Identifying Hotspots of Transport Disadvantage and Car Dependency in Rural Ireland

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ABSTRACT

This paper explores the concepts of car dependency and transport disadvantage and the correlation between them in rural Ireland as a means of highlighting incidences of possible forced car ownership with the use of Geographical Information Systems (GIS). Societal and cultural challenges associated with the prevalence of the private car as the primary or in some cases the only form of mobility for people living in rural areas are examined resulting in potential cases of forced car ownership (FCO) (Curl et al, 2018). Those defined as being forced to own a car are those who may find themselves in circumstances with low transport accessibility and low income, which is intensified by the need to economically participate in society for financial gain (Mattioli, 2014; Taylor et al., 2009; Currie and Delbosc, 2009; Currie and Senbergs, 2007). This paper examines the existing gap between the necessity of transport and the provision of reliable public transport in rural Ireland, which is frequently attributed as a major determinant of FCO in the literature. While it is acknowledged that forced car ownership similarly exists in urban areas under the same or similar conditions, this paper focuses exclusively on the incidence of FCO in rural areas due to potentially higher levels of car dependency. The main objective of this paper is to identify hotspots or areas that are susceptible to increasing rates of FCO and transport disadvantage. Using the information gained from identifying the locations of these hotspots, transport planners and policymakers can tailor interventions to improve sustainable mobility in these areas and address equity concerns.

1. INTRODUCTION

Three out of four journeys outside Dublin were made by car in 2016 (Department of Transport, Tourism and Sport (DTTAS), 2017) and levels of car dependency tend to be even more exacerbated when there is a need to travel over longer distances within rural areas (Currie, and Senbergs, 2007). However, potential ways of promoting sustainable 'car-shedding'[1] behaviour (Carroll, et al., 2017) in these areas must equally consider the pressing issue of public transport inaccessibility. This paper highlights instances of possible FCO in rural areas of Ireland and explores the potential root cause of this, namely transport disadvantage.

In the UK, research conducted by Jones (1987) and Banister (1994) suggests that the ownership of a private car is not entirely a decision that is made willingly, but in some cases it is an indispensable asset and in this way 'forced' upon socially disadvantaged groups and those living in relatively remote areas where no practical alternative to the private car exists. This paper presents an examination of instances where notwithstanding issues linked to low incomes and financial problems, car ownership may be a necessity for those living in rural areas as a result of transport inequity and poor accessibility to transport services. There are many reasons, why people opt to live in rural locations, however academic literature has long illustrated that 'low income households trade off lower housing costs for transport costs by deciding to locate on the urban fringe' (Faulkner, 1978).

The research presented in this paper examines the results of a study that identifies potential concentrations of FCO in rural part of Ireland, with the use of GIS and measures of transport disadvantage risk. The hotspots referred to are defined as concentrations of homogeneous conditions of poor transport accessibility and income levels that signify the existence of forced car owners (Curl, Clark and Kearns, 2018; Rau and Vega, 2012; Currie and Senbergs, 2009). This work identifies specific Electoral Divisions (ED) that have or are experiencing high levels of disadvantage and accessibility issues to important social services and amenities, such as access to schools, health care, banks and post offices as well as employment centres in rural Ireland. The findings reported in this paper provide weight to the argument that more resources, infrastructure provision and policy action are needed to adequately reduce the dependency on the private car in rural areas by providing more practical alternatives to the car and funding to support people who are often geographically and socially disadvantaged. To further examine this issue and to determine the effectiveness of rural transport in Ireland, the relationship between job accessibility and levels transport disadvantage risk is also explored by analysing journey times by car and bus services in scenarios with and without the existence of the rural transport programme (RTP). This analysis determines the changes in transport disadvantage risk values and the variance in journey times for commuting purposes since the introduction of this programme. Even though a large proportion of government investment is centred on improving transport infrastructure in the five regional cities of Ireland, i.e. Dublin, Cork, Limerick, Galway and Waterford, the analysis presented in this paper highlights the need to also seriously consider an expansion of the successful local, community-based public transport schemes such as Local Link.

This paper is organised in five sections, the first section has introduced the context for the research explored and the work that will be presented; Section 2 provides a review of relevant literature on car

[1] Car-shedding is defined as the incidence of a reduction in private car trips, by means of encouraging the reassessment of the need to utilise a private car for certain trip purposes.

dependency, forced car ownership, the Rural Transport Programme (RTP) and the how it relates to transport disadvantage. Section 3 delineates the methodology and criteria employed in the analysis using GIS tools, spatial datasets (NaPTAN) and Census data. Section 4 then presents the results of the spatial and statistical analyses conducted, and finally, the paper concludes with a further discussion of the results and policy implications generated from the findings.

2. LITERATURE REVIEW

Car dependency as a result of transport disadvantage and the deprivation or inaccessibility to alternatives to the private car in rural areas has been examined in several empirical studies in countries such as Australia, UK, Germany, and China (Zhao and Bai, 2019; Mattioli, 2017; Lucas, 2012; Delbosc and Currie, 2012), yet there is scope for more. For example, Lucas, et al. (2012) state that transport poverty is under-explored and a poorly articulated issue, even within developed countries. Inaccessibility to transport due to the lack of available public transport services is a causal factor for social exclusion (Lucas, et al., 2012), which is often exacerbated in rural areas with dispersed patterns of residential development. However, a key issue is not necessarily the availability of the public transport services themselves but rather the societal effect of limiting access to various social, employment, health and educational opportunities, which are typically in greater supply in dense urban areas. Thus, this places those whom are able bodied and possess the financial means to own and maintain a private vehicle with an automatic advantage in accessing essential amenities and services in rural areas. Therefore, the aim of this paper is to identify the effectiveness and requirement for reliable, cost effective and efficient public transport services in rural parts of Ireland as a means of reversing the reliance on and dominance of private car use. This not only facilitates rural living but enables rural communities to grow in a sustainable and futureproof manner.

Car dependence is linked to low-density dispersed residential characteristics akin rural areas (Walks, 2018; Simma and Axhausen, 2001; Newman and Kenworhy, 1999). Mattioli 2014 and Walks (2018) state that there are two main strands of transport disadvantage that are connected to car dependence; the first being related to the disadvantage of not owning a car in an area with limited public transport coverage, and the other in reference to low income households experiencing financial stress as a result of owning and maintaining a car (Delbosc and Currie, 2012; Currie and Sendbergs, 2007). The former strand will be examined further in this paper, as there are more opportunities available to address this form of transport disadvantage as a result of integrating land use and transportation planning and by offering feeder community-based public transport services that link lower density areas to the mainstream public transport network. Chevaillier, et al. (2018) determine that car-related economic stress (CRES) has limiting effects on individuals and households living in outer-suburban areas that are designed with the car in mind, that can result in residential relocation and travel for social activities being limited to local areas. These are in effect coping mechanisms to for the financial stress that owning a private car can have on a low-income household.

Perceived accessibility of particular modes has also been shown to influence the mode choice process and positive relationships may increase the likelihood of potential modal shifts occurring (Scheepers, et al., 2016). In this study the objective characteristics of the study area were acquired and analysed using ArcGIS, which is akin to other studies such as Preston and Rajé (2007) and Mackett, et al. (2008) where GIS mapping tools have been employed to analyse accessibility planning processes and the social inclusiveness of transport policy. Moreover, since 2011 the Irish Government has increasingly supported the use of GIS systems to explore the needs of people affected by transport disadvantaged in rural areas (DTTaS, 2011). Nevertheless, to the best of knowledge of the authors, no GIS-based studies addressing FCO in Ireland have been published to date.

