GIS-based accessibility modelling as a means of evaluating geospatial data usability

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Abstract

GIS-based accessibility modelling as a means of evaluating geospatial data usability

This thesis arose from the recognised lack of previous research into the usability of geospatial data. Whereas considerable study has been made into the usability of devices and their interface, the underlying data has been subject to less consideration, though a substantial literature exists regarding data quality. With the rapid expansion of geospatial data availability through a multitude of platforms (much of it free and crowdsourced), and the increase in creation of such data as mobile devices track location, there is a need to investigate the usability of the data in different contexts and applications. This thesis contends that data quality and data usability, though closely related, are separate characteristics, and that quality is an important element of data usability.

Usability of different data types from various sources is examined here in the context of the well-established application of GIS-based accessibility modelling. Sensitivity analysis techniques were utilised in a novel way to highlight usability issues with the data being studied through the use of statistical and visual approaches. Comparisons were made between a variety of proprietary datasets and data from other sources, such as free and open-source software (FOSS) volunteer geographic information (VGI) network data from OpenStreetMap (OSM), and observations made as to their usability, while addressing cross-cutting topical themes, such as examining different sources of locational representation, different sources of network representation, and questioning the effect of supply and demand on accessibility. The use of both an urban and a rural study area enabled comparisons to be drawn in different geographical contexts.

Several specific proposals are made with regard to improving usability of the proprietary (Ordnance Survey) and VGI (OSM) datasets. An aide to decision making is also suggested through the use of a usability checklist, enabling sample or trial data to be assessed quickly and simply in any given context. A novel Utility Factor is proposed, which draws together contributions from the quantitative aspects of this study into one figure, and is suggested as a context-based proxy of usability based on measures of data similarity, difference and effect.

The results obtained confirm the need for further research to both clarify aspects of data usability and widen the scope of future research into different contexts and applications.

Abbreviations, acronyms and glossary of terms

2SFCA	Two-step floating catchment area
A&E	Accident and Emergency unit
ABP	OS AddressBase Premium© dataset
AL2	OS Address Layer 2©
AR	Augmented Reality
CAD	Computer aided design
CGI	Collaborative geographic information
CSV	Comma separated values. As .csv, a standard file format
DCLG	Department for Communities and Local Government
DEM	Digital Elevation Model
E2SFCA	Enhanced two-step floating catchment area
ESRI	Environmental Science Research Inc
FID	ArcGIS Shapefile Feature ID
FOSS	Free open source software
gdb	Geographic database; .gdb is the file extension given to Arc geodatabases
GI	Geographic information
GIS	Geographic information science; geographic information system
GML	Geography Markup Language, a modelling language for representing geographical features; (as .gml) an open geographical data interchange format
GP	General Practitioner, one aspect of the NHS primary healthcare system, also known as 'family doctors.'
GUI	Graphic user interface
GZ	(As .gz), a file compression format
HCD	Human Centred Design
HCI	Human Computer Interface
HF	Human Factors
InfoVis	Information Visualisation
INSPIRE	Infrastructure for Spatial Information in the European Community
ITN	OS Integrated Transport Network© dataset
ISO	International Standards Organisation
LA	Local authority
Mashup	A common way of using web services and data from different sources, often using maps as a base, to present information in a novel or useful way (Goodchild 2008)
MAUP	Modifiable area unit problem
NCGIA	National Center for Geographic Information and Analysis, an independent US research consortium dedicated to basic research and education in geographic information science and related technologies

NLPG	National Land and Property Gazetteer
NSDI	National Spatial Data Infrastructure
OA	UK Census Output Area
OD	Origin-Destination
OFAT	One factor at a time
ONS	Office for National Statistics, the national statistical institute for the UK
Ontology	A structural framework for organising information.
OpenRd	OS Open Roads© network dataset
OS	Ordnance Survey
OSM	OpenStreetMap
OGC	Open Geospatial Consortium
PAF	Postcode Address File
PC	Post code
PGI	Professional geographic information
PoI	Point(s) of interest; OS Points of Interest© dataset
SDI	Spatial data infrastructure
Topo	OS MasterMap© Topographic layer
TOID	OS MasterMap© Topographic identifier: a unique identifier associate with every feature in many OS large-scale products
UCD	User centred design
UE	Usability engineering
UGC	User generated content
UP	OS Urban Paths© dataset
URP	Usual resident population
USGS	US Geological Survey
VB	Visual Basic programming language
VGI	Volunteered geographic information
VOA	Valuation Office Agency
WG/WAG	Welsh Government / Welsh Assembly Government
WISERD	Wales Institute of Social and Economic Research, Data and Methods

Contents

Index of Tables

Index of Figures

Index of Equations

Chapter 1 Introduction and Background

As well as introducing the topic of the thesis, this chapter will set out the aim and objectives of the research, before providing background and context relating to usability in general, the less-explored areas of data usability, and the somewhat neglected topic of geographic data usability.

1.1 Aim and objectives

This thesis sets out to explore aspects of usability of a variety of proprietary and crowd-sourced geographic data. The specific issues to be explored will be identified through the use of sensitivity analysis conducted within the context of several accessibility case studies, using typical GIS techniques. The changing outputs from the GIS processes will be used to investigate strengths and limitations of different sources of spatial data drawing on the results from an analysis of accessibility to a range of public services.

Usability is defined by international standard ISO 9241-210, which states that usability is:

> "The extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." (BS ES ISO 9241-210, 2010).

In this chapter, more detail is provided on recent developments in the theories of usability, and on alternative emphases and definitions. The usability characteristics of *effectiveness*, *efficiency* and *satisfaction* will be introduced and discussed in more detail, along with their constituent usability elements. Geographical data is data which relates to the world in which we live, specifically to the study of Earth's landscapes, peoples, places and environments (Royal Geographical Society, 2015). Geographical data is different from other data (such as financial data or health data) in that it is in some way referenced to a location on the earth, and may have additional information (attributes) associated with it, usually in a tabular format. It may be made up of points, lines or polygons, text, numbers or imagery, or in a variety of combinations. With such a wide range of types of data available, the documentation describing the data, the metadata, is extremely important and provides a major focus of this thesis.

Advances in technology, particularly in web technology, have resulted in a rapid expansion in the use of digital information. With this also came a recent proliferation of geographic data, due to the rapid expansion in numbers of producers of geographic data (through the increased uptake of satellite navigation technology (such as hand-held or phone-based GPS devices) and crowd-sourced map products (such as OpenStreetMap). This new digital geographic information is being used (and produced) by people from a wide range of disciplines, often from outside the traditional boundaries of geography and the geographical sciences (ISO 2003) in order to support better, faster and better informed decision making. However, the quality and homogeneity of such products have been questioned across both spatial and thematic dimensions (Feick and Roche, 2012). How such data compares to that from 'official' sources in terms of completeness and coverage has been the subject of previous research (discussed in Chapter 2), such as that of Haklay (2010a) and Zielstra and Zipf (2010).

The above research also looks into the quality of these products, but not necessarily at the usability of the underlying data used. Past usability studies have tended to ignore aspects of the data, and have instead concentrated on the system or on the interface, and how their human users interact with them. Little research has been carried out on the usability of the data itself, and less still on that of geographic data, particularly in the context of applied GIS tasks that are typically used by a wide range of users.

