3 students' trips were excluded from this analysis due to this reason. As a result, the travel and activities of 127 students are reported in this paper. This has affected the total number of visited unique activity locations and is therefore reducibly reported to 217 in this paper. These 217 locations were visited 1352 times by the students.

7 The number (117) is less than expected (130+27 = 157) because one street name was used to refer several students' home on the one hand. On the other hand, 4 primary homes and 9 secondary homes are located outside of this analysis.

8 Primary homes are the term time residences of the students.

2.3 Examination of student activity spaces

Student travel behaviour was examined using the size of activity space. Indicators such as travel time, distance travelled, number of trips, number of unique activity locations visited, frequency of visit, and activity duration were derived in this research through a geo-visualisation of their travel and activities. However, the area based measures (discussed in Section 1.1) were not derived in this research due to their spatially aggregated nature of representing the size of activity spaces. Both the *database tables* and the *shapefiles* were exported to a *personal geodatabase* in *ArcGIS*. The *Make Query Table* tool of *ArcGIS* was used to *geo-reference* the origin, destination and segments of each trip. From the *geo-referenced shapes,* individual travel patterns were extracted using *Person ID* and several summary tables were prepared using the associated attributes of each trip (e.g. travel time, activity duration etc.). The summary tables were exported to *SPSS* for statistical analysis.

Results from an analysis of the relationships between these indicators using linear regressions are reported in this paper. A positive correlation was found between student travel time and distance travelled of each trip (Figure 2a), as a result, travel time was not considered and only travel distance is reported. Previous studies measuring travel distance have relied on the shortest path distance as a proxy of real distance travelled over the network as an indicator of the size of activity space (see for instance, Buliung and Kanaroglou, 2006; Schönfelder and Axhausen, 2003). Geo-referencing of routes travelled has provided an opportunity to investigate the relationship between the observed distances and the shortest path distances. Figure 2b shows that these two measurements of distance are highly correlated. However, the *Paired Sample T-Test* shows that there exists a significant difference between these two measurements of distance (t = 12.342); as a result, the observed travel distance is reported in this research. Although the number of trips has been used as an indicator of the size of activity space, Schönfelder and Axhausen (2003) have indicated that the number of trips cannot be used as an indicator unless the number of unique visited locations are associated with it. They have added that many trips are involved with only few locations. The regression analysis shows that students number of visited unique activity locations grew with the number of trips (Figure 2c). Although activity duration has rarely been used as an indicator of the size of activity spaces, Burchardt et al. (2002) have noted that activity duration measures the magnitude of participation. Dijst and Vidakovic (2000) found a positive correlation between travel time and activity duration although such a correlation was not confirmed in the case of students (Figure 2d). As a result, this research uses activity duration as an indicator of the size of activity spaces. Frequency of visit was only used to examine students' activity density spatially (Section 2.5) and no statistical analysis was conducted using this indicator.

This research collected a 2 days students travel and activity diary. Regression analysis also shows that distance travelled and activity duration on the first day is significantly correlated with distance travelled and activity duration on the second day respectively whereas no association was found to the number of unique locations visited between the days (Figure 2e and 2f)[9]. In addition, few students reported diary for a single day as a result travel distance and activity duration were averaged for a single day. Therefore, average daily travel distance, number of visited unique activity locations, and average daily activity duration were used as indicators to examine the size of activity spaces in this research. These indicators therefore reflect an individual's mobility (ability of daily travelling), actual accessibility (opportunities that actually were participated in), and extent of participation respectively. Previously, Buliung and Kanaroglou (2006) have used total daily household kilometres travelled (DHKT) as an indicator of household's mobility. These indicators of the size of activity spaces are the dependent variables and were analysed by linking them to the explanatory variables.

The explanatory variables are categorical data (e.g. gender: male and female). The chi-square test for independence was conducted to investigate the significance of association amongst these variables (Table 4). A significant association was observed between age and income variables, and between home location and lifestyle variables; income and home location variables were kept for further analysis together with other two (sex, car ownership) explanatory variables. The cross-tabulation of the chi-square measure reveals that older students have significantly higher income on the one hand. On the other hand, students who live outside of the catchment of 163a service have a predominantly rural lifestyle. The values of the dependent variables are *ratios* whilst the explanatory variables are *categorical* data with two categories (*dichotomous*). The one way ANOVA test was conducted to examine the intra-group variations to the size of activity spaces using the selected explanatory

[9] Although the collected data represents students weekdays travel and activities, no specific day information (e.g. Monday) of a week was collected. As a result, it was not possible to report the day to day variations of travel and activity participation in this paper.

variables (Table 2). Besides, a *linear multiple regression* analysis was conducted using the simultaneous (enter) method to examine the relative impacts of the explanatory variables to the size of activity spaces.

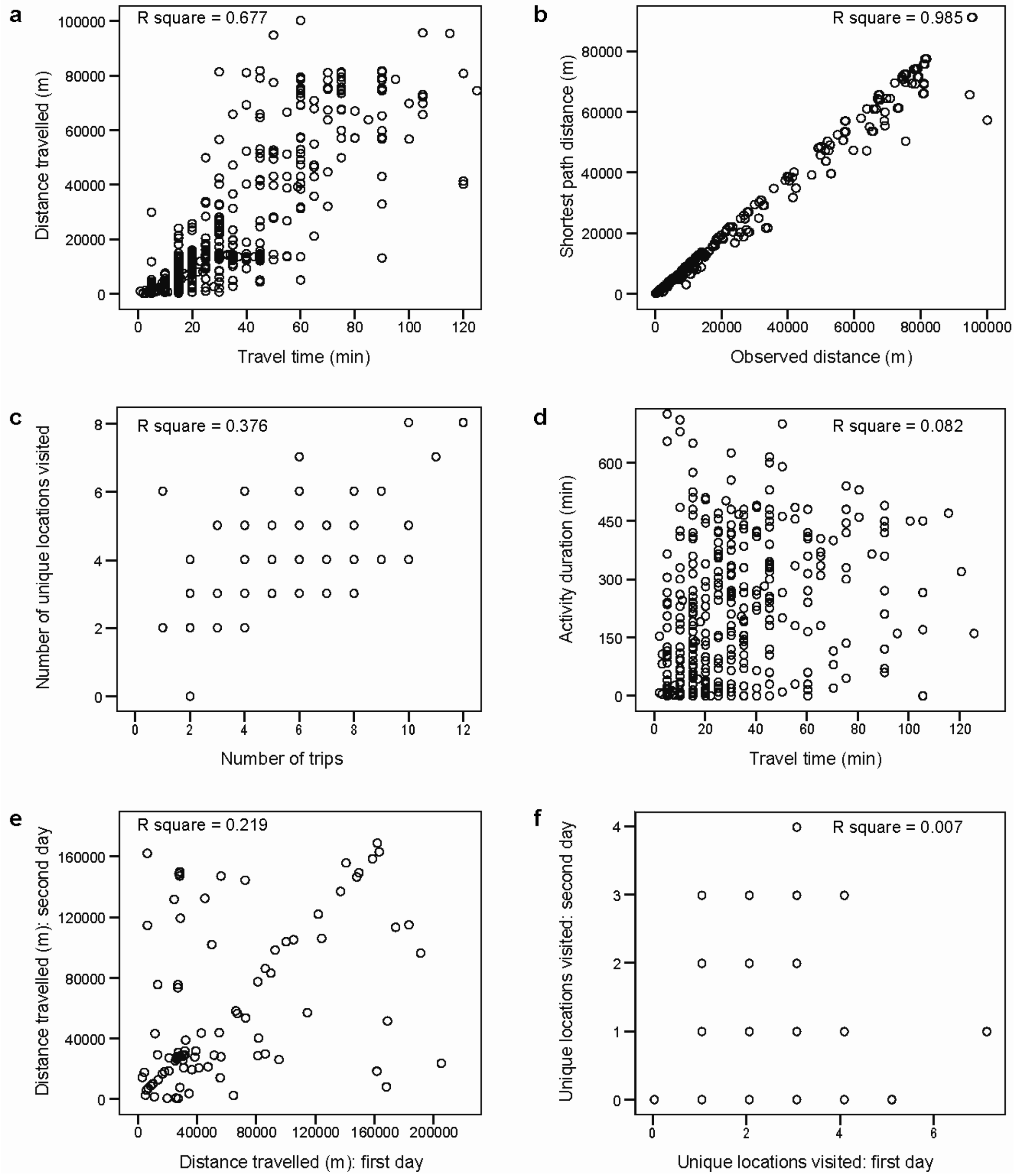


Fig. 2. a) Travel time and trip length are significantly correlated, b) Significant differences were found between observed trip distance and the shortest path distance, c) Number of visited unique activity locations increased with the number of trips, and d) No correlation was found between travel time and activity duration

2.4 Evaluation of the 163a service

In addition to the statistical analysis reported in Section 2.3, a geo-visualisation of student travel and activities was used to assess their activity spaces. An activity density surface was prepared using four individual density surfaces: population density, road use density (frequency), time use density (activity duration), and activity visitation density (frequency). Figure 3 outlines the process of calculating the activity density surface. *Kernel density*, a widely used method for density calculation, was used to calculate the individual density surfaces (see, Kwan, 2000; Schönfelder and Axhausen, 2003). The

Kernel density tool in *ArcGIS* was used to calculate the individual density surfaces. The tool uses Silverman's (1986) quartic kernel function. A problem associated with the calculation of *kernel density* is the selection of the right *kernel bandwidth* which strongly affects the resulting density surface (Schönfelder and Axhausen, 2003). O'Sullivan and Unwin (2003) have proposed that the *kernel bandwidths* should be selected based on the context of the study. 1100 metres was chosen as *kernel bandwidth* in this study because the analysis of students' travel behaviour shows that their average walking trip distance is 1100 metres, as a result, it is expected that the activity locations that are within 1100 metres from each other would influence student travel behaviour.