Rau and Vega (2012) determine that there are more cases of disadvantage emerging in rural Ireland that are being triggered by unmet transport needs, in addition to other societal and political factors such as land use and associated residential issues linked to an unstable housing market. Central to this issue is the historic separation and disintegration of land use and transport policy in Ireland, which, as a result has exacerbated the incidence of one-off rural housing developments that are often disconnected from the mainstream public transport network. Over time this leads to potential incidences of transport poverty or poverty of access in rural areas (Farrington, et al., 2004). In Scotland, Velaga, et al. (2012) demarcate that reasons for low patronage on rural public transport services are due the lack of available services, and the services that are available are infrequent and inefficient leading to delays and overcrowding. A lack of joined up thinking and low levels of collaboration between urban and transportation planning professionals in planning for the transport requirements of new developments is often highlighted as primary cause for rural transport disadvantage. The spatial separation of activities such as employment, education, health and recreational, and the resulting derived need to travel to access these services is ultimately what exacerbates this issue. Njenga and Davis (2003) state that one of the most effective methods of addressing this is by integrating transport into land use planning processes. Lucas, et al. (2012) conclude that mainstream public transport services are one of the solutions to transport related exclusion however, community-based services, which are often more flexible and informal are effective in complementing conventional services.

Table 1 displays a review of the findings of some of the literature concerning transport disadvantage, car dependency and FCO.

Table 1: Review of the literature

Author(s)	Findings
Zhao and Bai (2019)	Distance to basic public services (e.g. hospitals, schools) was found to be related to 'forced' car ownership of low-income households in rural China.
Mattioli (2017)	While Germany presents a higher incidence of FCO in rural and suburban areas (following the spatial trends of other continental countries like Australia), findings from the UK reveal FCO is also similarly present in urban areas due to the poor quality and high prices of public transport services.
Walks (2018)	Automobile dependence was found to be positively associated with the burden of automobile loan levels among low-income households in seven of the largest Canadian metropolitan areas.
Chevallier et al. (2018)	Low-income households in car dependent areas on the outskirts of Paris and Dijon (France) tend to reduce their trips to become less vulnerable to car-related economic stress (CRES) and avoid residential relocation
Curl, et al. (2018)	At the individual and aggregate levels, the relationship between financial difficulties and car ownership has weakened, indicating a more complex and dynamic relationship between financial circumstances and car ownership than conventional wisdom would indicate.
Lucas, et al. (2016)	Transport subsidies such as concessionary fares for targeted populations, such as older people and disabled do little to address the widespread issues transport poverty.
Rock et al. (2016)	Results from the study survey pointed to considerable problems in suburban areas of Dublin that are disproportionately and unfairly impacting on particular population groups, including those that are not traditionally seen as disadvantaged.
Currie and Delbosc (2013)	The vulnerability of low-income households, living in the urban fringe is a major policy concern with regard to their inability to afford potential increases in fuel prices.
Ahern and Hine (2012)	Focus group discussions demonstrated that men find it more difficult to move from car use and car ownership to public transport and community transport use. Older women, while still experiencing difficulties in travelling, seemed to adjust to life without a car more easily than older men who were more likely to have driven themselves.
Delbosc and Currie (2012)	Voluntary and involuntary one-car households were more likely to be low-income and contain unemployed people than households running 2+ cars. Involuntary one-car households were still heavily reliant on car travel which resulted in greater problems with access, lower participation and social support and lower well-being.
Lucas (2012)	Transport-related exclusion can be identified as a universal and operational concept, although it is differentially experienced within and between nations and by different social groups in different social and geographical contexts.
Velaga et al. (2012)	Challenges to providing accessibility and connectivity in rural communities include: understanding basic technological requirements in rural areas, considering trust and reliability issues with the crowd-sourced information provided by passengers during their journeys, and understanding an anticipating passenger behaviour change in response to technological innovations.
Currie et al. (2009)	FCO households make less trips (12.9%), travel shorter distances (-7%) and slightly shorter time (-6.8%) than average 2+ car households in Outer Melbourne. This propensity to travel less might be illustrative of financial pressures and a desire to reduce the costs of travel compared to other income groups in similar circumstances.
Preston and Rajé (2007)	Accessibility planning should not be limited to analysing social exclusion. In particular, charging mechanisms targeted should also be examined as they provide funding streams to promote personalised travel marketing and transport services that may more effectively deal with exclusion.
Currie and Senbergs (2007)	Results have shown that low-income households with high car ownership make 12.9% fewer trips, travel 7% shorter distances and have 6.8% shorter travel times than the average of 2+ car households in outer Melbourne (Australia).
Njenga and Davis (2003)	Transport is necessary in achieving a wide range of objectives including economic growth, personal welfare, governance and empowerment as well as security. However, the effectiveness of the sector in delivering these objectives is limited by an absence of policy links to other sectors to which it plays an important role.

2.1 Rural Ireland and The Rural Transport Programme

In recent decades rural areas of Ireland have undergone a relatively dramatic demographic shift, which has led to many young and educated people either moving to urban areas in Ireland in search of higher paid employment opportunities in regional cities such as Dublin, Cork, Galway, Limerick and Waterford, or have chosen to emigrate from Ireland. As a consequence of this, many rural areas have experienced rapid depopulation, with the average age profile in such areas also increasing at a similar rate. The extent of this shift in population from rural to urban areas in Ireland is clearly illustrated in Figure 1 and 2. Figure 1 and Figure 2 (a) indicate that counties on the West coast of Ireland such as Donegal, Sligo, Mayo and Roscommon have experienced the highest decreases in population, while cities in the East and South coasts experienced the highest increases, namely in Dublin, Waterford, Cork, with exceptions in Galway and Limerick. Figure 2 (b) similarly reveals that these same counties in rural Ireland that are experiencing incidences of depopulation, also have the highest average age profile of 39.8 to 42.5 years nationally.

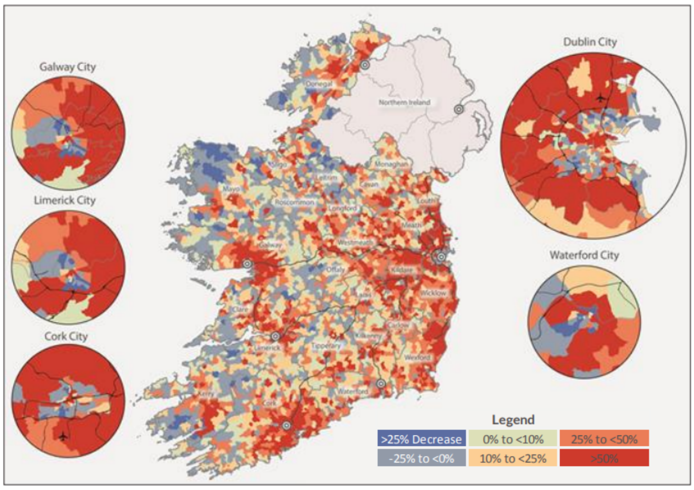

Figure 1: Percentage population change by electoral division, 1991 to 2016 (Department of Housing, Planning and Local Government, 2016)