It is the assertion in this thesis that the overall usability of geographic data should be considered one of its key characteristics, and has a wider scope than that of data quality. Although some authors consider that usability is an aspect of quality (see Chapter 2 for more details), this thesis will show that geographic data quality is an inherent component of geographic data usability. This thesis will also explore the quality and usability of selected data, and will investigate whether the inherent characteristics of each data set lead to differences in the results of typical GIS tasks. The aim is to draw on such analyses to explore if differences in the data affect their usefulness in practice. These issues will be examined through the novel approach of applying sensitivity analysis to the data, used in relatively recent approaches to measuring spatial patterns of accessibility, highlighting differences and similarities between their performance through a comparison of outcomes. Different sources of data were used to vary the inputs into the models in order to enable the effects of using alternative sources to be quantified.

The process chosen for this was accessibility analysis, which is commonly used by GIS professionals within academia and public sector organisations, and by third sector organisations. The purposes of such assessments may include looking at access to health facilities, optimising business locations, or assessing environmental justice (by, for example, looking at proximity to pollution sources, etc). In this research, accessibility was assessed to five different services, represented in the GIS analysis by different sources of data, taking the results obtained from the use of different supply datasets and different networks and looking for similarities and differences, in both spatial and thematic dimensions. More specifically, consistency will be assessed in the identification of nearest supply point to demand point, using a variety of network datasets through the use of destination overlap figures. Furthermore, accessibility by pedestrian travel distance and walking times will be compared and contrasted by network and by method of locating the supply features. The use of the different supply and network datasets in a more sophisticated measure of accessibility (a form of gravity model) will also be compared and contrasted. Few studies to date have varied the sources of data to represent supply-side, demand-side and network parameters within such models and this study will specifically investigate the sensitivity of calculated access scores to such variations.

Geographical data products from Ordnance Survey along with a selection of third-party datasets (OpenStreetMap, for example), as detailed in Chapter 3, will be examined using a case study approach. Drawing on these findings an assessment will be made of their usability in the context of the public service under consideration. They will be used in various typical geographical analyses, and their performance assessed, both in absolute and comparative terms.

Much is made in the literature on crowd sourcing regarding the ongoing development of OSM as a potential equivalent (or more) of national street maps and so an important element of this research is to explore its potential in a range of geographic contexts. Temporal developments in OSM in the study area will also be assessed, and the practicality of using OSM Points of Interest data to locate supply features will be examined. Little research has been done in the past on OSM development outside large urban areas in a range of GIS application areas.

Several researchers (for example Burkey, 2012) have suggested simple conversion factors for assessing travel distances and times from Euclidean distances. This exercise will offer the opportunity to compare network with Euclidean distances in both an urban and a rural context, with a variety of features, through including Euclidean distances in the accessibility assessments. In addition to a statistical analysis of destination consistency and accessibility by distance and gravity measures, implications for the visual interpretation of the results from using the subject data will also be examined, drawing on the ‘traditional’ representations of geographic data and the use of visualisation tools such as cartograms. This thesis will demonstrate that the combination of assessments outlined here can contribute to an overall assessment of usability of geographic data, through examination of the different outputs from GIS processes, and through investigation of the potential reasons for differences in findings.

1.2 Geographic data infrastructures

Advances in technology, particularly in web technology, have resulted in a rapid expansion in the use of digital information. This includes digital geographic information, of varying quality, which is being used (and produced) by people from a wide range of disciplines, often from outside the traditional ‘spheres’ of geography and the geographical sciences (ISO 2003). Such sources of geospatial data aim to support better, faster and better informed decision making. The importance of geospatial information has been coined in the phrase, “everything happens somewhere” (UK Location, 2011b, p. 4). UK Location recognised the importance of geographical information (GI), and its objective is to maximise the value of geospatial data to the public, government, UK business and industry. It aims to provide a consistent framework for publishing, discovery, evaluation, access and re-use of GI. Increased exploitation of this national asset is forecast to stimulate the economy through generating opportunities for enterprise, driving innovation in the digital economy and helping the growth of data-driven businesses (Ordnance Survey, 2015a). National mapping agencies aim to meet the needs of the varied and disparate uses of geographical data within government, business and public domains by providing accurate and detailed products, suitable for integration with users’ own systems and software, enabling much more data to be analysed in a geographic context, and encouraging developers and entrepreneurs to work with their data. The overall aim of the anticipated increase in the use of geographical data is to contribute to an improvement in the UK economy, with benefits including reduced public sector costs, improved place-based planning and programming, increased innovation in the delivery of public services, and improved commercial exploitation of public sector data.

Other countries have also recognised the value of their geospatial data. Many have also taken steps to make more such data ‘open,’ and so realising its potential in their respective nations. From large nations such as the US, with its NSDI initiative (Federal Geographic Data Committee, 2015b) encouraging open use of its geographic data via the Geospatial Platform portal (http://www.geoplatform.gov/), to small nations such as Iceland (Geo, 2013), governments are recognising the potential of geographic data to help drive their economies forward when made available to a wide variety of business, scientific and public users. These portals act, effectively, as access points to SDIs, and have been variously termed geoportals, geodata portals or geospatial portals, and were defined by Maguire and Longley (2005) as websites where geographic content can be discovered, which organise content and services such as directories, search tools, community information, support resources, data and applications, which permit metadata content to be queried and then link the user directly to on-line content.

Geoportals offer user-friendly interfaces to enable access to information. The inclusive language used in the websites, and the guidance provided, all indicate the encouragement given to general users, who may be unfamiliar with geospatial technology and terms, with specialists and experts still catered for, allowing easier interactive access to the geospatial services provided and thus widening the potential user base for previously-produced data. Further details on an EU pan-national geoportal, INSPIRE, are provided in Section 2.2 of the Literature Review. Emphasising the overlapping nature of usability elements is one key part of geoportal use: the essential requirement for compliant metadata to ensure findability. Data entry standards apply to data being added to geoportals. One geoportal developed by researchers in Wales, WISERD, provides a desk-top manual data entry program which ensures metadata is compliant with international standards (in this case Dublin Core metadata standards) as well as additional information regarding various aspects of the data itself (Fry et al, 2012). Through the use of such initiatives, access to geographic data is being moved closer to the general public. Although much of the published intent in the UK and USA reflects economic and commercial opportunities, the fields of education and tourism also gain opportunities to use the data. To date, however, there has been less focus on usability aspects of such data sources.

It is not only national mapping agencies and governments who are making more and more data available. The ever-widening and ever-growing number of producers as well as users means the amount of geographical data is growing both in volume and in complexity. However, as users and producers from outside as well as inside the field of geography contribute to the growing data 'mountain' it has become increasingly apparent that ways are required of ensuring the data is fully understood, able to be identified, and used to their full potential. The role of national and international standards will be acknowledged as part of the solution to organising such data, but with the proliferation of individually-submitted (with and without geographical training) or crowd-sourced data conforming to few (if any) ad-hoc standards, questions will undoubtedly be raised as to the potential of such data being used to complement or replace official, government or commercial alternatives. This is especially the case given the impact on the functional utility of such data and of the lack of professional oversight (Feick and Roche, 2013).