Table 4: Coefficients of chi-square test for independence among the explanatory variables

Variables	Sex	Car ownership	Age	Income	Home location	Living form
Sex	-					
Car ownership	0.791	-				
Age	3.617	4.912	-			
Income	0.107	0.044	9.572[a]	-		
Home location	0.316	3.199	5.128	3.025	-	
Living form	0.636	3.091	1.043	0.455	39.627[a]	-

[a] Coefficients are significant at 95% confidence level

From the analysis of the data some activity locations were used either more frequently or were occupied by more students. It was also evident that students spent more time at certain locations than others. As a result, frequency of visit, occupancy number, and activity duration were used as the weights of these locations in order to calculate the individual density surfaces. A 10 metre pixel size was used for the calculation of individual density surfaces; this was chosen because the shortest segment length represented within the *road network shapefile* is 10 metres. The width of roads in Northern Ireland is also not more than 10 metres (DoE, 2005). In addition, as the value range of the individual density surfaces vary, they were standardised before aggregation (Figure 3). The *Spatial Multi Criteria Evaluation* (*SMCE*) tool of *ILWIS,* an open source software, was used for these standardisations (standardised score ranges from 0 to 1 were used) (ITC, 2009). The standardised individual density surfaces were aggregated using the *SMCE* tool. The individual density surfaces were considered as benefit criteria as the higher density values represent the greater utility associated with a place by students. A weighted summation method was followed for the aggregation and an equal weight (25%) was assigned to the individual density surfaces.

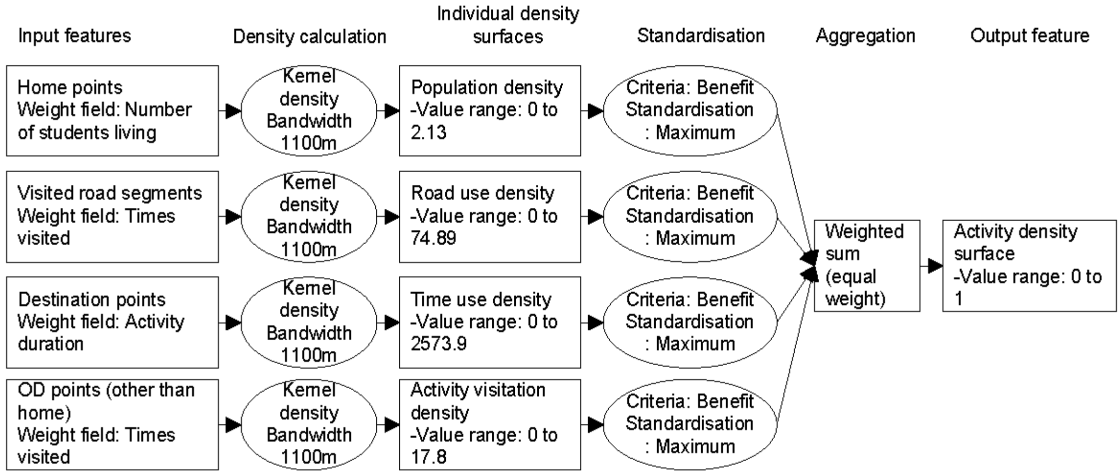


Fig. 3. Flow diagram for the generation of composite activity density surface

The activity density surface was used to evaluate the performance of the 163a service. The process of this evaluation is outlined in Figure 4. The service area of the current route was calculated using 1100 metres network distance from the stop locations (both intermediate and at end stops) of the service. The service area was used to extract a density surface from the activity density surface that fell within the service area. The sum of the activity density values of the extracted surface was compared to the total values of the activity density surface. The area and volume of the positive activity density values were calculated for both the extracted surface and the activity density surface and were compared using the *volume calculation* tool of *ArcGIS*. The performance of the 163a service was also examined visually. The activity density surface was converted into a 3D format and added to a 3D scene in *ArcGIS* where the activity density values representing the height of the scene were used (Figure 5a). In order to enhance the analysis two additional layers were added: the motorway networks and Loughs and a conversion factor of 10000 was applied to the height value to enhance the visualisation. A similar 3D scene was also visualised excluding the service area of the 163a to show the activity spaces that were geographically excluded from the current service (Figure 5b).

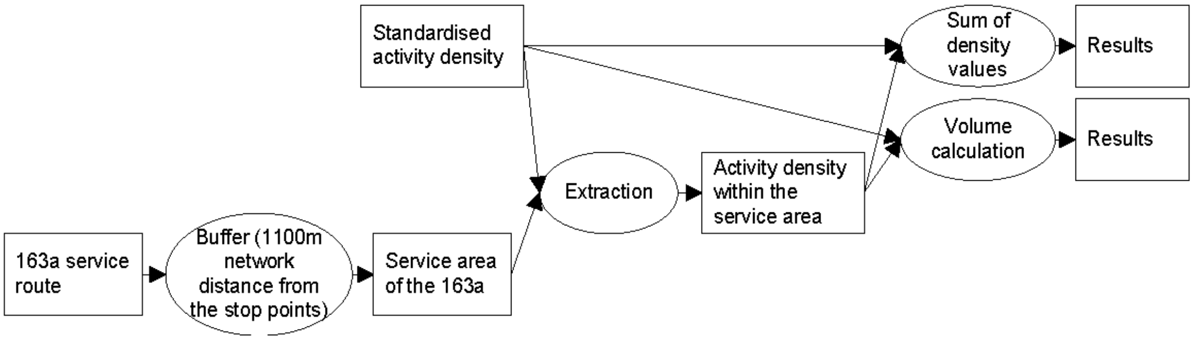


Fig. 4. Methodology to evaluate the performance of the 163a route

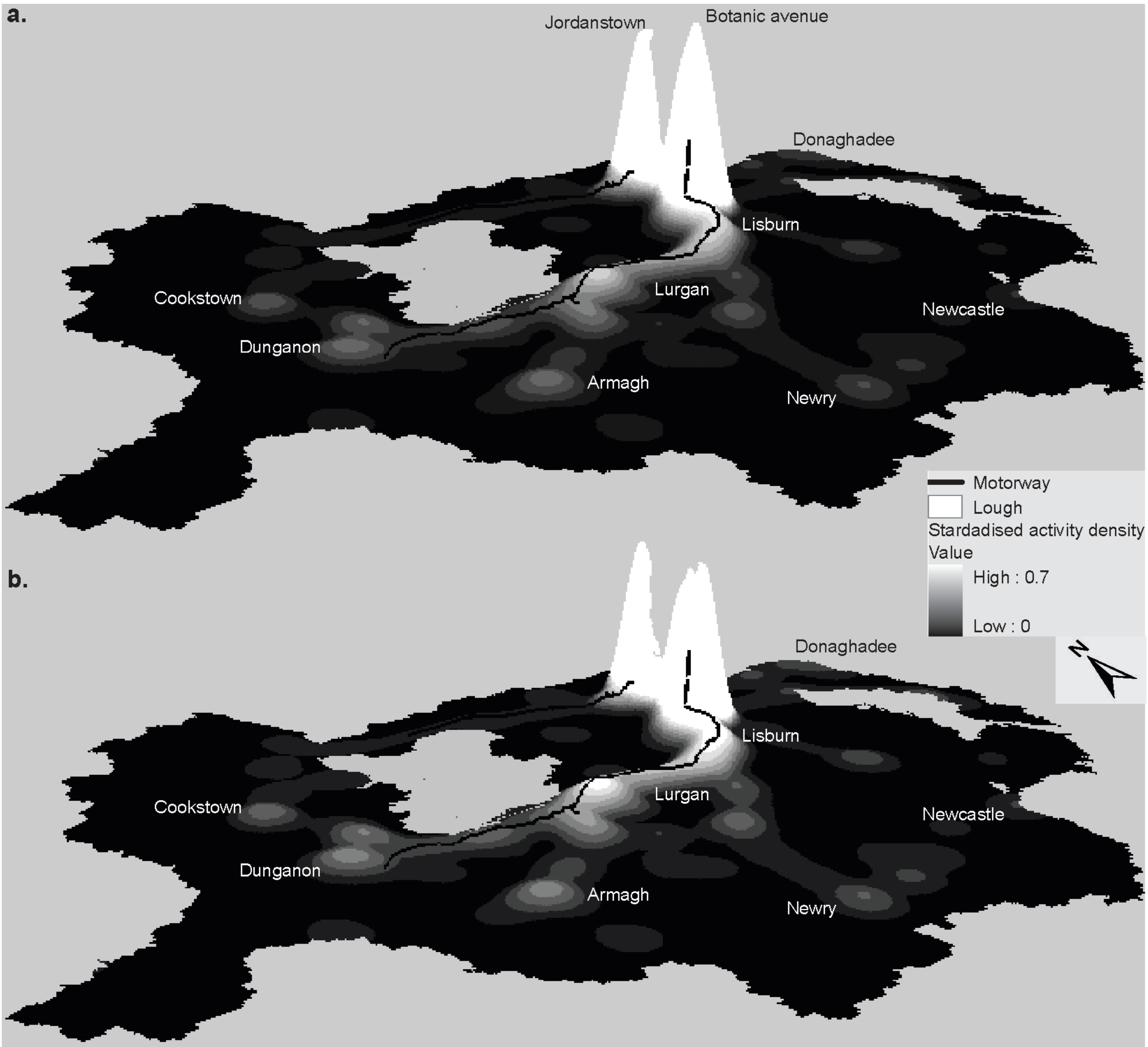


Fig. 5. a) 3D visualisation of students activity spaces, and b) Activity spaces that are geographically excluded from the 163a service

2.5 Design of new routes

The evaluation of the 163a service found that a considerable number of the activity spaces were excluded from the current service. As a result, this study went on to address the design of new routes to meet the coverage policy goal of the DRT service. Six new routes were designed and are shown in Figure 6. Attention was focused on developing the new routes so that they followed the higher activity density values represented by the density surface measure. This analysis required that a lower impedance value was in place in order for the routes to pass through these locations. As a result, the activity density values were inverted by subtracting them from 1 (the highest possible activity density value). The sum of the inverted pixel values of the activity density surface underneath a segment of the *road network shapefile* was transformed into an impedance value for that road segment. Figure 7 outlines the process of generating these routes. A *cross* tabulation operation was made between the inverse activity density surface and the road network in *ILWIS* in order to obtain the pixel values beneath a road segment (Figure 8)[10].