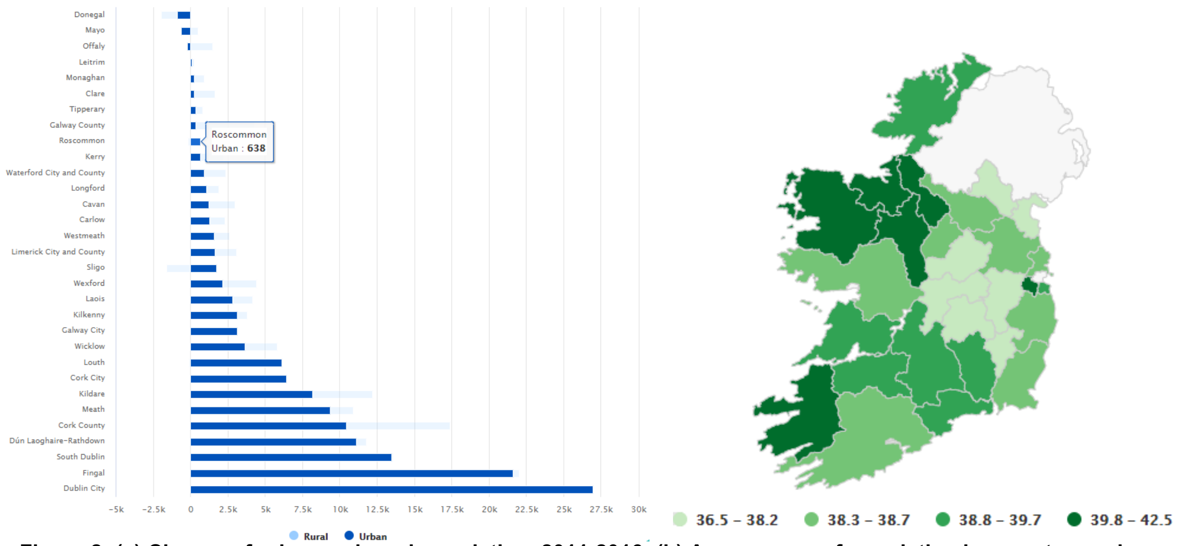

Figure 2: (a) Change of urban and rural population, 2011-2016; (b) Average age of population by county, rural area, 2016 (Central Statistics Office, 2016)

As a result of this phenomenon, which is not exclusive to Ireland, public services and amenities such as public transport services, health care and banking facilities have suffered from a loss in business and this has ultimately led to the closure and relocation of such services due to inadequate levels demand to financially sustain the services. However, the Rural Transport Programme (RTP) is a true exception to this trend, as it was introduced to address the mobility needs of the rural population in areas experiencing a lack or in some case a total absence of public transport services.

The Rural Transport Programme (RTP) or Local Link, which launched in 2007, was formed on the foundations built by the Rural Transport Initiative of 2002, to meet the transport demand of those experiencing rural social exclusion and isolation or cases of ‘market failure’ (NTA, 2013). The programme has grown to become a major lifeline for people in rural areas of Ireland, who previously experienced difficulties in accessing service like hospitals, banks, post offices, retail centres and areas of employment etc. To demonstrate this, there were 1.76 million RTP passengers recorded 2015 alone (DTTAS, 2017). Since its restructuring in 2012-13, the National Transport Authority (NTA) established 17 Transportation Coordination Units (TCUs), that reduced a number of previous Rural Transport Groups, of which there were 35. These TCUs are responsible for identifying the demand for local transport services to the NTA (NTA, 2013). This restructuring was conducted for a number of reasons, of which the principal ones were: a lack of data on the changes made to social exclusion as a result of the Programme, the organisational structure being cost-ineffective and could be improved by addressing certain inefficiencies such as high administration costs in comparison to other state funded programmes, and various issues regarding the structuring of fares and the branding or marketing of the programme nationwide (NTA, 2013). However, as confessed by a former Minister of State for Public and Commuter Services, Alan Kelly, ‘not every area of the country is covered by an RTP company despite our best efforts’ (NTA, 2013). In rural Ireland, McDonagh (2006) identified that there are still many areas with poor access to public transport services that only operate on one day per week from a ‘hinterland catchment area’ to a market town and suggests that there must be a multi-faceted solution that must be tailored to the needs of each specific area, with local community support. This paper presents a method can be applied to such as solution by initially detecting the worse hits areas of transport disadvantage risk and inaccessibility.

Thus, this paper seeks to offer a method of identifying areas of the country that are currently not being serviced by the RTP and that are exhibiting signs of transport disadvantage risk and deprivation. It is understood by the authors that research highlighting hotspots of FCO in Ireland has not been conducted to date, therefore, this paper offers a novel approach that could aid transport planners in identifying areas in need of service provision under the RTP and provide an evidence base for strategic investment in public transport.

3. METHODOLOGY

This methodology aims to build on previous work conducted in this area (McGoldrick and Caulfield, 2015; Preston and Rajé, 2007; McDonagh, 2006), by adding an innovative tool to complement the evaluation of areas in most in need of public transport. This methodology utilises a variety of GIS analyses to enable a more objective verification of transport needs. In that sense, a fourfold analysis was developed, which is presented in the following section.

The research presented in this paper was conducted as part of a fourfold methodology, which is presented in Figure 3. Each part of this methodology will then be delineated in the subsequent sections of this paper:

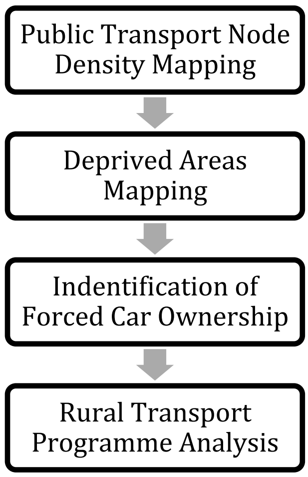

Figure 3: Methodology Flowchart

3.1 Public Transport Node Density mapping

Large gaps have been consistently reported on the availability and accuracy of GTFS[2] and other transport-related data covering rural and peri-urban areas globally (Benevenuto and Caulfield, 2019; Oloo, 2018; Evans et al., 2018; and Starkey et al., 2013). In Ireland, despite recent efforts of enhancing these geospatial databases (NaPTAN, 2017), the level of services of public transport in rural areas is still not fully captured by the existing databases (DTTaS, 2011). Thus, this section aims to propose an alternative model to estimate the level of public transport availability in rural and remote rural areas in Ireland.

The model that is proposed applies a Kernel Density (KD) function to estimate the availability of the National Public Transport Access Nodes (NaPTAN, 2017). In total there are 19,630 nodes including bus stops, rail stations, taxi ranks, and ferry ports, which were used in this research. It is important to mention that the transport nodes introduced by the Rural Transport Programme were not included in this dataset

[2] GTFS or General Transit Feed Specification is a common format for public transport data that combines spatial and tabular datasets including routes, stops and timetables.

at this stage. Rather the focus for this step was to examine the existing level of mainstream public transport.

This approach allows converting a point-based dataset into an area-based measure that can be aggregated at the ED level to allow further comparisons with other socio-economic indicators (e.g. HP deprivation index). Moreover, this method (represented in Figure 4) also considers the mutual influence of nodes placed at neighbouring EDs, minimising thus the modifiable areal unit problem (MAUP)[3] (Openshaw, 1984).

KD maps have long been applied in similar studies to estimate the decreasing level of influence exerted from a particular point of interest in its surrounding areas (Benevenuto and Caulfield, 2020; Polzin et al., 2014; Guagliardo, 2004). The KD function that applied to this research consists of a continuously gradual decay function within a threshold distance and with no effect beyond, as presented in Equation 1. This formula draws upon the quartic kernel function proposed by Silverman (1986) and it is automatically utilised when KD maps are generated by means of ArcGIS 10.5.

$$Zj = \begin{cases} \dfrac{1}{(dist_{max})^2} \displaystyle\sum_{i=1}^{n} \left[\dfrac{3}{\pi} \cdot \left(1 - \left(\dfrac{dist_i}{dist_{max}} \right)^2 \right)^2 \right] & \text{, if } dist_i < dist_{max} \\ 0 & \text{, otherwise} \end{cases}$$

Equation 1

Where:

Z_j is the influence score generated by the transport nodes around grid cell j

n is the number of transport nodes within the threshold distance from grid cell j (i.e. only if $dist_i < dist_{max}$)

$dist_{max}$ is the threshold distance (also called as search radius) that is further discussed later

$dist_i$ is the distance between the grid cell j and the transport node i.