This thesis contends that the usability of such data is key to it being fully used, and that studies into such usability aspects have been few, certainly when compared to the attention that has been paid to the usability of the user interfaces and the systems on which the data is used for analysis and presentation (examples cited in Chapter 2 including those described by Haklay and Zafiri, 2008; and Taigel et al 2013). This chapter will introduce, briefly, some of the issues relating to this study of data usability, issues which will be examined in the course of the case studies that form a major element of the empirical work conducted during the course of this research. In view of the ever-widening audience for geographical data, a difficult balance must be sought by data producers to enable those from a non-scientific background to find, access and use the data successfully, as well as to allow scientists from other disciplines and geographers to obtain sufficient, detailed information that they require for their own specific needs. This balance applies similarly to this thesis, where the needs of the wider user community will be kept in mind when, for example, the data is assessed. Wider lessons for the users of such proprietary and crowd-sourced data go some way to providing such organisations with a detailed consideration of the advantages and limitations of using such data in ‘typical’ GIS tasks.

As stated in section 1.1, geographical data has characteristics that set it apart from other types of data. One fundamental characteristic of geographic information (GI) or geospatial data is its usability. Hunter et al (2003) pointed out that although the concept of data usability was well known in the fields of software engineering and computer interface design, its extension to include geospatial data was a new development. This development coincided with the explosion in demand for spatial data, as a wider audience accessed or demanded more and more geographical information, often via the internet. Many sites providing such data either collapsed, were abandoned, or withered through lack of use, while others thrived and grew. Did this happen because some sites were more usable than others? Was some data more usable than others? Of course, failure and success could be due to reasons other than usability: it could be down to the algorithms used, the quality of the data, how current the data was, whether it was of interest to the audience, or perhaps luck played a part. Some of these aspects will be looked at here and in later chapters, with a summary of how the definition and concepts of usability developed over the years, and an outline of the approach to usability taken here.

1.3 Usability theory

1.3.1 Definitions of usability and related terms

Usability is a broad term, taking in many different aspects of use. Many of the definitions used for spatial data usability have been adapted from definitions suggested by a range of authors from different subject areas, who took the international standards for products and systems and applied them to data, with other authors applying them to spatial data. They used ISO definitions and guidance as a framework against which to assess the usability of the data in their particular field, for example Bevan (1999), Wachowicz et al (2002), Hunter et al (2003), Wachowicz and Hunter (2003), Shneiderman and Plaisant (2005), Bucher and Balley (2007), Haklay (2010a) and Brown et al (2012a). Several of these related the standards specifically to geographic information, and will be discussed in Chapter 2. In many instances, the terms 'data usability' and 'data quality' were considered interchangeable, with Cai and Zhu (2015) amongst others classifying usability as a data quality element, but in their case restricting the indicators of usability to the provision of documentation and metadata, and relating that provision to the credibility of the data itself.

Citing usability as subset of data quality dated back to a 2001 standard (ISO/IEC 9126:2001) which included usability as one of six categories of software quality (the other five being functionality, reliability, efficiency, maintainability and portability), defining usability as:

> "The capability of the software product to be understood, learned, used and attractive to the user, when used under specified conditions."

Including the user as part of the definition was an important step, but still took a data-centred view of quality as the most important factor. The similarities, differences and frequent overlaps between data quality and data usability will also be discussed throughout this thesis, with data quality one of the many intertwined components that make up the complex issue of data usability. Bevan (1999) had earlier noted the 'portability' category of data quality as the capability of software to be transferred from one environment to another, an interoperability issue which also had implications for geographic data usability.

The Introduction chapter set out the definition of usability to be used throughout this thesis:

> "The extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." (BS ES ISO 9241-210, 2010, p. 3).

In the context of this research a user is defined (by ISO 9241-11) as a person who interacts with a product or service. The product or service may be hardware, software or materials, any part of the equipment for which usability is to be specified or evaluated (ISO, 1998). A more detailed definition and outline of different types of user are provided in Section 1.3.2.

This definition was developed from earlier versions with the inclusion of services, to reflect more web-based transactions, to widen the scope of usability to reflect changing uses of technology from physical products to (for example) web-based services. The standard ISO 9241-210 also reflected other important issues, one of which was that different users may use the same data for widely different purposes, a concept rarely acknowledged by data producers. Another important point was the identification of the three key characteristics of usability: effectiveness, efficiency and satisfaction:

- Effectiveness **-** the accuracy and completeness with which users achieve specified goals (commonly measured by task completion rates and error rates);

- Efficiency - the resources expended in relation to the accuracy and completeness with which users achieve goals (commonly measured by time to complete a task, but mental effort, physical effort and financial efficiency can also be examined);
- Satisfaction - the freedom from discomfort, and positive attitudes towards the use of the product.

The 2010 standard clearly emphasised that the term 'usability' did not just refer to the attributes of the product itself (in this case, the data), but also in the context of use. The context would be influenced by who the users were and what they wanted to achieve, what equipment was employed, and the physical and social environment in which the data was being used. These standards developed from more general standards on usability, with the first authors adapting standard ISO 9241-11 which related to the ergonomics of computer VDUs (ISO, 1998). This included both the study of usability and user experience, as well as physiological factors, but was mostly focused on work environments.

The 2001 standard (ISO, 2001) on software engineering and quality recognised two roles for software usability: first as a detailed design activity; second to achieve an overall goal of meeting user needs. Through the years the user had slowly become an acknowledged factor in data usability standards. Kuniavsky (2003) included the user again, and defined usability as being functional, efficient and desirable to its intended audience. With research into usability moving away from being data-led and system-led towards including the user, HCI (Human Computer Interaction) studies developed which looked at usability from the point of view of user experience and functionality. Most research looked at the usability of systems, again generally via the computer system interface, but there was little research on the usability of the data itself even at the turn of the millennium (Hunter et al 2003). Brown et al in 2012 and many others (for example Wachowicz et al, 2002) came full circle and defined usability in similar terms as ISO 9241-11 (1998), and this will be elaborated in Chapter 2. The standard states specifically that it can also apply in other situations where a user is interacting with a product to achieve goals, and has been interpreted to include data use.

Changes occurred with the explosion of data from the wide variety of sources such as personal devices and the availability of types of geographical resources previously restricted to professionals or scientists. Google Maps, GPS, OSM, Google Earth, etc opened up geospatial data to a wide new audience, an audience which could contribute as data producers through volunteered geographical information (VGI) and citizen science projects. Geographers, scientists and researchers realised that the data being produced in such volumes was an underused resource, and usability issues (not just quality issues) can promote or restrict its use and eventual exploitation. Examples will be described in more detail in Chapter 2 and briefly summarised in this chapter, where the complex issue of usability has been neglected by many, and deserves more consideration.

The standards noted above stated the clear need to identify goals and to split effectiveness, efficiency and satisfaction into components and sub-components, each with measurable and verifiable attributes. It could be argued that in order to assess the usability of any data (including geographic or geospatial data) the minimum requirements would include a description of the intended goals, a description of the context in which the data was being used, and the target or actual values of effectiveness, efficiency and satisfaction. ISO 9241-11:1998 provided examples of how to specify the context of use, examples of usability measures and examples of usability specifications. This ‘user-and-goals’ centred approach classified the data and methodology as part of the working environment, each with their own properties.