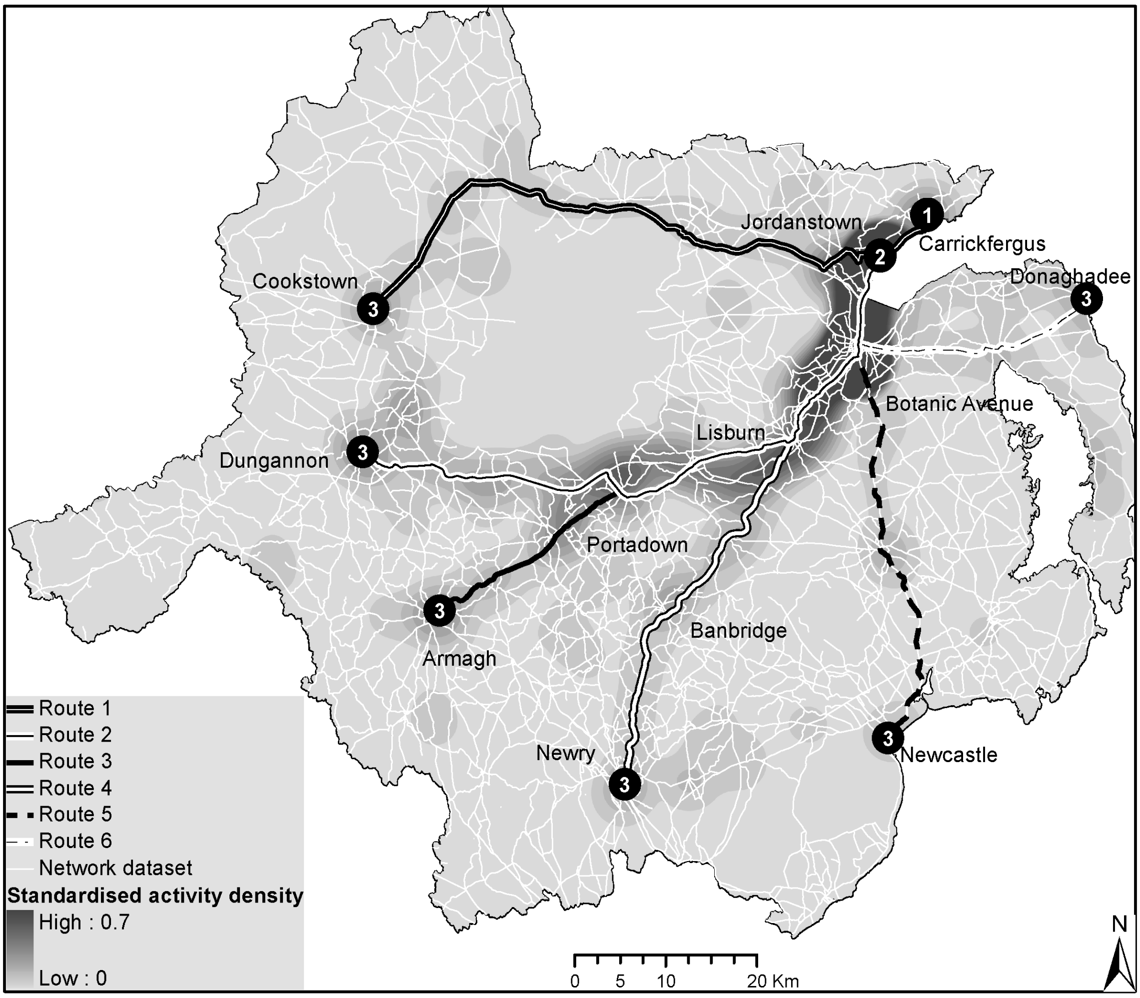


Fig 6. The new routes connected the geographically excluded activity spaces

The *road network shapefile* was converted to a *network dataset* with the inverse activity density measure acting as a measure of network impedance. The elevation *fields* of the *shapefile* which contain elevation data for the segments used to separate elevated motorway sections from other road classes. A one way restriction was also applied during the conversion process. The six new routes, designed in this study, were for intercity services. Local roads were excluded from the *network dataset;* as a result, the *dataset* only contains motorway, A-class, B-class, and C-class roads. *ArcGIS Network Analyst* was used to design the new routes. Origins and destinations were identified through a visual exploration of the activity density surface. Six density peaks were identified and selected as

10 Figure 8 shows that underneath *Road ID 9*, there are two pixels with value 0.97 and one pixel with value 0.98. Thus the total impedance to pass through this segment of road network is 2.92.

the key destinations. These peaks represent: Cookstown, Dungannon, Armagh, Newry, Newcastle, and Donaghadee. One of these routes was designed for one specific destination as the current DRT service is destination specific (Figure 6). All the routes originated from Carrickfergus; the only peak activity density surface located on the eastern side of the university. As a result, an intermediate stop point was placed at Jordanstown so that the routes could pass through the university site.

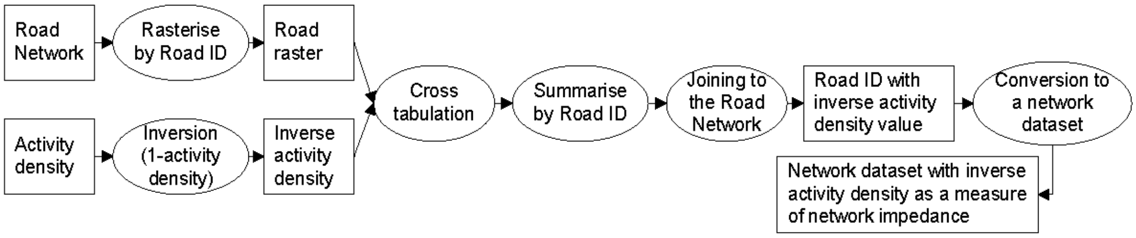


Fig. 7. Flow diagram to derive inverse activity density as a network impedance measure

2.6 Evaluation of the alternative routes

The six new routes are connected to different activity spaces, as a result, the provision of similar DRT services, like the 163a, is deemed to be necessary for all these routes. In considering the patronage goal the new routes were subjected to a further evaluation. The aim of this was to find the best route (or ranking of routes) that satisfied the patronage and coverage policy goals for a viable DRT service. The six generated routes together with the existing 163a route were evaluated using the criteria listed in Table 5[11]. These criteria and their weights were generated through consultations with a number of stakeholders. Two groups of stakeholders were identified and consulted: a) transport provider; and b) the university/students/society. This process provided information on the policy goals, objectives and decision criteria of the stakeholders. The criteria were classified into spatial factors and non-spatial costs. The presence of both spatial and non-spatial criteria suggests the need to adopt a Spatial Multi Criteria Evaluation (SMCE) technique. The operational cost criterion was obtained by summing up all the relevant operational costs listed in Table 5. The operational costs of the existing 163a service were gathered through a personal communication with *Translink* and are listed in Table 6. Table 6 was in turn then used to calculate the generalised operational cost per bus kilometre in order to determine the operational costs of the six newly designed routes. This is a commonly used method to evaluate transport efficiency (see, Cole, 2005; White, 1995). Table 7 shows the calculated operational costs of the new routes. The *required number of buses* on each route was calculated using a given average headway time of 15 minutes (average headway time of the existing service) (Equation 2) (White, 1995). The *round trip running time* for each route was calculated using the average travel speed of the 163a service (32km/hour) and the length of each designed route. The operational costs of the individual routes were calculated using Equation 3.

Required number of buses = Round trip running time (min) / headway (min) ……..Equation 2

Total operational costs (£/yr) = Number of buses × operational cost per bus kilometre per year (£/metre/yr) × route length (metre) × 2 ……..Equation 3