The KD analysis generates a raster grid in which every cell receives a value representing the density of transport nodes considering a given search radius of 10 km and a distance-decay effect calculated by the equation specified above. The average distance travelled to work in Ireland based upon the census is 14 km and this informed the 10 km distance. The authors do note that this does not take into account of the possibility of “park and ride” or “kiss and ride” possibilities, however, the data utilised in this study was not conducive to multi-mode trips. The Irish census data only takes into account the main mode of transport used and for the longest distance. This is a limitation of the work and when interpreting the results this should be considered. The 10km distance is examined further in the results section in Table

[3] MAUP is a source of statistical bias that refers to the fact that the observed values may vary depending on how the data is aggregated into spatial boundaries (Openshaw, 1984).

3, where a sensitivity analysis is conducted examining 5km and 15km distances compared to the model fit.

This search radius is needed to determine if a particular demand is covered (Radke and Mu, 2000) and even if not specified, geoprocessing tools from platforms such as ArcGIS apply specific algorithms to determine a default search radius either way (ESRI, 2019). Moreover, references from the transportation literature based upon Park & Ride surveys undertaken in Europe and the US point out that the vast majority of trips from home to the closest transport node are shorter than 10km (Tennøy et al., 2020; Kompil et al., 2019 Stieffenhofer et al., 2016; Turnbull et al., 2004). Therefore, the threshold distance of 10km, that represents 15 minutes driving at 40km/h, is proposed as a reasonable search radius taking into account i) the spatial distribution of public transport nodes, ii) the average distance to work in Ireland and iii) references from the literature. Finally, the average density of cells intersecting each of the 3,409 EDs was then given as a new attribute in each ED.

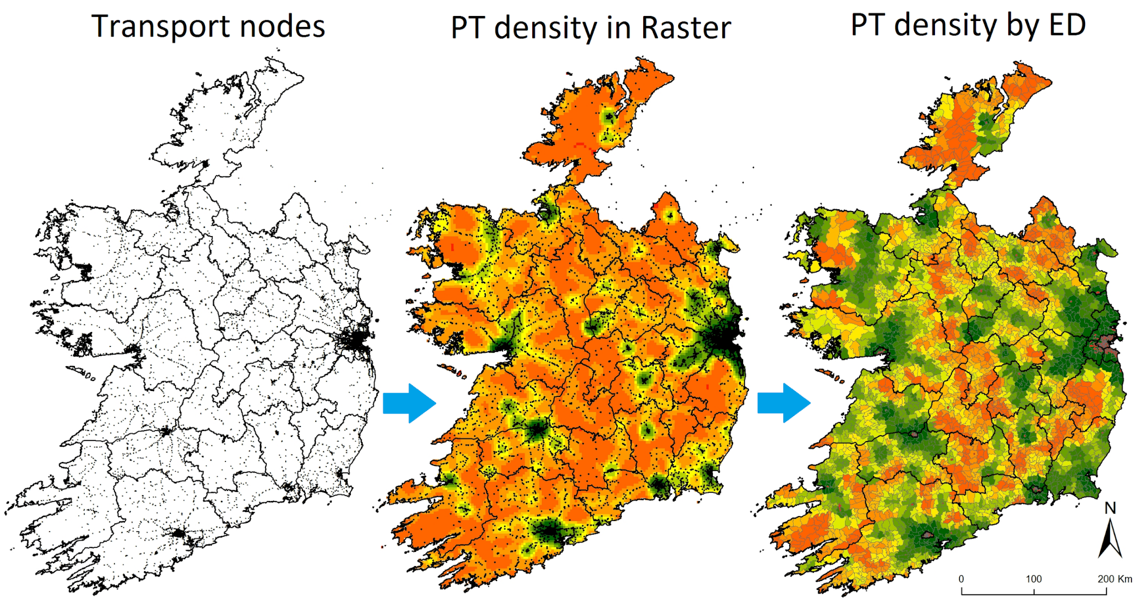

Figure 4: Access to Public Transport calculation

The indicator of public transport density by ED is thus applied as a proxy for transport disadvantage risk at a local level. In that sense, a region with a lower density of public transport nodes can be considered as more at risk to transport disadvantage. It is important to remark that this proxy has been tailored to the Irish context by applying a model that is compatible with the level of spatial data that is currently available and is able to capture the socioeconomic and demographic characteristics described earlier. Nonetheless, other accessibility indicators (e.g. cumulative opportunities, logsum benefit, two-step floating catchment area, etc) may be also appropriate to better proxy transport disadvantage in other contexts where further spatially disaggregated data is consistently available.

Finally, in order to further evaluate the presence of clustering patterns of ED’s at transport disadvantage risk, a ‘Hot Spot Analysis’ (Getis and Ord, 2010) was then undertaken by means of ArcGIS. This analysis applies the Gi*-statistics methods (Ord and Getis, 1995) to identify local "pockets" where spatial autocorrelations are more likely to occur. In other words, these hotspots highlight areas with high concentration of homogeneous conditions of poor transport accessibility.

3.2 Deprived areas mapping

For the purpose of this research, the deprivation values from the Pobal HP index (2012) were applied to each ED in a shapefile extracted from the CSO database (2017). The HP Index is widely recognised as an accurate proxy for deprivation in Ireland, which measures the relative affluence and/or disadvantage of a particular area (Pobal, 2017). This measure of deprivation varies from a value of -35 (most disadvantaged) to +35 (most affluent) and it is based on a number of factors including age dependency rate, level of education number of persons per room, unemployment rate, number of lone parents, and professional classes (Pobal, 2012). Similar to the previous indicator, a hotspot analysis was also carried out to identify clustering patterns of deprived ED's by means of ArcGIS. Following the categorisation proposed by Haase and Pratschke (2017), all areas below the threshold of -10 in the HP index were considered as deprived areas.

Finally, statistical correlations between transport disadvantage risk and deprivation were performed through (i) a Spearman's correlation analysis, and (ii) linear regression between these two variables with the aid of SPSS software. Since several hot and cold spots of Transport Disadvantage and HP Deprivation were found at a higher level of aggregation, the final evaluation of correlation between these two variables was conducted at county level. Moreover, as EDs from the main regional cities (e.g. Cork, Limerick, and Galway), and from the whole county of Dublin presented extremely low levels of transport disadvantage, due to the high density of public transport in urban centres, they had to be excluded following a process of outlier removal.

3.3 Forced car ownership

In addition to the previous layers, another map was then plotted in order to assess potential of FCO. The datasets from the two latest censuses (2011 and 2016) have been used to evaluate the changes in potential FCO over the past years. As explored in Section 1, similar empirical studies have reported that forced car ownership often emerges in contexts of high social deprivation combined with high public transport disadvantage (Curl et al., 2018; Mattioli, 2017; Currie et al., 2009). Thus, in order to be considered as being potentially affected by FCO, the Electoral Districts were selected based on three simultaneous conditions that are described below:

1. <u>High social deprivation</u>: As already described in the previous item, socially disadvantage areas can be proxied by a HP Deprivation index. According to Haase and Pratschke (2017) areas with an absolute HP index score below -10 can be considered as socially disadvantaged.