The 2010 standard (ISO 9241-210:2010) took a wider view of human-system interaction, broadening out from a concentration on the system itself to focusing on the needs and requirements of the users. The standard also looked at Human Factors theory (described in more detail in Section 1.3.3), usability knowledge and techniques and, with an adaptation of the 2000 standard, referred to the 'user experience' rather than 'usability.' The user experience was:

> “The user's perceptions and responses resulting from the use and/or anticipated use of a product, system or service.” (ISO 9241-210:2010, p. 3).

This standard moved the emphasis of usability from one of being purely goal-focussed to including all the users' emotions, beliefs, preferences, perceptions, responses (both physical and psychological), behaviours and accomplishments that occur before, during and after use. Note that the overall experience did not only arise from direct interaction with the product or system (and how its performance was received) but also of brand image, presentation and interactive behaviour of the system, as well as the users' ‘baggage’ of preconceived ideas about the system built up through experience. This was also affected by the attitude and personality of the user, their skills, and in the context of use.

1.3.2 Definitions of users

As research became more centred on the user, it was realised that not all users were the same. Harding et al in 2009 and Haklay (2010a) defined several different categories of geographic information (GI) end user, summarised as follows:

- System administrator - imports and manages geographic information in an organisation. This user may, for example, only be interested in 'change only' datasets;

- Developer - designs applications and is interested in fitness for purpose and data structures. Such users may find that ease of use and learning has become the most important user feature of data, rather than using the 'best' format data (for example using Esri shapefiles in preference to OGC file formats), and may not be aware of the cost of data;
- Power user - a GIS professional, operating and integrating geographic data for specific tasks on a daily basis. They may use metadata to identify appropriate data, even though most datasets are not well annotated, and they themselves may not be familiar with dataset semantics.
- Specialist domain user - uses GI as a tool for their tasks. To this user, both the data and the software are treated as ‘black boxes;’
- General user - uses GI on an occasional basis as part of another task, such as car navigation. This category of user believes all the data used is authoritative, factual and current, which may have implications for their use if they place absolute trust in the system (for example, when such users follow their car sat nav to misfortune (BBC, 2007 and 2009).

Monmonier (1996) had previously noted that people generally trusted maps and saw them as an authoritative source of irrefutable fact (especially, as Monmonier pointed out, some maps presented themselves as such). An aspect perhaps less understood by those with a non-geographical science background was that the geographic information and data used to describe the complexity of the real world had to interpret and distort reality in order to present it in an understandable form. Any such description of reality was therefore always partial, always an abstraction, and just one of many possible views of reality. For example, any map that tried to reproduce faithfully the detail-rich truth of the real world would be impossibly cluttered, and if not generalised in some way would be unusable, in practical terms. The value of a map, according to Monmonier, depended on how well the generalised content reflected a chosen aspect of reality. This aspect of choice, that some view or opinion had influenced the map, and tailored it for particular audience for a particular reason, may not be something of which the wider public was aware. Ideally, all users should have some degree of map-literacy and be aware of such issues. They should have the opportunity to investigate the back story that resulted in the final product. This also highlights the importance of metadata in influencing how geographical data is used.

Different types of users of GI were also identified by Brown et al (2011a), categorising them into three main groups:

- Data producers – including commercial organisations such as Ordnance Survey (OS) and Google, but also the growing numbers of non-professional data producers (which some may consider a separate category);
- Developers - including those that enhance GI for specific uses, for example developing in-vehicle navigation systems;
- GI end users - including mash-up makers, crowd-source participants, public and community groups (such as ramblers, cyclists, environmental action groups); local and national government (town planners, etc); commercial organisations (in the retail and insurance sectors, for example); the education/academic sector; and individual members of the general public.

These terms provide a useful typology in describing different types of users, and will be used in this thesis whenever differentiations between users require to be made (although in most instances the 'default' user will be assumed to be a General or Specialist Domain user, from the GI end users category). What is apparent is the wide range of users of GI data, who all interact with geographic information in different ways, but those differences often receive little attention from GI data producers.

1.3.3 Human Factors theory and Human Centred design

As the emphasis moved further towards the user at the centre of usability, as outlined in ISO standard 9241-210:2010 (as detailed in section 1.3.11), Human Factors theory and Human-Centred Design concepts became more emphasised. Human Factors theory was defined as:

> "The scientific discipline concerned with the understanding of interactions among human and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance." (ISO, 2010, p. 2).

The standard also adopted the concept of human-centred design (HCD), on the basis that highly usable systems and products tended to be more successful, both technically and commercially (ISO, 2010). HCD operates on the following principles:

- Design is based on an explicit understanding of who the users are (and including those who may be affected by the use of the product), what tasks they have to complete, and the context and environment in which they are working;
- Users are involved throughout the design and development processes. By doing this, user and task requirements specific for particular groups can be included in the design and development process;
- Design is driven and refined by user-centred evaluation. This enables a product to be tested in 'real world' situations, with results obtained used to inform refinements and improvements. It also helps prevent introducing a product that does not meet user needs;

- The process is iterative (which means repeating a sequence of steps until a desired outcome is achieved, whether involving the product as a whole, or individual component parts);
- Design addresses the whole user experience (unless the system is safety-critical, in which case efficiency and effectiveness would be more important), including factors mentioned above such as emotional aspects, user job satisfaction and the elimination of monotony;
- The design team includes multidisciplinary skills and perspectives (this could include HF or ergonomics specialists, user representatives, experts in the particular subject matter, interface designers, user support staff, software engineers, and any other relevant stakeholder who can bring ideas, skills or issues into the process).

User Centred Design (UCD) may be viewed as a subset of HCD, with UCD defined as:

> "An approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements." (ISO, 2010, p. 6).

Using HCD principles should ensure that the design of any product met user requirements. These principles, where applied, should improve the usability of any product, whether physical or purely data.

1.3.4 Data usability concepts

The definitions of usability therefore moved towards the perspective of the user and their personal goals, which may be beyond the immediate task at hand, and involve aspects of perception and emotion not addressed in previous, related standards or definitions. In terms of geographical data, this indicated that data producers had to think about how using their product makes users *feel*. This may have been a lot to ask, as the typical attitude of data producers to the data they provided, and to those they provided it to, may not have actually reflected what is seen today as best customer service practice. For example, in 2002, Wachowicz et al pointed out that although data producers believed their job was finished once data was collected, they were slowly realising that adapted and adaptable products must be provided to maximise their reach to potential customers. The usability of the data would be an important factor in finding multiple uses for it and would have a considerable knock-on impact on profitability. Wachowicz and colleagues surmised that data could therefore be treated as a commodity, and traded as such in the market, with usability as a key selling point. Commercial and national geographic data providers realised that although they produced some products for specific applications, they also needed to meet the many and varied data needs of an equally varied range of users, and that achieving this would be unlikely without improving aspects of usability. Usability considerations therefore continued to move further away from treating the data as a stand-alone feature, towards an ever-more user-centred position.

Josselin (2003) also took ‘usability’ to be centred around the human who, recognising the reliability and quality of underlying data, used the data to make as good or as adequate decisions as possible. Although ‘spatial data usability’ had been defined by international standards (as outlined earlier in this chapter), as centred on the user and their goals and linked by ergonomic factors, Josselin moved it towards a ‘system-oriented’ approach, whereby all components are part of a single package, all interlinked, the quality of which affected decisions made in many ways. Usability could therefore be defined as the relationship between these components. This is illustrated in Figure 1.1 (adapted from Josselin, 2003), showing usability as the link between the data, the users and the design of methodologies used in analysis.