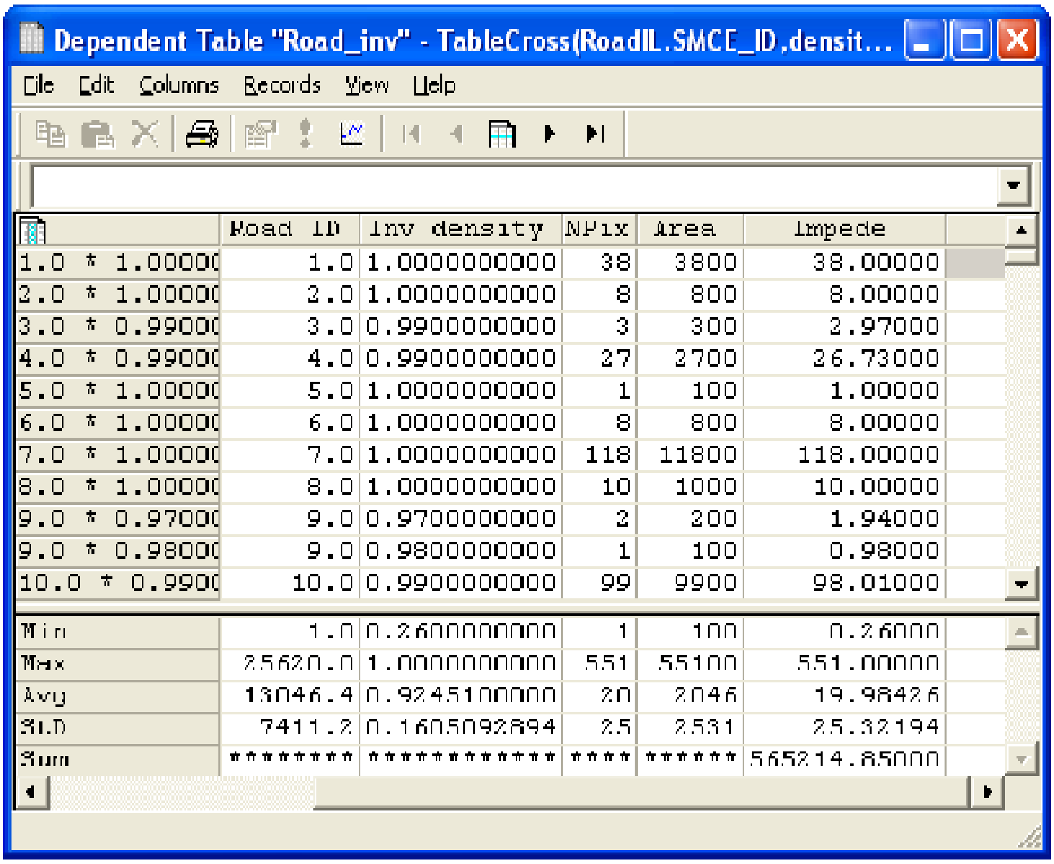
3. Results

3.1 Student travel behaviour

On average each student made 5.2 trips and visited 3.59 unique activity locations on the two days surveyed (Table 2). Each student travelled an average 102 km and spent 160 minutes travelling on these two days. The average trip length and trip time are 19.6 km and 31 minutes respectively (Table 8 and Table 9). Each student spent an average 196 minutes undertaking a single activity (Table 9). However, the average daily travel distance and average daily activity duration are 56 km and 388 minutes respectively (Table 2). Table 8 shows that student mode choice behaviour is more closely linked to the Northern Ireland average except in situations where the car is the main mode. This was found to be at a similar level to that found in Great Britain (GB). A higher proportion of student car trips were found in comparison with the Northern Ireland average. This is due to higher levels of car

11 Sharifi et al. (2004) have classified criteria into spatial factor, spatial cost, non-spatial factor, and non-spatial cost on the one hand. A factor criterion favours an alternative unlike a cost criterion. On the other hand, both spatial and non-spatial constraint restricts the performance of any criteria.

ownership amongst students, 79% of the students own a car in compare with 41% of NI population (Table 2) (NISRA, 2001). Students appear to be structurally dependent on the car due to: firstly, the need to make longer trips than the Northern Ireland average (Table 8); secondly, a higher proportion (56%) of students are living in areas not well served by public transport (Table 2 and Figure 9a).



	Road ID	Inv density	NPix	Area	Impede
1.0 * 1.00000	1.0	1.0000000000	38	3800	38.00000
2.0 * 1.00000	2.0	1.0000000000	8	800	8.00000
3.0 * 0.99000	3.0	0.9900000000	3	300	2.97000
4.0 * 0.99000	4.0	0.9900000000	27	2700	26.73000
5.0 * 1.00000	5.0	1.0000000000	1	100	1.00000
6.0 * 1.00000	6.0	1.0000000000	8	800	8.00000
7.0 * 1.00000	7.0	1.0000000000	118	11800	118.00000
8.0 * 1.00000	8.0	1.0000000000	10	1000	10.00000
9.0 * 0.97000	9.0	0.9700000000	2	200	1.94000
9.0 * 0.98000	9.0	0.9800000000	1	100	0.98000
10.0 * 0.9900	10.0	0.9900000000	99	9900	98.01000
Min	1.0	0.2600000000	1	100	0.26000
Max	25620.0	1.0000000000	551	55100	551.00000
Avg	13046.4	0.9245100000	20	2046	19.98426
StD	7411.2	0.1605092894	25	2531	25.32194
Sum	********	************	****	******	565214.85000

Fig. 8. Cross tabulation between road networks and inverse activity density in *ILWIS*

Table 5: Criteria used to evaluate the alternative routes

Goal	Objectives	Criteria and constraint
To maximise coverage	To maximise activity density (within the service area of 1100 meters network distance from each route)	To maximise density value To maximise areas with positive activity density To maximise activity density volume Spatial factor: the higher the activity density, the better the route.
To maximise patronage	To maximise income	Spatial factor: higher coverage will bring more income in term of fares; as a result, this objective and the above objective represent same values. However, only one of these was realised to avoid double counting as proposed by Sharifi et al. (2004).
	To minimise operational cost	To minimise driver's cost: non-spatial cost To minimise gross fuel cost: non-spatial cost To minimise tyre cost: non-spatial cost To minimise engineering cost: non-spatial cost To minimise vehicle depreciation: non-spatial cost To minimise overheads: non-spatial cost To minimise claims: non-spatial cost

Table 6: Operational costs of the 163a service

Cost category	Cost incurred in 2007-08 (£)	Number of buses	Cost per bus kilometre per year (£)
Driver costs	22 741	-	177.7
Gross fuel cost	6 626	-	51.8
Tyre cost	219	-	1.7
Engineering cost	24 198	-	189.0
Vehicle depreciation	5 897	-	46.1
Overheads	5 022	-	39.2
Claims	25	-	0.2
Total operation cost	64 728	4	505.7

Table 7: Operational cost of the alternative routes

Alternative Routes	Route length (m)	Headway (min)	Speed (m/hr)	Round trip time (min)	Number of required vehicles	Total operational cost per year (£)
Route 1	76 594.4	15	32 000	287.23	19	1 471 884.78
Route 2	84 244.1	15	32 000	315.92	21	1 789 293.27
Route 3	76 986.8	15	32 000	288.70	19	1 479 423.61
Route 4	77 411.8	15	32 000	290.29	19	1 487 591.69
Route 5	65 228.9	15	32 000	244.61	16	1 055 560.56
Route 6	44 851.9	15	32 000	168.19	11	498 995.76

Table 8: Comparison of students mode choice behaviour with GB and NI average[a]

Mode	Number of Trips	Comparison: % of total trips			Comparison: average trip length (m)		
	Student	Student	GB	NI	Student	GB[c]	NI
Bus	84	12.7	6.3	14.0	13 320.8	7 331.7	13 185
Car	423	64.0	63.5	45.86	26 223.9	13 929.7	12 236
Lift[b]	26	3.9	-	24.54	18 975.3	-	11 270
Motorcycle	1	0.2	1.8	9.9	40 190.1	6 270.5	15 939
Taxi[b]	12	1.8	-	1.94	8 604.3	-	6 279
Walk	115	17.4	24	17.65	1 080.0	1 299.6	1 288
Total	661	100	100	100	19 625.8		10 530

[a] National data were collected and processed from DfT (2007) and DRD (2008) are reported here for those modes that matched the categorisation of this research.

[b] DfT (2007) has not classified 'taxi' and 'lift' as separate modes whereas DRD (2008) has classified 'lift' as 'car passenger'

[c] The average trip length of GB was calculated using total number of trips and total distance travelled per person per year by modes

Student trip length as well as activity duration was the largest for educational purposes (Table 9). Figure 9b and 9c show the relative complexity of students travel behaviour with respect to their home location who do not own a car whereas figure 9d shows that car ownership not only enables students to attend the university with relative ease but also enables them to participate in distant activities (see also Table 2). 41% of student trips are associated with travelling back home from different activities (Table 9). This category was not reported separately by any of the national travel surveys (see, DfT, 2007; DRD, 2008). The proportion of these trips reported has been calculated ignoring a major source of trips. Students spent a considerable amount of time working. A few trips were associated with work suggesting that few students were engaged in work while studying (Table 9). The students who reported temporarily living in Belfast, have work locations close to their secondary home (parental) (Figure 1c). In term time, these students are within the service area of the 163a (Figure 1d and 1c). Shorter activity durations (8.7 minutes) for the trip purpose 'associated with study' (e.g. pick up, to get bus) suggests that ICT played a larger role before students commenced these trips. Students were aware of their picked up time or public transport timetable.