2. Transport Disadvantage: Based on the transport disadvantage risk indicator described in section 3.1, areas with low access to public transport have been selected. Any ED with less than at least one transport node in its average public transport density was considered to be in transport disadvantaged.
3. High share of single car ownership: Finally, the third symptom considered that may indicate potential FCO is the high share of single car ownership. Even though the Irish Census also includes indicators accounting for multiple car ownership (2, 3, 4 or more), it is reasonable to assume that the most socially deprived households would not be able to afford more than one car even if experiencing FCO. Therefore, the intersection of high shares of single car ownership, social deprivation, and transport disadvantage may indicate where FCO is more likely to occur at a local level. As the average of single car ownership of the census of 2011 and 2016 were 37% and 38% (CSO, 2011; CSO 2016), respectively, the minimum threshold considered in this criterium was 40% (i.e. greater than the national average).

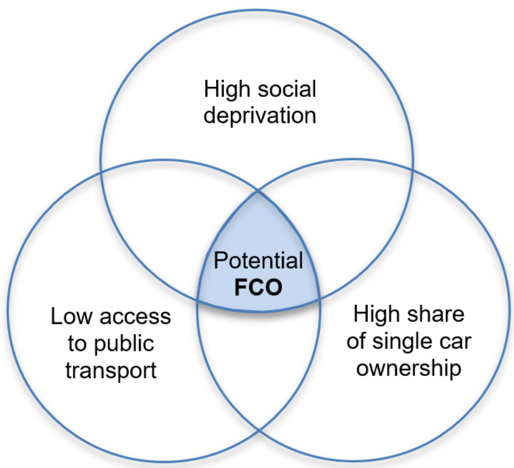

Figure 5: Forced car ownership hypothesis

3.4 Rural Transport Programme Analysis

In order to further investigate the impacts of the RTP on the existing levels of access to the public transport network, the stops/stations of fixed routes serviced by this programme were incorporated in the transport disadvantaged risk analysis. The RTP stop nodes were sourced from the National Transport Authority of Ireland (NTA) and then mapped in ArcGIS in order to conduct an analysis of the distribution of these stops in the road network and to determine the accessibility of these stops by means of a buffer/ catchment analysis.

In this way, spatial and statistical comparisons could then be conducted by contrasting the transport disadvantage risk indicator with and without the RTP. To do so, the same methodology applied to estimate transport disadvantage risk described in Section 3.1 was applied now also considering the public transport nodes introduced by the RTP. The comparison of the percentage increase in availability of public transport (i.e. proxy for transport disadvantage risk) is then provided in visual and statistical terms.

Moreover, due to the concentration of high levels of transport disadvantage risk in West region of Ireland, further statistical analysis was conducted to explore the accessibility of jobs in this region. This analysis examined data generated from the National Transport Authority (NTA) Regional Transport Modelling System, specifically average journey time data for employment/ commuting trips in the West Regional Model, which is a four-stage transport model. In this model trip times from and to each Electoral District (ED) in the country are estimated as a result of computing a generalised cost function, which is composed of the following components:

Table 2 Generalised cost components for car and public transport modes

Car Generalised Cost	Public Transport Generalised Cost
In Vehicle Time (IVT)	Perceived Walk Time (Actual Access + Egress walk time)
Travel Distance	Perceived Initial Waiting Time (Based on Service Headways)
Travel cost: Cents per Minute (per time period and user class) Cents per Kilometre (per trip purpose & user class) Tolls	Boarding Penalties (15mins for Rail, 10mins for other modes) Perceived Fare (divided by Value of Time) Perceived Transit Time (Transit time x IVT factor)
	Perceived Transfer Wait Time Transfer Penalties (min) (Mode-specific)

The ED to ED journey times calculated in this model are disaggregated by trip purpose (commute, education, etc.), time of day (AM peak, Interpeak, PM Peak, and Off Peak) and mode of transport. Journey times by public transport are estimated as result incorporating bus and rail schedules into the model estimation process, which includes the services provided by the RTP. This journey time data was then utilized in conjunction with Census employment data (employment numbers per ED), similarly supplied by the NTA, to determine the number of cumulative employment opportunities accessible in 30 minutes and in 45 minutes by private car and bus transport within and between Electoral Districts (EDs) in the West region of Ireland. Furthermore, when these results were generated, correlation tests were conducted to identify the strength of the statistical between the number of employment opportunities accessible and the transport disadvantage risk measure utilised in Section 3.3. To explore this relationship, employment data (i.e. number of jobs in each ED) from the Census was utilized to determine the total number of jobs accessible from each ED in the west region in 45 and 30 minutes when travelling by car and bus in both the ‘with RTP’ and ‘without RTP’ scenarios for 643 EDs from this region. Finally, these figures were then used to determine the relationship between number of jobs accessible by these modes and the values of transport disadvantage risk for each ED in the west region. Spearman correlation tests were subsequently employed using SPSS software to analyse the statistical relationship between these two variables.

4. RESULTS

The Hot Spot analysis shown in Figure 3 indicates a presence of large clusters of EDs with low HP scores, particularly concentrated in counties in the west and north-west of the country, such as Donegal, Mayo, Roscommon, Leitrim, Cavan. Clusters of affluent areas, which are shown in blue, are primarily found around the three largest cities of Dublin, Cork and Galway, which was expected given that there are greater levels of access to opportunities in these more urbanised areas.