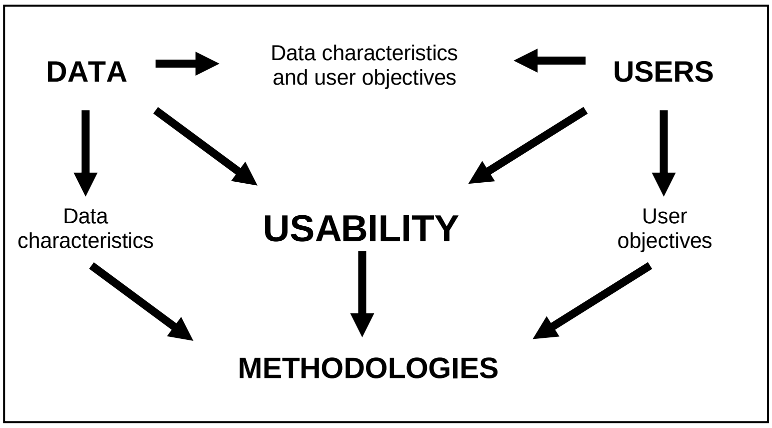


Figure 1.1: How usability links data and users. **Data** is described by its characteristics, all of which can be measured independently from the users. **Users** are described by their objectives, their personal experiences, point of view, and so on. **Methodologies** are described by their design, considering the tools available, their statistical efficiency, robustness, etc. **Usability** lists capabilities, such as whether data can be generalised, extrapolated, integrated, etc, as well as factors such as added value, ergonomics, and human factors. (Adapted from Josselin, 2003).

This is a useful conceptual model to keep in mind when considering aspects of usability in more detail, highlighting the constant interaction between data, users and methods, all of which combine to describe a dataset’s usability. The acknowledgement by Josselin that data could (or would) be subsequently analysed was a rarity when considering usability. Edsall (2003) also contended that all the definitions outlined in the standards consistently missed key issues regarding analysis. Specifically, the possibility was ignored that any users would conduct any analysis on the data provided to them, along with an implicit denial that data producers bore any responsibility whatsoever for this further use. This service divide between data producers and the data users continued to be the subject of much discussion and was a recurring theme in much of the research. This in turn provided the impetus to continually monitor the needs of data users in relation to the tasks ‘typically’ needed within organisations.

Identifying an agreed definition for data usability was difficult. Identifying any agreed approaches to measuring data usability was also difficult. It was found to be easier to make an indirect measure of the effects of using the data product (such as how much profit is made, how much time and effort is saved, the satisfaction of the users, etc) without assessing any underlying reasons. These measures demonstrated how usable the data was, but not why. If treated like an engineering product, this would not be satisfactory: bridges are not assessed for their usability after building, but the usability is determined in advance of construction. There was little knowledge of the intrinsic characteristics of a data product that made it more, or less, usable. There was therefore no knowledge of any rules or guidelines as to what made a usable product. Such knowledge would enable users or producers to predict usability and have usability 'designed-in' to any new data product.

Wachowicz et al (2002), Hunter et al (2003) and Wachowicz and Hunter (2003) see data usability as an umbrella term, consisting of elements grouped under the broad characteristics of effectiveness, efficiency and satisfaction. The broad categories and elements suggested by them will be looked at in Chapter 2, with reference to GI data where appropriate. Some elements could easily fall under more than one characteristic, and such categorisations would change depending on the circumstances in which the data was used. Consider, for example, how the 'novelty' of new data will generally decrease through time.
The ranking of these elements would also change depending on how the data is applied and on the specific situation, therefore the order they are listed here is not an indication of their absolute importance. For example, where the consequences of a decision will have a very high value attached, cost of the data will be a minor consideration, but perhaps accuracy would be a major factor. Where consequences were minor, cost would be a major factor, with high cost resulting in low usability. Whereas these elements are obviously important within themselves, the concept of usability brings them together to form a much larger, and more informative, picture which, when easily-communicated, could help inform and raise the awareness of those users who, perhaps, previously made completely uncritical or unsuitable use of the data obtained. As yet, this approach has been under-researched. With the profusion of (for example) crowd-sourced geographical data of, as Goodchild and Li (2012) stated, doubtful quality and provenance the opportunities for informed and suitable use of such free and timely data are many and varied, but with no way of assessing such data, the opportunities offered may be wasted.

This chapter previously summarised some of the concepts relating to recent developments in the definition(s) of data usability. The following elements of usability (Table 1.1) were adapted from the sources cited in this chapter and cover most of these concepts, forming a framework within which to assess geographic data usability for this thesis. Definitions and explanations of each element are provided in Section 2.2 along with examples of their use in research.

Characteristic	Element	Sub-element
Effectiveness	Added value	
	Content	
	Purpose	
	Utility	
	Novelty	
	Popularity	
Efficiency	Cost	
	Integration and convenience	Data Standardisation Data Integration
	Searchability	
	Security	
	Speed of access	
	Standardisation	
	Legal issues	
Satisfaction	Trust	
	Caveats on use	
	Certification and standards	
	Legal defensibility	
	Producer reputation	
	Metadata	
	Visual appearance	Data visualisation Interface design HCI
	Quality	Completeness Logical consistency Accuracy

Table 1.1: Characteristics of data usability and supporting elements.

There are many ways of classifying and categorising usability elements, depending on context, or on user preference. One such alternative is shown graphically in Figure 1.2, highlighting usability at the centre, between the characteristics of the data itself and the completion of the task.