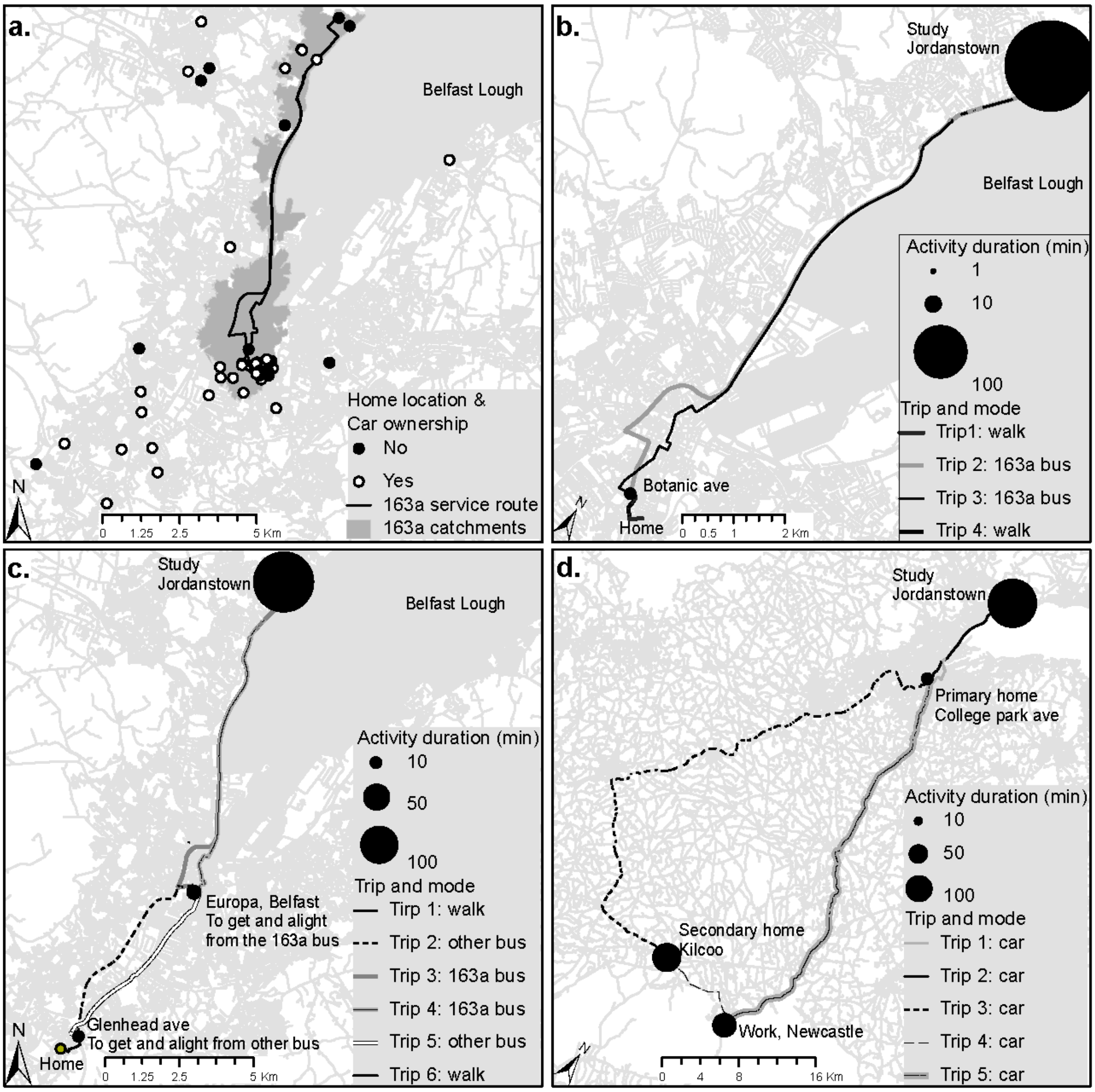


Fig. 9. a) Primary homes by car ownership in the context of the 163a route, b) Travel trajectories of a non-car owning student living within the service area of the 163a in a day, c) Travel trajectories of a non-car owning student living outside of the service area of the 163a in a day, and d) Travel trajectories of a car owning student in a day

A higher proportion (11%) of trips in the category ‘associated with study’ for student travel implies that many students did not travel directly to and from the university. Figure 10a shows that a higher proportion of these trips were associated with the two peaks related to morning commuting to the university and returning back from there in the afternoon. This behaviour is also explained in Figure 11 through the analysis of student trip chain patterns. Two different types of trip chain were found. The chain for a university attendance day is different to that of a non-attendance day. Out of 211 chains, 170 (81%) chains belong to the former category. On a university attendance day, home-university-home was the most dominant chain (56%). Other dominant forms were found to include: home-university-home-recreation-home (5%), home-university-home-shopping-home (5%), home-pick up friend-university-drop off friend-home (4%), and home-university-home-social event-home (4%). On a non-attendance day, the dominant form of trip chain is home-work-home (25%) followed by home-social event-home (12%). Part time work is prevalent amongst students on university non-attendance days. As a result; work trips appear throughout a day in Figure 10a. The above trip chain patterns suggest that student discretionary activities (e.g. shopping, social, recreation) are mainly centred around the home. As a result, a higher proportion of students discretionary activities appear in the early evening in Figure 10a. This trip chaining behaviour for discretionary activities is somewhat different from that recorded for other travellers whose discretionary activities are centred around two pegs: home and office (Dijst and Vidaković, 1997).

Table 9: Comparison of students activity behaviour with NI average

Trip purpose	Number of trips	Comparison: % of total trips		Comparison: average trip length (m)		Average travel time	Average activity duration [b] (min)
	Student	Student	NI	Student	NI	Student	Student
Associated with study[a]	76	11	5.17	10 066.5	3 542	19.8	8.7
Food	14	2	-	4 396.8	-	9.6	97.8
Recreation	30	5	22.9	9 029.5	13 202	16.5	138.6
Returning home[b]	271	41	-	21 274.6	-	31.8	119.3
Shopping	22	3	20.6	7 226.9	7 084	16.5	71.3
Social	32	5	-	13 122.2	-	20.0	109.7
Study	189	29	7.3	26 548.6	6 762	41.9	340.1
Work[a]	27	4	19.5	19 005.7	18 515	28.0	318.7
Total	661	100		19 625.8		30.9	196.0

[a] 'Escort education' and 'commuting and business' category of DRD (2008) are represented as 'Associated with study' and 'Work' respectively

[b] Average activity duration was calculated from 449 intermediate trips which belong to the 211 chains. Home activity duration was calculated using only 95 returning home trips that appeared in the middle of the chains.

Table 10 shows the results of the multiple regression analysis measures related to the impacts of the explanatory variables to the size of students activity spaces. Among the three measures of the size of activity spaces, two significant models emerged from the analyses that are related to average daily distance travelled and average daily activity duration. The *t* values reveal that home location and car ownership are the significant contributor to the distance travelled model whereas income is the significant contributor to the activity duration model. Table 2 shows that students who own car travelled longer distances than who do not on the one hand. On the other hand, students who are living within the service area of the 163a travelled significantly shorter distances than their counterpart. This does not necessarily mean that the students who live outside of the 163a service catchments own a car as no such association was found previously (Table 4).

The shorter travel distances for the students who live within the service area cannot be misjudged due to the fact that these students tend to live closer to the university and also due to the largest trip length for the purpose of education (Figure 1a, 1b and Table 9). A further analysis using only non-study trips shows the similar result for the home location variable but not for the car ownership variable[12] (Table 10). This suggest that the extra distance travelled by the car owning students is due to undertaking associated with study activities (e.g. to pick up friends to go to university). A larger Standardised Beta Coefficient value for home location variable indicates that this explanatory variable has a larger effect on distance travelled for all trips and the only determinant for non-study trips. A negative value for the Beta coefficient of car ownership variable for all trips implies that distance travelled would be reduced for non-car owning students. Both the all trips and the non-study trips models account for 27% (adjusted R Square) of variance in the distance travelled scores.

Table 2 shows that lower income students spent more time undertaking activities than higher income students. Despite significant model emerged for average daily activity duration for all trips, this is found to be an insignificant model for the non-study trips. In addition, income is found to be an insignificant contributor to this non-study model. This suggests that lower income students spent extra time undertaking study related activities only. Despite no significant model emerged for unique locations visited, the *t* values for unique locations visited reveal that sex is the significant contributor to this model. Table 2 shows that female students visited more place than male students for all trips. However, no such significance observed for the non-study trips model. This reveals that the extra visited locations of the female students are confined to undertaking study related activities (e.g. presenting study materials to a different location other than the university, to pick up friends to go to university).

[12] Study trips, associated with study trips, and returning home trips were excluded for this analysis which returned a total of 125 non-study trips.

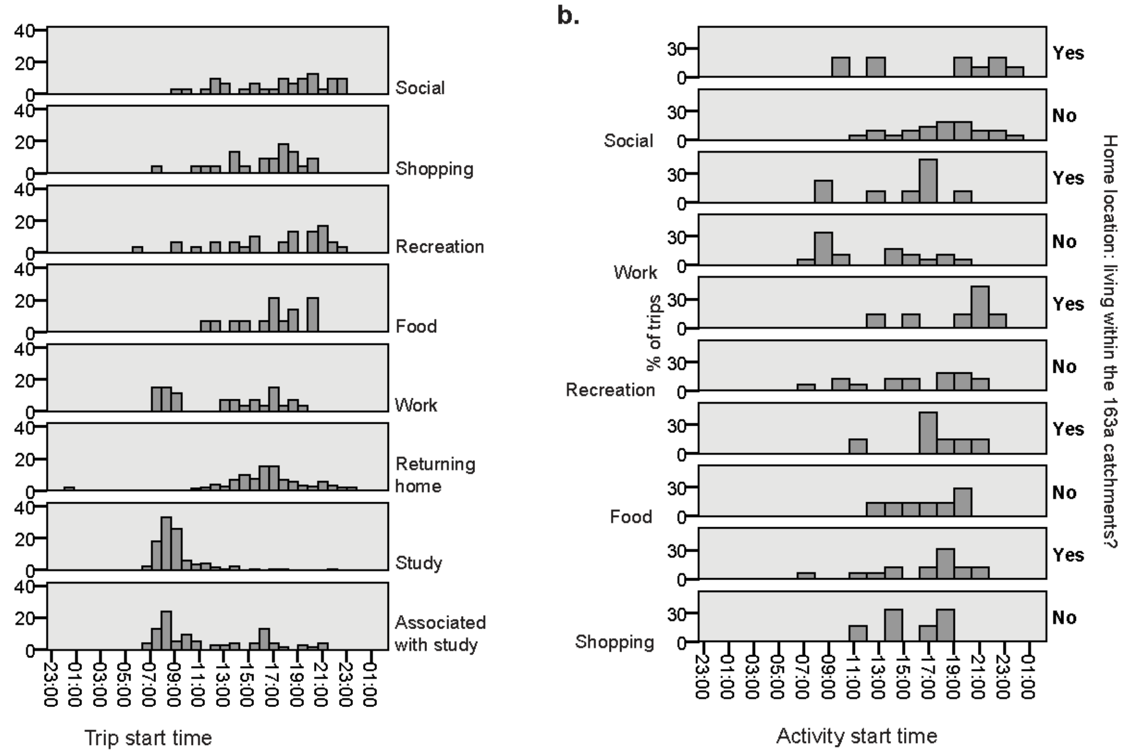


Fig. 10. a) Temporal variation of trip departure time for all trips, and b) Comparison of activity starting time between the students who live within the service catchments of the 163a and their counterpart for non-study trips.