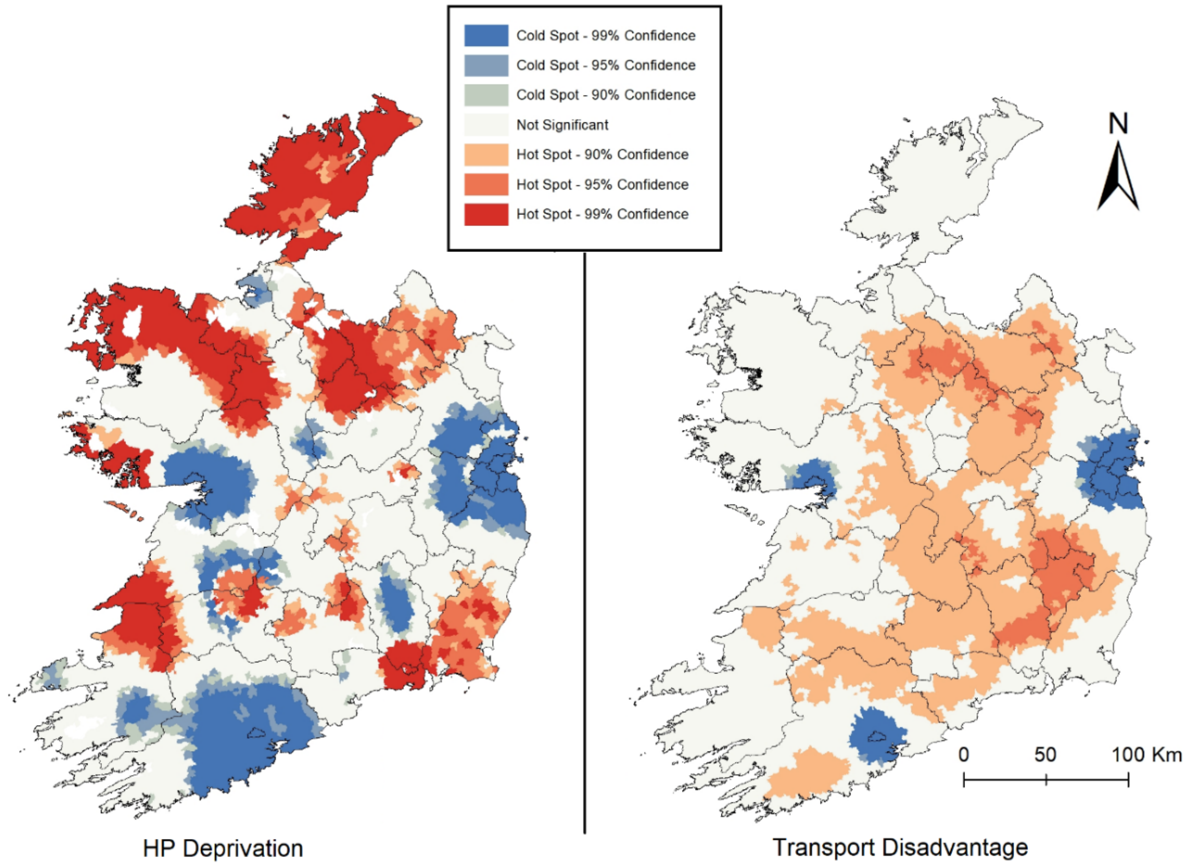

Figure 6: Hotspot analysis of social (left) and transport (right) disadvantage

As previously delineated, areas affected by high social deprivation, public transport disadvantage risk and high shares of single car ownership are potential spots of FCO. Figure 7 presents the changes in potential levels of FCO between 2011 and 2016 in EDs in Ireland. Counties such as Donegal, Mayo, Roscommon and Sligo were found to have higher incidences of EDs with potential FCO levels in this analysis. A higher reduction in potential FCO is particularly noticeable in the south west and mid-west regions, including counties such as Kerry, Cork and Limerick. The findings show that a total of 245 EDs were lifted out of the register of areas with potential FCO in this period, 204 of these EDs were due to improvements in the HP deprivation index, 16 as a result of a decrease in the single-car ownership rate, and 25 for both reasons. This is also in line with changes in the management of the RTP from Pobal to the NTA 2013 (LocalLink, 2019), Ireland's post-recession economic recovery and increases in public transport investment between the 2011 and 2016 Census years, resulting in an increase in public transport patronage and which was concentrated in the Greater Dublin Area and in the regional cities of Cork, Galway and Limerick (DTTAS, 2018).

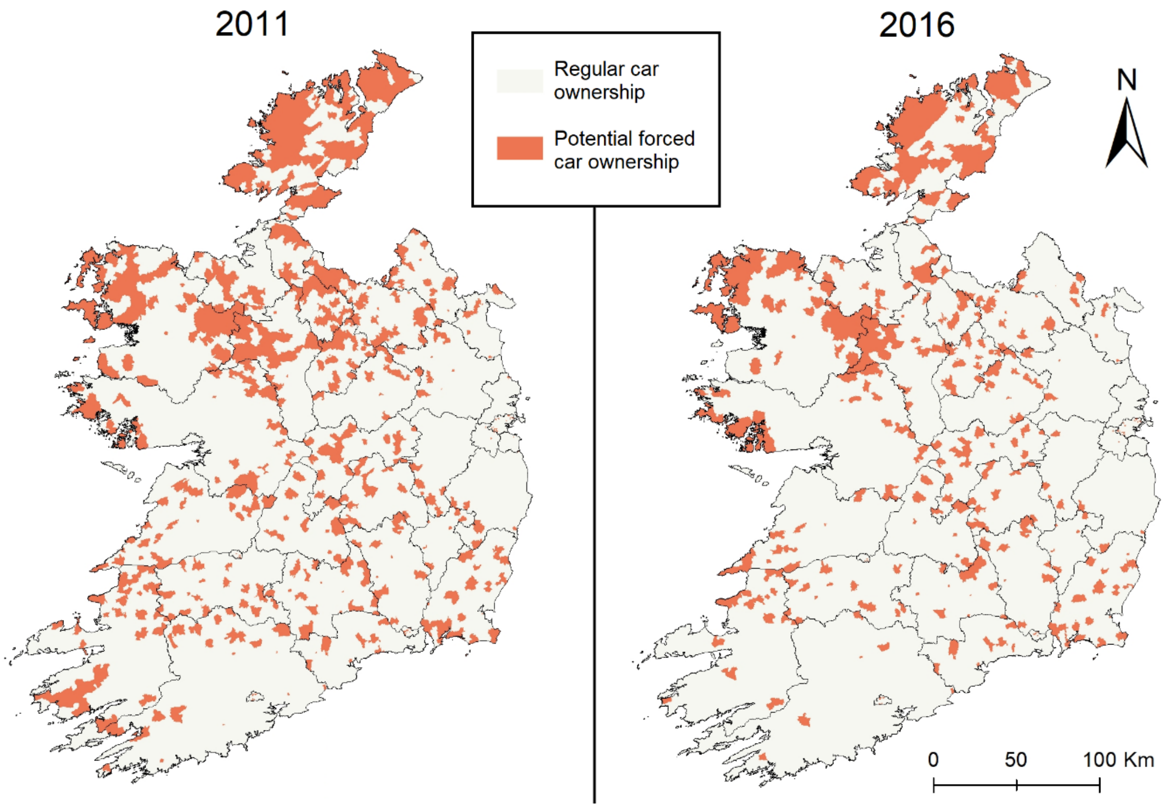

Figure 7: Variations of potential FCO at Electoral District level in Ireland between 2011 and 2016

The Spearman's test presented in Table 3, shows that in 20 out of the 26 counties there is a statistically significant (Sig<0.05) correlation between the transport disadvantage risk and the deprivation indices. A total of 2820 ED's were aggregated at a County level and then analysed. The coefficients estimated from the linear regression vary from +3.6 to +36.5 and the rho-squared values vary from 0.01 to 0.38 depending on the county. These results show a clear trend in how lower levels of transport disadvantage risk are associated with lower levels of deprivation, which are elevated in countries in the west and north-west of Ireland. A sensitivity test was conducted, which examined the transport disadvantage and deprivation index values at both the 5km and 15km search radii. The results, which are presented in Table 3 show that for the 5km and 15km radius, 8 and 14 respectively out of the 26 counties are statistically significant (Sig<0.05). A comparison also shows that at the 10km radius, 14 out of the 16 R-Square values are stronger, indicating a better model fit.

Table 3: Linear regression and Spearman correlation sensitivity test results between transport disadvantage risk and deprivation results (5km, 10km, and 15km search radii)

	5km			10km			15km		
County	X coeff.	R-Square	Spearman's Sig	X coeff.	R-Square	Spearman's Sig	X coeff.	R-Square	Spearman's Sig
Carlow	-10.077*	0.069	0.150	28.147**	0.075	0.029	24.158	0.160	0.361
Cavan	-1.748	0.003	0.095	32.919***	0.218	0.000	24.304**	0.050	0.043
Clare	6.428*	0.023	0.155	16.414***	0.173	0.000	11.982***	0.156	0.000
Cork	4.798***	0.030	0.000	10.084***	0.121	0.000	5.961***	0.102	0.000
Donegal	11.277***	0.077	0.105	16.857***	0.118	0.005	19.299***	0.097	0.004
Galway	10.176***	0.078	0.000	15.128***	0.200	0.000	11.883***	0.167	0.000
Kerry	9.027***	0.078	0.004	7.842**	0.055	0.027	13.100***	0.760	0.004
Kildare	4.758*	0.037	0.099	9.565***	0.216	0.001	10.301***	0.243	0.000
Kilkenny	1.221	0.001	0.768	5.174*	0.028	0.268	5.458*	0.027	0.101
Laois	1.992	0.005	0.481	3.647	0.023	0.044	10.377**	0.068	0.007
Leitrim	13.311	0.033	0.030	36.57**	0.117	0.007	56.228***	0.221	0.006
Limerick	1.871	0.003	0.236	6.25**	0.030	0.042	6.907***	0.084	0.001
Longford	0.538	0.000	0.187	17.023***	0.093	0.007	25.714**	0.081	0.003
Louth	-2.834	0.031	0.856	5.133***	0.100	0.003	5.834	0.055	0.172
Mayo	9.499***	0.093	0.000	14.267***	0.117	0.000	18.967***	0.124	0.000
Meath	9.864***	0.197	0.000	13.642***	0.379	0.000	6.367***	0.130	0.000
Monaghan	5.841	0.022	0.058	24.715***	0.212	0.000	41.884***	0.209	0.000
Offaly	-0.041	0.000	0.671	13.041**	0.106	0.062	22.192***	0.101	0.043
Roscommon	-1.427	0.032	0.502	10.098**	0.068	0.302	15.910***	0.065	0.168
Sligo	16.037***	0.236	0.003	14.481***	0.381	0.000	22.326***	0.402	0.000
Tipperary	-9.657**	0.038	0.074	-1.537	0.000	0.671	4.236	0.002	0.791
Waterford	2.176	0.009	0.300	6.004**	0.069	0.002	5.248**	0.047	0.009
Westmeath	8.226***	0.074	0.008	15.541***	0.188	0.000	20.377***	0.203	0.000
Wexford	-1.052*	0.003	0.139	4.495**	0.049	0.187	2.786	0.015	0.975
Wicklow	4.516	0.021	0.221	14.684***	0.156	0.008	14.185***	0.233	0.000