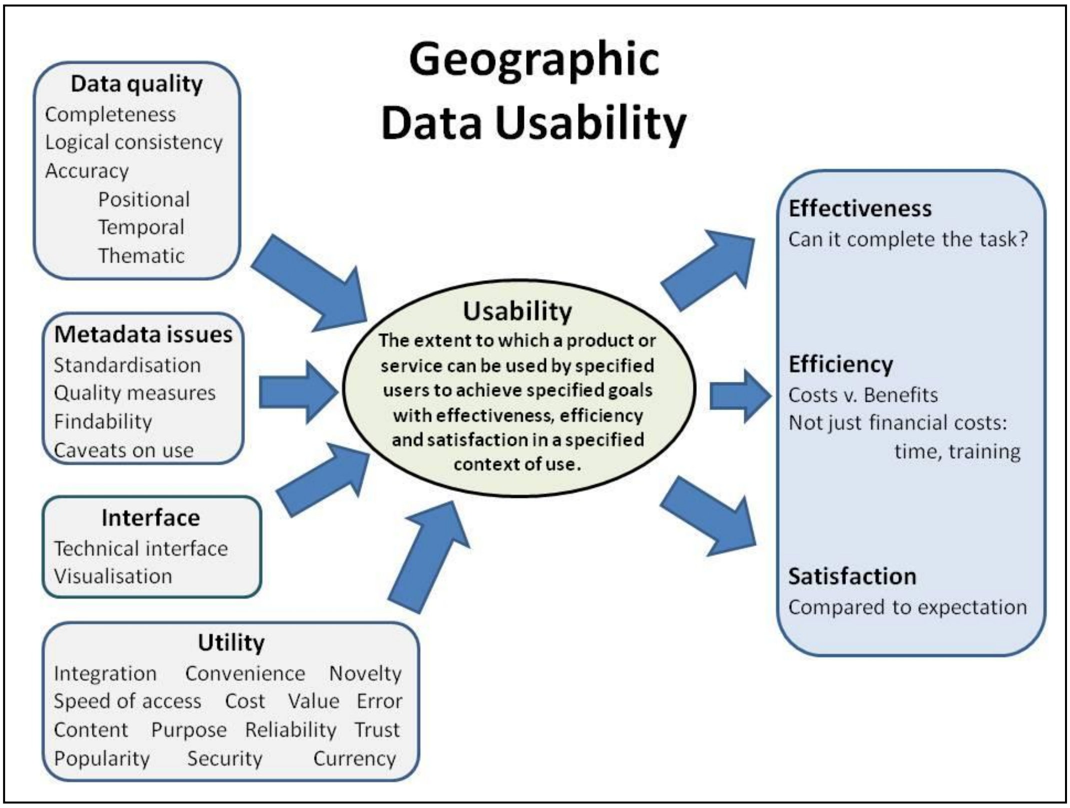


Figure 1.2: Usability at the centre of quality, metadata, interface and utility assessments. In the past, each theme or element was, and still is on occasions, used as a stand-alone measure of data quality and/or usability, with both these terms almost interchangeable. Based on ISO 9241-11 (ISO, 2010) and ISO 19157:2013 (ISO, 2013).

1.4 Assessing usability

The various approaches taken to assess usability are discussed in more detail in Chapter 2 but are summarised briefly here to reiterate the approach adopted in this research based on the use of sensitivity analysis. Most involved observations of users and how they interacted with the data and/or the system in question (van Elzakker, 2005) or some other performance or subjective criteria (Harding and Pickering, 2007). However, Brown et al (2011b) noted the lack of GI usability studies compared to those looking at other types of data, and also the lack of objective measures of usability with respect to all types of data. There is still a paucity of work into identifying quantitative measures of usability, a gap which this thesis attempts to address.

As outlined in Chapter 2, there is a clear need for a scientific methodology to quantify the usability of data for comparison purposes. As Wachowitz et al (2002) pointed out the methods already developed in the field of Information Technology were based on performance testing, beta sites, expert reviews, cognitive walk-throughs, heuristic evaluation, satisfaction questionnaires, and user interviews, all of which were post-purchase activities, and these activities are still being used, though rarely, in usability assessments. Whatever methods are chosen to assess usability, Kuniavsky (2003) emphasised that the researcher must know why they are testing usability before they begin testing. Kuniavsky gave examples where usability testing was conducted as a trawling exercise on products that were seen as unsuccessful, hoping to identify factors on which to blame the lack of success. This example emphasises one of the points made repeatedly throughout the remaining chapters of this thesis: context is key, and without knowing the context in which the data is to be used, assessing usability will be impossible.

In this thesis the approach was taken of using sensitivity analysis to 'stress test' the data in order to highlight differences and identify similarities between the datasets in question. In a past study Jones (2010) used sensitivity analysis to compare walking times to medical facilities in the West Midlands, using different network datasets. The approach found differences between the results obtained through using the different networks, and these differences were investigated to identify their causes. A similar approach was taken here, but different datasets were also used to locate the destination facilities. Again, results were compared and differences investigated. Not all differences occurred with all datasets, and the use of sensitivity analysis enabled identification of specific issues with individual datasets, as well as identifying overall trends and patterns. One drawback to this approach was that (without further validation) the results will only apply to this specific choice of accessibility analysis, using the same GIS and the same tools and techniques. However, the use of sensitivity analysis provided a way of comparing datasets and producing a series of objective results quantifying their differences and similarities, thus addressing specific outcomes which were to be investigated.

1.5 Thesis structure

This thesis is comprised of seven chapters, with this first chapter providing an introduction to the research into geospatial data usability, and the last summarising the main conclusions, the specific outcomes and areas of further work that follow on from this study. Chapter 2 is a review of the literature relating to this thesis covering the entire scope of the research, from usability in general to the specific approach taken in this study. The methodology taken is described in Chapter 3. Results are split between Chapters 4 and 5, with the former detailing the results in tabular form and the latter examining the visualisation of the results. Chapter 6 discusses the results, and Chapter 7 draws conclusions from the results obtained and the experience gained in the course of the research. More detail on each chapter is given below.

Chapter 2 details the constituent elements of data usability, taken from recent standards and literature, defining each element and explaining its role in usability. The divide between 'data usability' and 'data quality' is explained in some detail as this is an important, but fine, distinction. The significance of context is emphasised, a point which is repeated throughout the thesis, and is vital to the issue of geospatial data usability. Particular issues with the quality and usability of crowdsourced geospatial data are discussed. There is not a large body of research into the usability of geospatial data, but a review is made of the work to date, and of the methodologies used. Literature is cited in support of the approach taken in this thesis, specifically the use of sensitivity analysis, and a brief review is made of the context of which the sensitivity analysis is carried out here: accessibility analysis, outlining different approaches and summarising their advantages and disadvantages.

Chapter 3 describes in detail the methodologies used in order to achieve the aim of this thesis (see Table 1.3), introduces the geospatial datasets that are to be assessed for usability (both proprietary and VGI datasets were used) and the geographical areas in which the study will be conducted. The accessibility measures are described, with the specific gravity model used being explained at some depth. The rationale behind the use of sensitivity analysis is explained, and the process undertaken is detailed. Justification is made of the statistical tests used in the analysis of results, and the approach taken to visualise the results is outlined. Specific details relating to the accessibility analysis are then explained, for supply-side features, demand-side features and network datasets, with explanations of any characteristics of these datasets that may affect usability.

Chapter 4 reports the results from the many calculations carried out to ascertain the usability of the datasets in question. The results are presented in tabular form to enable the identification of patterns, whether between networks, between different approaches to representing location or between urban and rural areas. The results of statistical analyses are reported and suggestions made as to how the results could be combined to provide an overall impression of trends and patterns. A separate analysis was conducted on OSM completeness and coverage over time, and the results obtained were used to inform overall assessments of usability of this VGI dataset, and potentially other VGI or crowdsourced geospatial products.

The visualisation in Chapter 5 was used as an analytical tool to identify differences and similarities between results, and also to assess whether the differences identified in statistical analysis resulted in a visual effect when translated into typical map presentation form, such as choropleth maps. The usefulness of different presentational scales was assessed using choropleth maps (comparing OA polygons to postcode polygons, for example) and alternative forms of presentation, specifically cartograms.

Chapter 6 discusses in detail the results obtained, and what were found to be the underlying causes of specific issues that were identified through the analyses carried out in Chapters 4 and 5. Many of the root causes related to data quality issues, and some had geographic components. Wider issues encountered in the data in the particular context of accessibility were identified and discussed, with specific examples provided to illustrate these issues.

Chapter 7 summarises the findings from previous chapters and assesses the outcomes of the thesis against the aim and objectives initially set out in Chapter 1, with any shortfalls identified. Specific, practical proposals are provided which aim to aid the decision-making process when considering the usability of a geospatial dataset, and a method of assessing an overall Utility Factor proposed, putting both forward for future validation. In addition to this, suggestions for future research are outlined, and also ways in which (with hindsight) this study could have been improved, due to limitations identified during the course of the thesis.