Table 10: Impacts of the explanatory variables to the size of activity spaces (Multiple Regressions)

Explanatory variables	Unique locations visited[b]			Daily distance travelled[b]			Daily activity duration[b]		
	Beta	*t*	F	Beta	*t*	F	Beta	*t*	F
Sex	0.194	2.189[a]	1.753	0.012	0.152	11.348[a]	0.071	0.811	2.631[a]
	(0.068)	(0.755)	(0.480)	(0.084)	(0.726)	(4.907[a])	(0.100)	(0.767)	(01.076)
Car ownership	0.010	0.115		-0.186	-2.363[a]		-0.057	-0.648	
	(-0.091)	(-0.998)		(-0.059)	(-0.488)		(0.063)	(0.468)	
Income	0.015	0.166		-0.116	-1.480		-0.265	-3.018[a]	
	(-0.013)	(-0.144)		(0.127)	(1.085)		(0.106)	(0.813)	
Home location	-0.122	-1.344		0.462	5.820[a]		-0.063	0.711	
	(-0.047)	(-0.512)		(0.448)	(3.675[a])		(0.221)	(1.620)	

[a] Coefficients are significant at 95% confidence level

[b] The values in parentheses are related to non-study trips

Therefore, it appears that there are no differences among the students in terms of accessing opportunities (unique locations visited) and in terms of extent of participation (activity duration) in these opportunities. However, there is a significant difference in their mobility patterns (distance travelled) which is not due to their socio-economic differences (e.g. sex, income) but due to their geographical differences (home location). Students who are living outside of the 163a service route travelled significantly longer distances to access goods and service. However, 51% of these high mobility students live in rural areas where proximate opportunities are relatively scarce in Northern Ireland (DRD, 2001; Nutley, 2005). As a result, it is reasonable to say that their higher level of mobility was compensated to access opportunities at distance to the hubs.

Although all groups of students visited equal number of unique activity locations and spent equal amount of time, this does not necessarily mean that they participated in equally both in terms of spatially (in all land uses) and/or in terms of temporally (at all time). Equal number of visited unique locations could be due to the visitation of same type of activities (e.g. recreation) located in different places. Since home location with respect to a transport opportunity (163a service) is the deciding factor to distance travelled, this variable was further been analysed to assess the nature of participation in activities between these groups. This means that the analysis is directed to examine whether this mobility differences is contributing to a lack of participation in any of these groups either spatially or temporally. The analysis was confined with data related to non-study trips.

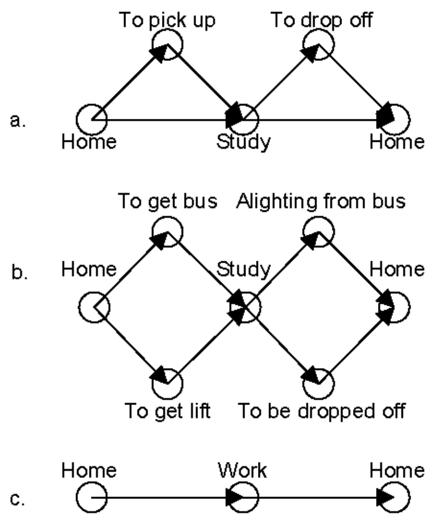


Fig. 11. a) Trip chains of the car owning students in a university attendance day, b) Trip chains of the non-car owning students in a university attendance day, c) Trip chain in a university non-attendance day

Table 11 shows that a significant association exists between home location and the types of activity participated in. Investigation shows that both groups participated in all types of non-study activities (e.g. social, recreation, work). They also equally participated in food and recreational activities. However, the higher level of mobility (living outside of the catchments) allows students to participate significantly higher number of social activities due to the fact that participation in this type of activity is not influenced by the authority constraints on the one hand. On the other hand, students who live within the service catchments participated in significantly higher number of shopping activities. Participation in shopping activities is subject to its opening hours. Considering the fact that students mainly participate in discretionary activities from home (after returning from the university – trip chain behaviour discussed earlier) as a result temporal availability to participate in the shopping activities is thus limited. Figure 10b shows that the activity started time for shopping for the students who live outside of the service area ended by early evening whereas these were extended to late evening for the students who are living within the catchments. This is due to the fact that the outside students needed traversing significantly longer distances from these opportunities to reach home. As a result, although they did not trade-off activity duration with travel time but they traded-off access time with travel time. Similar trend is also found for food and recreational activities (Figure 10b). Therefore, it is certain that although none of these groups lack participation in activities spatially (from land uses), the students who live outside of the catchments of the 163a route are excluded temporally precisely because of their nature of lifestyle (rural). Further investigation among the students who live outside of the catchments shows also a significant difference to distance travelled based on the lifestyle variable. Students who live in urban areas travelled shorter than their counterpart for non-study activities. This suggests the closeness of opportunities who live in urban areas.

Table 11: Coefficients of chi-square test for independence among explanatory variables, activity types, and mode choice behaviour (non-study trips)

Variables	Home location	Sex	Car ownership	Income
Trip purpose	10.945[a]	1.456	8.837	9.396
Mode	30.711[a]	4.172	22.574[a]	0.607

[a] Coefficients are significant at 95% confidence level

It is reasonable to expect that students who live outside the public transport opportunity will make significantly higher number of trips by car than bus (Table 11). However, student whose home locations were found within the service area of the 163a route made a significantly higher number of trips on foot than their counterparts. This also suggests the closeness of opportunities in urban areas. From data presented in Table 11 it is also found that car owning students are most likely to use their car as their main mode of travel. No significant associations were found between gender and travel mode, between gender and activity types, and between car ownership and types of activity participated in for non-study trips. Mode choice behaviour and trip purpose are also not associated with income.

3.2 Evaluation results of the public transport (DRT) routes

The service area of the 163a route covers a small part (0.24%) compared to total analysis area. Similarly, it covers a small proportion (0.23%) of total area with positive activity density (Table 12). Despite this little geographical coverage, the service area contains 11% of the total students activity density. A geo-visualisation of this can be seen in Figures 5a and 5b. In Figure 5a, two sharp activity density peaks can be found that related to the dominant features associated with the students activity spaces. The activity peaks can be seen to fall away after the exclusion of those activity spaces that are located within the route 163a service area (Figure 5b). Despite coverage by the 163a route of this high activity density, Table 12 shows that around 90% of the activity spaces are geographically excluded from the 163a route.

The six new routes were evaluated together with the current 163a route using the criteria set out in Table 5. SMCE technique was applied to the evaluation. The criterion scores were aggregated following the Path 2 approach (see, Sharifi et al., 2004; Zucca et al., 2008 for more information) of SMCE. This was followed by using the *weighted summation* method (which is a compensatory approach) for the aggregation of the individual criterion scores. The evaluation provided the utility scores for each route from the perspectives of the stakeholders. The results of the evaluation are shown in Table 13. This shows that the current 163a route possesses a greater utility score when compared with the other alternatives when a greater emphasis (larger weighting) was placed on achieving the patronage goal. By placing a policy emphasis on the coverage goal, this changed the ranking of the alternatives and Route 3 (Carrickfergus-Armagh) became the most favourable option. This route is also advantageous for two reasons. Firstly, it can be operated by replacing the existing route as it completely contains the service area of the 163a. Secondly, it overlaps with a significant portion of the service area of Route 2 and Route 4 (Figure 6). However, when equal weighting were placed on both policy goals, the analysis indicated that the data almost reverts back to the original rankings. These weights were assigned using the *rank order* method.

Table 12: Evaluation of the 163a route based on students activity density

Evaluation of the:	Area (m^2)		Area with positive activity density (m^2)		Volume of positive activity density (m^3)		Sum of standardised activity density values	
	Total	%	Total	%	Total	%	Total	%
163a service area	16 617 959.19	0.24	16 038 200	0.23	8 020 515.13	11.09	81 854.10	10.56
Analysis area	6 943 933 168.61	100	6 938 291 700	100	72 312 649.26	100	774 923.96	100

Table 13: Evaluation results of the alternative routes

Alternative routes	Priority on patronage goal		Priority on coverage goal		Equal priority	
	Standardised score	Rank	Standardised score	Rank	Standardised score	Rank
Route 1	0.2867	6	0.4329	7	0.3598	7
Route 2	0.2771	7	0.7590	2	0.5181	6
Route 3	0.3975	4	0.7738	1	0.5856	4
Route 4	0.3857	5	0.7475	3	0.5666	5
Route 5	0.5169	3	0.6582	4	0.5876	3
Route 6	0.7079	2	0.6090	6	0.6585	2
163a service route	0.8741	1	0.6224	5	0.7482	1

4. Discussion and conclusion

Recent research examining the participation in activities using the concept of activity spaces has focused on general travelers (Schönfelder and Axhausen, 2003), the disabled (Casas, 2007), and the low income women (McCray and Brais, 2007) rather than students. No comparable data was therefore found from other studies in relation to student travel behaviour. Despite this limitation, the findings of this research are similar to that found by Schönfelder and Axhausen (2003) as no significant differences were observed to the size of activity spaces based on socio-economic classification of the students. The findings of this research are also similar to that found by other researchers (see for instance, Buliung and Kanaroglou, 2006; McCray and Brais, 2007; Newsome et al., 1998) that home location is an important determinant to the size of activity spaces.