* Significant at 90% confidence, ** Significant at 95% confidence, *** Significant at 99% confidence

As mentioned above, notwithstanding the success of the RTP, it was found that indeed not every rural area of the country is covered by their services. As a result of the analysis conducted with GIS, it was possible to substantiate that 109 rural settlements (48,375 people) were located in areas not covered by the RTP, and in 100 out of these 109 settlements there were no transport nodes available within a 10 km radius. The calculated average of the deprivation index at ED level for these settlements was found to be -8.1, with 54 out of these 109 settlements considered as deprived or very deprived (i.e. less than -10) on the HP index. Since the settlement pattern of the rural population is dispersed and only a minority of live in rural settlements, it is accepted that these numbers are only a measurable part of a much larger problem.

As a means of conducting a comparison of the coverage of public transport services in Ireland with and without the inclusion of the Rural Transport Programme; levels of transport disadvantage risk were visually represented in the maps presented in Figure 6, based on the density of transport nodes. The composite indicator of transport disadvantage risk utilised here was determined by the same criterion used to detect potential FCO spots in Figure 6. By visually representing this indicator of transport disadvantage risk, it was possible to determine the impact on possible incidences of forced car ownership with and without the existence of the RTP. Figure 8(a) displays a map of transport disadvantage risk based on the density of transport nodes from the NaPTAN network without the existence of the RTP. This map shows that there are large areas of the country, particularly in the north-west, west and south-west that are experiencing high levels of transport disadvantage risk indicated by the number of EDs displayed in blue.

Figure 8(b) shows a marginal improvement in transport disadvantage risk levels in certain areas as a result of the inclusion of the RTP services. This was particularly evident in EDs in the west of the country, where areas that once exhibited poor transport accessibility without the RTP, were found to have increased levels of accessibility (i.e. displayed in red and orange) with the provision of the RTP nodes serviced by Local Link services. The results also showed that EDs facing potential FCO in 2011 had their transport disadvantage risk indicator improved by 12% on average, while other EDs had only an 8% improvement. This suggests that the introduction of community-based rural transport services can enable an increase in public transport coverage, which is vital for households in isolated areas of the country, who do not have access to a private vehicle. However, this analysis also highlights that many EDs in rural Ireland continue to experience high levels of transport disadvantage risk even when considering the provision of the RTP, thus, providing a justification for the expansion of this community-based scheme to service disadvantaged areas and households in remote areas of rural Ireland. For the sake of clarity the improvements in transport disadvantage after the implementation of the RTP are also shown in terms of percentage change in Figure 9.

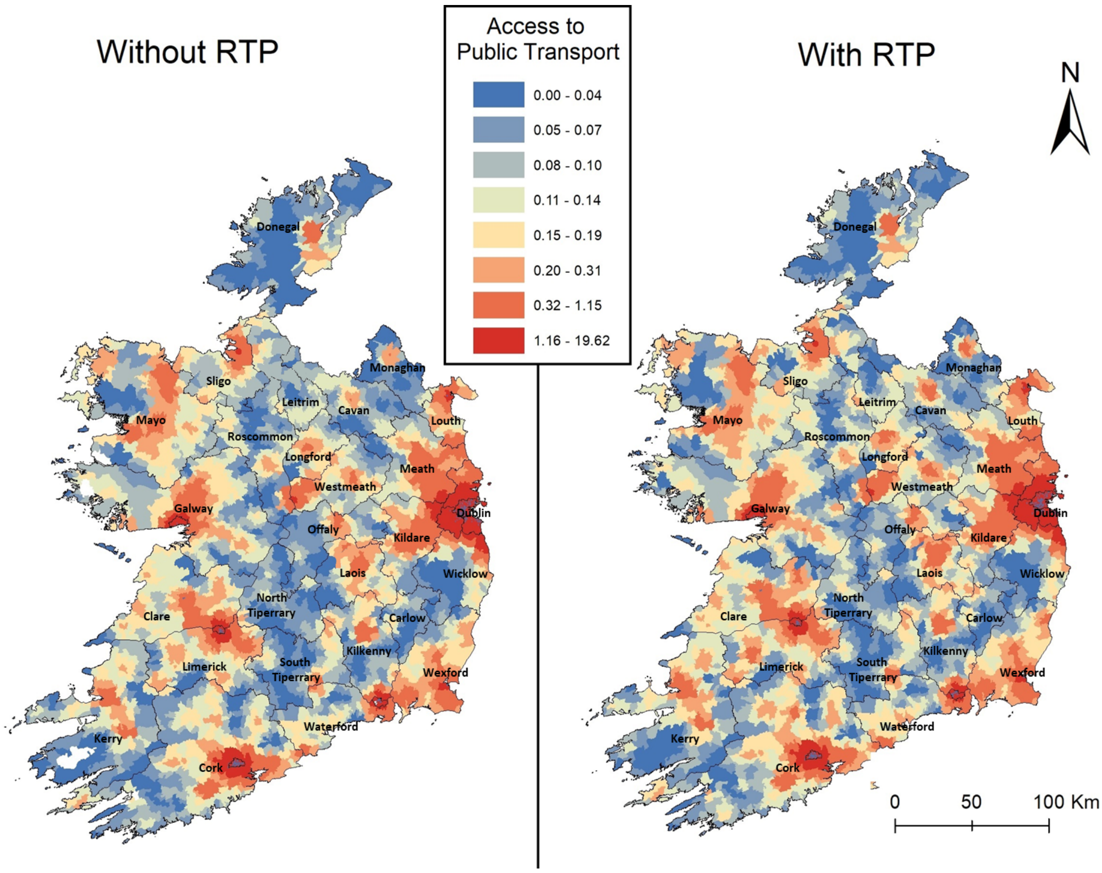

Figure 8:(a) Transport disadvantage risk without the RTP; (b) Transport disadvantage risk with RTP