1.6 Chapter summary

This thesis tests the usability of a variety of geographical data, some of which may be used for purposes that may not have been considered during its creation, and examines the level of usefulness provided by that data. It is contended that such an examination of usability has not been conducted previously on geographical datasets from a wide range of sources in this way, particularly in a pre-procurement situation. This neglected subject area provided an opportunity for original research which this thesis will address. The overarching aim of this thesis is, therefore:

> To investigate the usability of geographic information through the exploration of a range of selected geospatial data sets, using (GIS-based) accessibility modelling.

Although aimed primarily at helping to identify the most appropriate dataset in the context of accessibility modelling, this thesis proposes a quantitative and objective method of assessing elements of geospatial data usability which could serve to aid data producers in improving the usability of their datasets in a wide range of GIS tasks, and the methodology may also have wider relevance to users of other types of data.

The usability factors outlined in this chapter were used to inform the approach and analysis carried out during this research and form the basis of this thesis. It is anticipated that the relative importance of the factors will vary from situation to situation, again emphasising the importance of context when considering the fluid nature of usability assessment. However, this will be tested by using the datasets in question in different ways within an accessibility context.

As will be outlined in Chapter 2 there is no agreed standard methodology to measure the usability of data, and of the various methods proposed very few are quantitative and objective. In the absence of such a methodology this thesis takes the novel approach of assessing the performance of several geographical datasets by comparing variations of output, both statistical and visual, when used in different combinations in a typical GIS task, represented in this instance by accessibility analysis. By conducting this sensitivity analysis, then using various usability elements and factors outlined in this chapter, conclusions can be drawn as to the usefulness of the data in the context of the tasks that were conducted, conclusions that will prove informative to data producers and useful to data users. In so doing, detailed comments on particular data services will be made to aid potential users of the data. A brief summary of the overall aim and objectives of this thesis is given below:

Overall aim	**To investigate the usability of geographic information (GI)**
Objectives	Explore the quality and usability of a range of selected data.
	Defend the assertion that usability is a key characteristic of GI.
Approach taken	Use sensitivity analysis to stress the data and highlight differences and identifying similarities between datasets.
Context	Accessibility analysis.
Outcomes investigated	Quantifying effects of variables on results using three separate assessments of accessibility: nearest distance; a two-step floating catchment area (2SFCA) method; and destination overlap.
Specific outcomes investigated	How usable is OS data in the context of accessibility analysis?
	How interchangeable is GI in this context?
	What is the impact of the ongoing development of OSM?
	Can conversion factors for assessing network travel distance from Euclidean distance be identified?
	Can data be ‘stressed’ in order to highlight usability aspects?
	Are there themes or patterns regarding usability issues within the GI in this context?
	Is it possible to identify a factor of usability for a dataset in a particular analytical context?

Table 1.2: Summary of aim and objectives.

A further exploration of the literature relating to aspects of this thesis can be found in the next chapter: Literature Review. The intention was to place the review in the context of the lack of a large body of literature into usability of GI data and lack of a wide or detailed literature on data usability assessment methods. The terms, concepts and theoretical background contained in this chapter should act as an introduction to Chapter 2.

Chapter 2 A review of research on geospatial data usability

2.1 Introduction to the literature review and proposed scope

There is a relevant paucity of literature regarding usability aspect of spatial data. This chapter reviews work on the usability of data in general, before concentrating on the literature relating to geographical data usability in particular. The importance of the usability of geographic data is increasing, with the advent of Web 2.0 encouraging an exponential growth in the users of the data as well as the number of contributors, the growth in the use of mapping technologies on a range of platforms and the heightened interest in the use of spatial data.

This chapter therefore considers the developments in the study of usability with particular emphasis on that of geographic data usability. The elements that make up the concept of 'usability' as introduced in Chapter 1 are discussed further in this chapter, with some emphasis on data quality aspects. The growth of Web 2.0 and the associated implications for GI usability is also discussed in some detail, looking not only at the data that is produced but at the VGI community models used by organisers of geospatial UGC. Recurring usability themes are also identified throughout the review, and are discussed in later chapters in the context of the datasets used in case studies conducting accessibility analyses on a variety of features.

The development of health information systems often produced systems that were difficult to use, generated more confusion than benefits, or were inadequate in some respects (Cinnamon et al 2009). As a result, health policy makers demanded evidence to justify investment in health information systems, and usability testing provided some of the quantitative and qualitative measurements required, noting improvements that can be achieved through the use of user centred design (UCD). Cinnamon's study compared the usability of three different types of health map: static, animated and interactive. Static maps are self-explanatory. Animated maps took the viewer through change by time series or variable. Interactive maps permitted pan and zoom and choice of layer/data to be visualised. From the scores of user questionnaires and structured interviews, Cinnamon's et al's (2009) results showed that different map types were most useful for different purposes, depending on satisfying the various skill levels relating to the previous geo-visualisation experience of the users.

Prins et al (2002) analysed the usability of patient data used for medical assessments and found the usability of the data, calculated using 14 indicators across elements of standardisation, completeness and accuracy, was insufficiently usable to make diagnoses of meningitis in children. Problems with completeness and accuracy, such as time points of events not recorded accurately or not recorded at all meant the data was not fit for purpose. This example illustrates how usability is the product of many different strands, but that a shortfall in only one key aspect can render the data unusable. Hunter et al (2007) reported on the usability of spatial information, with specific reference to Google Earth, noting that despite shortcomings that generate many user complaints, the product still achieves around one million downloads per year. This illustrates the complex nature of spatial data usability, with user needs over-riding the theoretical definitions of what is usable and what is not.

2.2 Elements of usability

This section provides detail from the literature on the elements of spatial data usability outlined in Chapter 1 (repeated below as Table 2.1). Specific examples supporting each element are also provided where relevant. These elements and their associated sub-elements and terms provide a useful aide memoire while giving a general overview of usability. The elements in Table 2.1 and in the following paragraphs are not listed in terms of importance, but there has been an attempt to group the elements thematically, under the three key characteristics of usability outlined here, namely effectiveness, efficiency and satisfaction. The themes and their emphasis may (and will) change from task to task, context to context (and an illustration of an alternatively-themed grouping of elements aimed more specifically at geographic data usability was provided in Figure 1.2), but overall aims will remain the same: can the task be completed; in an efficient manner; in a way that satisfies the user? And is there any way of assessing this, in advance of actually obtaining the data (perhaps at considerable cost)? There are many potential combinations and permutations of factors, but very little consideration has been given to identifying a definitive approach, should one exist. On the whole, examinations of data usability are few, and have not addressed the points raised here. In view of the amounts of geographical data available, and the potential uses to which they could be put (with associated financial and social implications) it seems an unjustly neglected area.

User satisfaction is one of the more recent additions to the definition of usability. In terms of data, it reflects the need to put the user, as a person, at the centre of usability assessments. The Satisfaction element includes both quantitative and qualitative evaluations and judgements, therefore not only are the performance and technical parameters of the data measured, so too are the user's feelings and perceptions regarding the use of the data. This challenged the traditional 'data provider – user' relationship, and helped to develop current user-centred usability models.