The behavioural analysis of disaggregated socio-economic, spatial, and temporal data relating to students travel shows that home location with respect to a DRT service is the most significant contributor to distance travelled. Despite being geographically excluded from this service, the analyses of actual accessibility and travel behaviour of these students show that their nature of participation in activities are spatially similar to those who are not excluded from the service. However, the temporal participation in activities of these excluded students is found to be constrained. This temporal exclusion is not due to their geographical exclusion from the DRT service rather than rurality reduces their chance of participation in certain activities in late hours.

The findings of this research suggest that although improvement in mobility will allow people to access distance goods and services spatially, they however may face participation problem temporally. The presence of greater travel distance for the non-study trips for the students who are living outside of the service catchment of 163a suggests that travel reduction potential exists within that region. As a result, the provision of innovative public transport options as the policy response of the RDS and RTS (discussed in Section 2) will not ensure an equal participation to access goods and services in the hubs for the people living in rural areas.

The decision support framework that was developed in this research was tested with a DRT service case study. The application of this framework is not restricted to DRT services and can be usefully applied in the route planning of public transport routes more generally. The framework, however, is restrictive in that it does not address several other important issues. The framework, for example, does not address issues associated with vehicle type and therefore needs to be developed in tandem with an appropriate business model such as that developed by Zografos et al. (2008) and discussed in Section 1.2 of this paper.

3D visualisation of activity density helps to identify areas of high demand. The trip patterns identified show that although the existing DRT route covers these areas of high demand, there is still scope on the basis of coverage goal to design new DRT routes which could be targeted at the geographically excluded. However, the new routes will not benefit the students as a process of fostering participation in activities in this case. This is due to the fact that their temporal lack of participation in activities is not due to a lack of access to transport but due to a lack of availability of proximate opportunities. Moreover, operationalisation of the new routes would not be a feasible option on the basis of putting equal priority to both on patronage goal and coverage goal. However, considering the sustainability issues sets out in the RDS, the operationalisation of the new routes would contribute to reducing congestion, improving air quality, and thereby positively influencing on health (DRD, 2001).

This research has demonstrated how SMCE can be used to convert multidimensional individual activity density surfaces into a single dimensional activity density surface in the form of a network impedance measure to route planning process. The *ArcGIS Network Analyst* was found to be an effective tool which could assist in the design of new routes aimed at addressing the travel needs of the transport disadvantaged using the impedance measure. SMCE was also used to evaluate the performance of the designed routes developed in this paper. It also effectively captured the interests of the stakeholders. The presence of both spatial and non-spatial interests within the stakeholders group justified the usage of SMCE as an evaluation method. It enabled the development of an approach which could evaluate alternative options. This clearly would be of assistance to transport providers who require clear information when making informed decisions about public transport networks. The evaluation method and the rankings applied to the different routes allowed an exploration of the effects that different policy goals can have on public transport provision. In this case, the patronage policy goal and the network coverage policy goal.

5. References

Accession, 2006. GIS public transit accessibility analysis. Citilabs, http://www.citilabs.com/accession.html Accessed on April 09, 2009.

Barber, G., 1995. Aggregate characteristics of urban travel. In: Hanson, S., (ed), The Geography of Urban Transportation, New York London: The Guilford Press, pp. 81-99.

Becker, U., Gerike, R., 2008. Background - Needs as the Focus of Transport Planning. In: Becker, U., Böhmer, J., Gerike, R., (eds), How to Define and Measure Access and Need Satisfaction in Transport, Dresden: Dresdner Institut für Verkehr und Umwelt e.V. (DIVU), pp. 5-24.

Beyer, H. L., 2004. Hawth's Analysis Tools for ArcGIS. Available at http://www.spatialecology.com/htools Accessed on September 04, 2008.

Bhat, C. R., Singh, S. K., 2000. A comprehensive daily activity-travel generation model system for workers. *Transportation Research Part A*, 34(1), 1-22.

Bowman, J. L., Ben-Akiva, M. E., 2000. Activity-based disaggregate travel demand model system with activity schedules. *Transportation Research Part A*, 35(1), 1-28.

Brake, J., Nelson, J. D., Wright, S., 2004. Demand responsive transport: towards the emergence of a new market segment. *Journal of Transport Geography*, 12(4), 323-337.

Buliung, R. N., Kanaroglou, P. S., 2006. Urban Form and Household Activity-Travel Behavior. *Growth and Change*, 37(2), 172-199.

Buliung, R. N., Roorda, M. J., Remmel, T. K., 2008. Exploring spatial variety in patterns of activity-travel behaviour: initial results from the Toronto Travel-Activity Panel Survey (TTAPS). *Transportation*, 35(6), 697-722.

Burchardt, T., Grand, J. L., Piachaud, D., 2002. Degrees of Exclusion: Developing a Dynamic, Multi-Dimensional Measure. In: Hills, J., Grand, J. L., Piachaud, D., (eds), Understanding Social Exclusion, Oxford: Oxford University Press, pp. 30-43.

Casas, I., 2007. Social Exclusion and the Disabled: An Accessibility Approach. *The Professional Geographer*, 59(4), 463-477.

Cass, N., Shove, E., Urry, J., 2005. Social exclusion, mobility and access. *The Sociological Review*, 53(3), 539-555.

Church, A., Frost, M., Sulivan, K., 2000. Transport and social exclusion in London. *Transport Policy*, 7(3), 195-205.

Cole, S., 2005. Applied Transport Economics: Policy, Management & Decision Making. London: Kogan Page.

Current, J., ReVelle, C., Cohon, J., 1985. The maximum covering/shortest path problem: A multiobjective network design and routing formulation. *European Journal of Operational Research*, 21(2), 189-199.

Current, J., Schilling, D. A., 1994. The median tour and maximal covering tour problems: Formulations and heuristics. *European Journal of Operational Research*, 73(1), 114-126.

Currie, G., Richardson, T., Smyth, P., Vella-Brodrick, D., Hine, J., Lucas, K., Stanley, J., Morris, J., Kinnear, R., Stanley, J., 2009. Investigating links between transport disadvantage, social exclusion and well-being in Melbourne--Preliminary results. *Transport Policy*, In Press, Corrected Proof.

Currie, G., Stanley, J., 2008. Investigating Links between Social Capital and Public Transport. *Transport Reviews*, 28(4), 529-547.

DCLG, 2008. The English Indices of Deprivation 2007. Department for Communities and Local Government (DCLG), http://www.communities.gov.uk/documents/communities/pdf/733520.pdf Accessed on December 18, 2008.

DETR, 2000. Social exclusion and the provision and availability of public transport. Department of the Environment Transport and the Region, London.

DfT, 2006. Social Inclusion: Transport Aspects (Final Report). Department for Transport, http://www.dft.gov.uk/pgr/inclusion/ Accessed on October 12, 2008.

DfT, 2007. Transport Trends: 2007 edition. Department for Transport, http://www.dft.gov.uk/pgr/statistics/datatablespublications/trends Accessed on September 20, 2008.

DfT, 2008. Social Exclusion. Department for Transport, http://www.dft.gov.uk/pgr/inclusion/se/socialexclusion Accessed on May 21, 2009.

DfT, GMPTE, 2004. Intermode: Innovations in Demand Responsive Transport. Department for Transport and Greater Manchester Passenger Transport Executive, http://www.dft.gov.uk/pgr/regional/policy/intermodeinnovationsindemand3722 Accessed on October 18, 2008.

Dijst, M., Vidaković, V., 1997. Individual action space in the city. In: Ettema, D., Timmermans, H., (eds), Activity-based approaches to travel analysis: Pergamon, pp. 117-134.

Dijst, M., Vidaković, V., 2000. Travel time ratio: the factor of spatial reach. *Transportation*, 27, 179-199.

DoE, 2005. Northern Ireland Environmental Noise Directive Mapping Data Study: Data Options, Feasibility, and Pilot Study Report. Department of the Environment: Environmental and Heritage Services. Final Report, Belfast.

Dong, X., Ben-Akiva, M. E., Bowman, J. L., Walker, J. L., 2006. Moving from trip-based to activity-based measures of accessibility. *Transportation Research Part A*, 40(2), 163-180.

DRD, 2001. Shaping Our Future: Regional Development Strategy for Northern Ireland 2025. Department for Regional Development, Belfast.

DRD, 2002. Regional Transportation Strategy for Northern Ireland 2002 - 2012. Department for Regional Development, Belfast.

DRD, 2007. Policy Review of the Northern Ireland Concessionary Fares Scheme. Department for Regional Development, Belfast.

DRD, 2008. Travel Survey for Northern Ireland 2005-2007. Department for Regional Development (Northern Ireland), http://www.roadsni.gov.uk/travsurvey_ni_05-07.pdf Accessed on February 26, 2009.

Dykes, J., 1996. Dynamic maps for spatial science: a unified approach to cartographic visualization. In: Parker, D., (ed), Innovations in Geographical Information Systems 3, London: Taylor & Francis, pp. 171-181.

Farrington, J., Farrington, C., 2005. Rural accessibility, social inclusion and social justice: towards conceptualisation. *Journal of Transport Geography*, 13(1), 1-12.

Farrington, J. H., 2007. The new narrative of accessibility: its potential contribution to discourses in (transport) geography. *Journal of Transport Geography*, 15(5), 319-330.