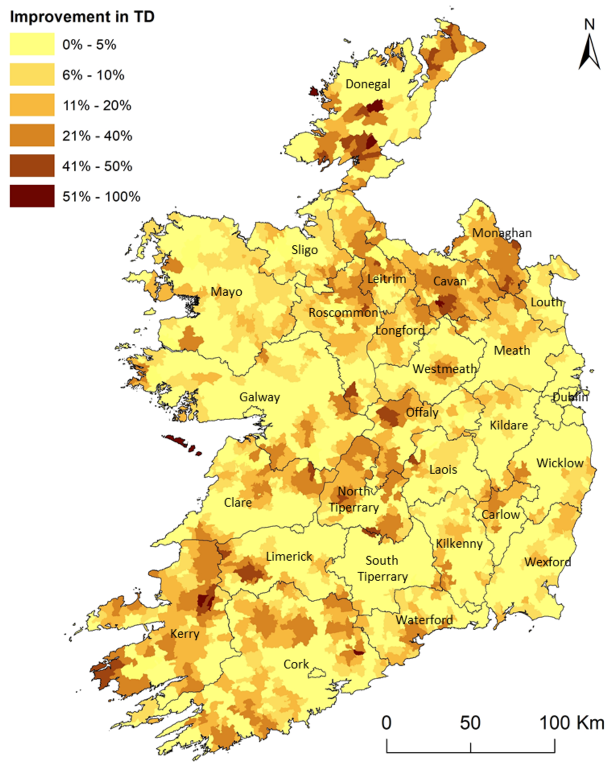

Figure 9: Percentage improvement in transport disadvantage risk after the implementation of RTP

To further examine the effect that the RTP has had on enhancing transport accessibility in rural Ireland, statistical analysis was conducted to investigate the relationship between commuting journey times and variances in transport disadvantage risk levels, in scenarios with and without the existence of the RTP. The study area for this analysis was the West region of Ireland, as the majority of counties in this region showed strong and statistically significant regression coefficients, thus showing a strong correlation between the transport disadvantage risk and deprivation variables in Table 3. As set out in the methodology in Section 3.4, journey times between EDs in the west regional model of the NTA regional modelling system were utilised in conjunction with employment figures taken from the Census of population to determine the number of jobs accessible in 30 and 45 minutes by public transport and private car. This data was then used to analyse the relationship between jobs accessible and transport disadvantage risk values explored in Figure 6 by means of a Spearman Correlation test, shown in Table 4.

Furthermore, the results of the correlation tests, which are presented in Table 4, showed that there is a statistically significant relationship between the number of jobs accessible and the transport disadvantage risk measure, in the west region of Ireland, consisting of 743 ED's. This is supported by the strong to moderate positive correlation coefficients and p-values being statistically significant at a 0.01 level, which are displayed in all cases in Table 4, both for car and bus journeys without and with the inclusion of RTP. In other words, a positive correlation was found between the number of jobs accessible and the transport disadvantage risk values in the west region, which suggests that these variables influence each other. The correlation coefficients show that there was a statistically stronger correlation for jobs accessible by car in 30 mins, while for bus the correlation coefficients were higher for number of jobs accessible 45 mins. The results produced from this analysis ultimately provides evidence to show that the number of jobs accessible in two different time bands is related to the degree of transport disadvantage risk experienced in these electoral divisions. Overall, these results showed that EDs with high a number of jobs accessible also had lower transport disadvantage risk score, suggesting that the number of cumulative opportunities accessible is a key indicator in identifying disadvantage and in this way, these measures are inextricably linked and influence each other.

Table 4: Spearman Correlation Test Results

			Spearman Correlation Coefficient	P-value Sig. (2-tailed)
30 mins	Car	Without RTP	0.503**	0.000
		With RTP	0.498**	0.000
	Bus	Without RTP	0.374**	0.000
		With RTP	0.380**	0.000
45 mins	Car	Without RTP	0.342**	0.000
		With RTP	0.345**	0.000
	Bus	Without RTP	0.396**	0.000
		With RTP	0.403**	0.000

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

5. DISCUSSION AND CONCLUSIONS

The research presented in this paper provides a useful method to identify hotspots of FCO and potential areas of transport disadvantage. The characteristics found in rural Ireland are similar to those in many other countries with large areas of rural populations. Therefore, the findings presented in this paper maybe common to other similar areas across the world. One of the key aspects of the paper is the identification of hotspots as a method to tailor sustainable mobility solutions to ease any future FCO or transport disadvantage. This identification of these hotspots is one of the main contributions of this paper.

Community-based and scheduled door-to-door style services will not always be viable for all rural households, thus, this paper supports the view that community-based services are an appropriate alternative to traditional high frequency and high capacity bus and rail services in rural areas. This bespoke type of service caters for the distinctly dispersed, low-density travel requirements and demand existent in such areas. For those whom require tailored transport services due to specific mobility requirements such as disabled and elderly people, school children, young families, etc., community-based services may provide the most cost-effective solution to meet their mobility needs, when designed appropriately.

While this study was focused on rural Ireland, it is acknowledged by the authors that the methodology developed in this paper is not only exclusive to the context of Ireland, thus the same methodology could be applied to rural settings in other countries. Moreover, this methodology is similarly appropriate for analysis in an urban setting, for instance in suburban areas, as such areas also experience transport disadvantage risk and difficulties accessing mainstream public transport services. In this way, the approach conducted in this study can be easily transferable to other countries and urban locations that experience comparable transport accessibility issues.

Even though GIS techniques have been widely applied in the literature to assess transport disadvantage (Shay et al., 2016, Pyrialakou et al., 2016; Blair et al., 2013; Kamruzzaman and Hine, 2012), the majority of studies assessing FCO to date are based on surveys, focus groups, or statistical analysis (Curl et al., 2018; Mattioli, 2017; Currie and Senbergs, 2007). The methodology applied in this study proposes a novel approach to identify geo-spatial patterns where FCO is more likely to emerge based on the spatial intersection of socioeconomic indicators by means of GIS techniques. Although the thresholds applied to these indicators are based on robust statistical references and well-grounded literature, future research is recommended to evaluate how FCO may respond to variations on these criteria in a sensitivity analysis. Likewise, further studies and tailored surveys are also needed to explore demographics factors (e.g. gender, education level, access to driving licenses, age of residents) of households considered to be living under FCO.

While this study has examined the topics of transport disadvantage risk and forced car ownership on an aggregate national level, a recommendation for future research would be to examine the neighbourhood or town specific characteristics on a more disaggregate, microscopic level in rural Ireland as a means of determining the effectiveness of the RTP.

As presented throughout this paper, the majority of areas at transport disadvantaged risk in rural Ireland are also deprived in socio-economic dimensions. As a result, this paper suggests a potential reinforcing cycle between social deprivation and transport disadvantage, which appears to be exemplified by FCO, particularly in remote areas where even programmes like the RTP are not proving to be beneficial to everyone in the community. This study has highlighted the importance of demand responsive transport solutions and vehicle borrowing schemes such as those under the RTP in Ireland as potential solutions for tackling FCO and transport disadvantage. This is due to the fact that there is not sufficient travel demand or political will to provide full mass transit or high capacity public transport solutions for dispersed, low density patterns of settlement as seen many parts of rural Ireland.

Nonetheless, there is a need for further research to greater understand and assess the effectiveness of other potential alternatives for rural Ireland such as car-sharing, carpooling and micro-mobility solutions. These alternatives are not only useful in addressing inaccessibility issues associated with non-car owning households and elderly and disabled people, but similarly they can enhance accessibility to regional transport hubs and other public transport nodes to create a more integrated and sustainable transport network that is open to everyone, consequently enabling the equal economic participation of all people in society. In order to lift people who are structurally marginalised out of situations of transport disadvantage and transport poverty, we must provide a built environment that is equitable and welcoming to everyone, and a transport network that is inclusive, accessible and reliable is fundamental in achieving this aim. In a broader extent, our findings also allude to the fact that promoting sustainable car-shedding behaviour (Carroll et al., 2017), when combined with a proper access to the transport system, acts not only as an environmentally friendly solution, but also a more socially inclusive transport policy that should be considered nationally by policy and decision makers.

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