Gahegan, M., 2000. The case for inductive and visual techniques in the analysis of spatial data. *Journal of Geographical Systems*, 2(1), 77-83.
Geurs, K. T., Wee, B. v., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography*, 12(2), 127-140.
Golledge, R. G., Stimson, R. J., 1997. Spatial behaviour: A geographic perspective. New York: The Guilford Press.
Gray, D., Shaw, J., Farrington, J., 2006. Community transport, social capital and social exclusion in rural areas. *Area*, 38(1), 89-98.
Grossardt, T., Bailey, K., Brumm, J., 2001. Analytic minimum impedance surface: Geographic information system-based corridor planning methodology. *Transport Research Record*, 1768, 224-232.
Hägerstrand, T., 1970. What about people in regional science? *Papers of the Regional Science Association*, 24, 7-21.
Hanson, S., Schwab, M., 1995. Describing disaggregate flows: individual and household activity pattern. In: Hanson, S., (ed), The Geography of Urban Transportation, New York London: The Guilford Press, pp. 166-187.
Higgs, G., White, S. D., 1997. Changes in service provision in rural areas. Part 1: The Use of GIS in Analysing Accessibility to Service in Rural Deprivation Research. *Journal of Rural Studies*, 13(4), 441-450.
Hine, J., Grieco, M., 2003. Scatters and clusters in time and space: implications for delivering integrated and inclusive transport. *Transport Policy*, 10(4), 299-306.
Hine, J., Mitchell, F., 2003. Transport Disadvantage and Social Exclusion: Exclusionary mechanisms in transport in urban Scotland. Hampshire: Ashgate.
Horn, M. E. T., 2004. Procedures for planning multi-leg journeys with fixed-route and demand-responsive passenger transport services. *Transportation Research Part C*, 12(1), 33-55.
Horton, F. E., Reynolds, D. R., 1971. Effects of urban spatial structure on individual behaviour. *Economic Geography*, 47(1), 36-48.
Hurni, A., 2006. Transport and social disadvantage in Western Sydney: a partnership research project. Western Sydney Community Forum, New South Wales.
ITC, 2009. Integrated Land and Water Information System (ILWIS). International Institute for Geo-information Science and Earth Observation (ITC), http://www.itc.nl/ilwis/default.asp Accessed on February 20, 2009.
Kawase, M., 1999. Commuting activity spaces of married women in a suburb of the Tokyo metropolitan area. *GeoJournal*, 48(3), 217-222.
Keshkamat, S. S., Looijen, J. M., Zuidgeest, M. H. P., 2009. The formulation and evaluation of transport route planning alternatives: a spatial decision support system for the Via Baltica project, Poland. *Journal of Transport Geography*, 17(1), 54-64.
Knowles, R. D., 2006. Transport shaping space: differential collapse in time and space. *Journal of Transport Geography*, 14(6), 407-425.
Kwan, M.-P., 1999. Gender and Individual Access to Urban Opportunities: A Study Using Space-Time Measures. *The Professional Geographer*, 51(2), 211-227.
Kwan, M.-P., 2000. Interactive geovisualization of activity-travel patterns using three-dimensional geographical information systems: a methodological exploration with a large data set. *Transportation Research Part C*, 8(1-6), 185-203.
Kwan, M.-P., Weber, J., 2008. Scale and accessibility: Implications for the analysis of land use-travel interaction. *Applied Geography*, 28(2), 110-123.
Lucas, K., 2006. Providing transport for social inclusion within a framework for environmental justice in the UK. *Transportation Research Part A*, 40(10), 801-809.
Mackett, R. L., Achuthan, K., Titheridge, H., 2008. AMELIA: A tool to make transport policies more socially inclusive. *Transport Policy*, 15(6), 372-378.
Mageean, J., Nelson, J. D., 2003. The evaluation of demand responsive transport services in Europe. *Journal of Transport Geography*, 11(4), 255-270.
Malczewski, J., 1999. GIS and Multicriteria Decision Analysis. New York: John Wiley & Sons, Inc.
Matisziw, T. C., Murray, A. T., Kim, C., 2006. Strategic route extension in transit networks. *European Journal of Operational Research*, 171(2), 661-673.
McCray, T., Brais, N., 2007. Exploring the Role of Transportation in Fostering Social Exclusion: The Use of GIS to support Qualitative Data. *Networks and Spatial Economics*, 7(4), 397-412.
McDonagh, J., 2006. Transport policy instruments and transport-related social exclusion in rural Republic of Ireland. *Journal of Transport Geography*, 14(5), 355-366.
Miller, H. J., 1991. Modelling accessibility using space–time prism concepts within geographical information systems. *International Journal of Geographical Information Systems*, 5, 287-302.
Miller, H. J., 2005. What about people in geographic information science? In: Fisher, P., Unwin, D., (eds), Re-Presenting Geographic Information System, London: John Wiley, pp. 215-242.
Miller, H. J., 2006. Social exclusion in space and time. In: Axhausen, K. W., (ed), Moving through nets: the social and physical aspects of travel, Amsterdam: Elsevier, pp. 353-380.
Moseley, M. A., 1979. Accessibility: The rural challenge. London: Methuen.
Newsome, T. H., Walcott, W. A., Smith, P. D., 1998. Urban activity spaces: Illustrations and application of a conceptual model for integrating the time and space dimensions. *Transportation*, 25(4), 357-377.
Niaraki, A. S., Kim, K., 2009. Ontology based personalized route planning system using a multi-criteria decision making approach. *Expert Systems with Applications*, 36(2), 2250-2259.

NISRA, 2001. Population and Migration. Northern Ireland Statistics and Research Agency, http://www.nisranew.nisra.gov.uk/census/start.html Accessed on March 03, 2009.
NISRA, 2005a. Education and Training: Number of pupils by type of school. Northern Ireland Statistics and Research Agency (NISRA), http://www.nisra.gov.uk/publications/default.asp46.htm December 14, 2007.
NISRA, 2005b. The Northern Ireland Multiple Deprivation Measure. Northern Ireland Statistics and Research Agency (NISRA), http://www.nisra.gov.uk Accessed on May 16, 2008.
NISRA, 2005c. Report of the Inter-Departmental Urban-Rural Definition Group: Statistical Classification and Delineation of Settlements. Northern Ireland Statistics and Research Agency (NISRA).
Nutley, S., 2005. Monitoring rural travel behaviour: a longitudinal study in Northern Ireland 1979–2001. *Journal of Transport Geography*, 13(3), 247–263.
O'Sullivan, D., Unwin, D. J., 2003. Geographic Information Analysis. New Jersey: John Willey & Sons.
Pas, E. I., 1988. Weekly travel-activity behavior. *Transportation Research Part A*, 15, 89-109.
Preston, J., Rajé, F., 2007. Accessibility, mobility and transport-related social exclusion. *Journal of Transport Geography*, 15(3), 151-160.
Robberts, D., Farrington, J., Gray, D., Martin, S., 1999. The distributional effects of fuel duties: the impact on rural households in Scotland. *Regional Studies*, 33(3), 281-288.
Røe, P. G., 2000. Qualitative research on intra-urban travel: an alternative approach. *Journal of Transport Geography*, 8(2), 99-106.
Rollinson, P. A., 1991. The Spatial Isolation of Elderly Single-Room-Occupancy Hotel Tenants. *The Professional Geographer*, 43(4), 456-464.
Round, A., Cervero, R., 1996. Future ride: Adapting new technologies to paratransit in the United States. University of California Transportation Center, UC Berkeley CA.
Sayers, T. M., Jessop, A. T., Hills, P. J., 2003. Multi-criteria evaluation of transport options - flexible, transparent and user-friendly? *Transport Policy*, 10(2), 95-105.
Schönfelder, S., Axhausen, K. W., 2003. Activity spaces: measures of social exclusion? *Transport Policy*, 10(4), 273-286.
SEU, 2003. Making the Connections: Transport and Social Exclusion. Social Exclusion Unit, The Stationery Office, London.
Sharifi, A., Herwijnen, M. v., Toorn, W. v. d., 2004. Spatial Decision Support System. Enschede, the Netherlands: International Institute for Geo-information Science and Earth Observation (ITC).
Silverman, B. W., 1986. Density Estimation for Statistics and Data Analysis. New York: Chapman and Hall.
Stanley, J., Lucas, K., 2008. Social exclusion: What can public transport offer? *Research in Transportation Economics*, 22(1), 36-40.
Stanley, J., Stanley, J., 2004. Improving Public Transport to Meet Community Needs: A Warrnambool Case-study. Bus Association Victoria and Warrnambool Bus Lines, Melbourne.
Translink, 2009. Translink Unilink Service. Translink, Northern Ireland, http://www.translink.co.uk/unilink.asp Accessed on March 01, 2009.
Verron, H., 2008. Do We Need a New Approach on Access for Assessing Benefits of Transport Infrastructure Investment? Theses in the Environmental Point of View. In: Becker, U., Böhmer, J., Gerike, R., (eds), How to Define and Measure Access and Need Satisfaction in Transport, Dresden: Dresdner Institut für Verkehr und Umwelt e.V. (DIVU), pp.
Walker, J., 2008. Purpose-driven public transport: creating a clear conversation about public transport goals. *Journal of Transport Geography*, 16(6), 436-442.
Westerlund, Y., Stahl, A., Nelson, J., Mageean, J., 2000. Transport telematics for elderly users: successful use of automated booking and call-back for DRT in Gothenburg. *7th ITS World Congress*, Torino.
White, P., 1995. Public Transport: Its planning, management and operation. London: UCL Press Limited.
Wolpert, J., 1965. Behavioral aspects of the decision to migrate. *Papers of the Regional Science Association*, 15, 159-169.
Wyllie, D. S., Smith, G. C., 1996. Effects of Extroversion of the Routine Spatial Behavior of Middle Adolescents. *The Professional Geographer*, 48(2), 166-180.
Zarkesh, M. K., 2005. Decision Support System for Floodwater Spreading Site Selection in Iran. International Institute for Geo-information Science and Earth Observation (ITC), Enschede, The Netherlands.
Zografos, K. G., Androutsopoulos, K. N., Sihvola, T., 2008. A methodological approach for developing and assessing business models for flexible transport system. *Transportation*, 35(6), 777-795.
Zucca, A., Sharifi, A. M., Fabbri, A. G., 2008. Application of spatial multi-criteria analysis to site selection for a local park: A case study in the Bergamo Province, Italy. *Journal of Environmental Management*, 88(4), 752-769.