Characteristic	Element	Sub-element
Effectiveness	Added value	
	Content	
	Purpose	
	Utility	
	Novelty	
	Popularity	
Efficiency	Cost	
	Integration and convenience	Data Standardisation Data Integration
	Searchability	
	Security	
	Speed of access	
	Standardisation	
	Legal issues	
Satisfaction	Trust	
	Caveats on use	
	Certification and standards	
	Legal defensibility	
	Producer reputation	
	Metadata	
	Visual appearance	Data visualisation Interface design HCI
	Quality	Completeness Logical consistency Accuracy

Table 2.1: Characteristics of data usability and supporting elements.

2.2.1 Effectiveness - Added value (or benefit)

The ability to add value to data or information is vital, not only for commercial organisations. There would be little point in any individual or organisation spending time, money and effort procuring, processing and analysing data if it could not be used in a useful, informative or profitable way. However, as Turner and Forrest (2008) pointed out, in the world of geographic information the value has long belonged to those companies that controlled the underlying data.

These companies sell the data like any other product or commodity, often to buyers who want the data to inform decisions. However, ascertaining the value of the data to the buyer may be difficult, especially if the buyer cannot confirm whether the data is fit for their purpose until they have it in their possession, and there being no definitive method of conducting such an assessment.   Moeller (1989) noted additional difficulties caused when costs may be incurred to address an intangible value, for example in the case of government land ownership records, where uncertainty and inaccuracy needed to be eliminated in order to foster public confidence in the data.

Brusegard (1989) stated that geographic information must be enormously valuable to anyone needing to know about spatial distribution or spatial relationships, and asserted that the value of such information derived from its use. Therefore, to research the value of information one must research the uses of information. Again, context is key, as without a use, geographic data is, in itself, worthless. However, knowing information is valuable is different from determining the value of that information, which is extremely difficult (Cetl et al, 2008). As far back as 1993, Onsrud and Calkins concluded this was best achieved by improving ways of tracking the use of such information. This retrospective approach was of little help in decision making, when deciding whether it is worth obtaining a particular dataset. Predicting the benefits arising from the use of a dataset, in order to decide whether it is worth purchasing, was much more difficult, though some authors have tried to produce a decision-support mechanism to help with such issues. Calkins and Obermeyer (1991) believed that case studies and surveys were the best way to understand the use and value of geographic information, and proposed a taxonomy to provide a suitable structure for such investigations. Dickinson (1989a), for example, looked at taking a Cost-Benefit Analysis approach (see below) and, as reported by other researchers, found many associated problems, some of which are outlined in the following sub-sections.

2.2.1.1 Establishing added value - Cost-Benefit Analysis

Dickinson (1990) noted the emphasis on case studies, with most focus on cost-benefit statements. Cost-Benefit Analysis often took the entire cost of any GIS into consideration (rather that the cost of the data only) and all the tangible benefits associated with it (such as cost savings, staff savings, higher standards of accuracy, and so on) but tended to ignore intangible benefits. Intangible benefits could include: the ability to conduct analyses not possible before; improved decisions; improved planning; and better understanding and analysis of highly complicated systems (Dickinson and Calkins 1988). It was stated that it was not impossible to calculate intangible values, but it was difficult, and often involved estimations or best guesses. Dickinson (1990) noted that ignoring intangibles could have the effect of value-enhancing projects being disadvantaged compared to efficiency-promoting projects, meaning fewer significant improvements being implemented due simply to the difficulty in quantifying future costs and benefits. Intangibles were completely ignored in the study by Cetl et al (2008) who, despite this, still found efficiencies resulted from the use of a SDI in Croatia.

Cost-Benefit Analysis was also used by Brown et al (2011a) to justify the application of UCD to Ordnance Survey data sets. Again, tangible costs and benefits were relatively simple to put a figure to (reduced customer service costs, increased sales, etc), but intangibles, though quantifiable, were somewhat more difficult to value in monetary terms. Improvements to brand image and increased customer satisfaction, for example, could be evaluated by questionnaire, but translating those results into monetary terms was not simple. Other common models of value were also found by Dickinson (1990) to have shortcomings when it came to geographic information:

- The Exchange Value method looked at the price an individual was willing to pay to obtain a commodity. With data and information, the user would be required to make the purchase and to subsequently find it of considerable value, or find it useless, or some point in between. This was therefore a retrospective method, and so would not help with purchase decisions. This method also completely ignored repeat use and the value of 'public good.'

- The Decision Theory method took the concept of the different payoffs between a decision made without information and a decision made with information. New information would decrease uncertainty in decision making, along with a probability distribution of each, uncertain, outcome. As new information became available, the probability distributions change and uncertainty decreases. This changing of probability is sometimes known as Bayesian updating of the probability distribution. One problem is that large amounts of data is required for each decision and probable courses of action and, again, users probably would not know how the new information will affect things before it was actually purchased. This method also assumes a monetary value can be placed on any possible result.

- The Multidimensional Attribute method calculates value based on the actual use of the information. It lists economically significant attributes of information (eg certainty, applicability, content, decision-relevance, timelines, prior knowledge, prior information, accuracy, quantity, etc) using ordinal ranking. Questionnaires are used, asking users to rank information products on these different attributes. Again, the method was retrospective.

2.2.1.2 Other methods of establishing added value

A method of determining the value of VGI was described by Parker et al in 2010. This involved identifying the stakeholders, how they interacted, what their motivations were, and what value they placed on the data. They pointed out that with this knowledge the relative usability of data could be determined, but that this was not an easy task. By considering value elements, such as emotion, function, knowledge and legal and cost perceptions, and conducting analysis on a wide range of interviews, they concluded that different stakeholders perceived and utilised VGI in different ways. This indicated that there were wide differences between user groups, and each may have their own, distinct requirements for VGI applications.

After a comprehensive review, Repo (1989) concluded that no single theory could explain the value of information. As with defining usability, the value for the same information or data differed depending on the context. Repo suggested abandoning the mathematical approach and instead recommended looking at empirical studies to see if any generalisations could be made. The possibility of the use of a ranking scheme for intangible costs and benefits, which may result in a usable proxy for the relatively simple CBA approach was suggested by Wilcox (1990), but it was acknowledged the intangibles were still often ignored. Even though Smith and Tomlinson (1992) argued that there were few things that could not be valued, there was no single, accepted system for calculating the value of data in advance of its procurement, and the topic appears to have gone out of fashion in geospatial circles since the1990s. The lack of recent research is surprising, given that the UK government (and others) is promoting open GI to boost the economy (Ordnance Survey, 2015a). Further investigation would be required to ascertain the relevant decision-making criteria for commercial exploitation of GI, and how added value is assessed. Ordnance Survey case studies (Ordnance Survey, 2015c) compiled evidence of cost and efficiency savings achieved through the use of their data on a case-by-case basis, but the UK government did not put an overall monetary value on any expected gain to the economy in general.

With little empirical research to fall back on, users have to use their own judgement or use unproven methods in order to justify procuring data and effectively take a gamble with their money. The alternative is to play safe and only purchase data where there is a sound case for doing so, or refuse to take the financial risks and accept that new opportunities may be lost as a result.

2.2.2 Effectiveness – Content

This may be the most obvious criteria by which data is assessed, and this element is again one which overlaps into other elements and sub-elements. For example, without metadata it would be extremely difficult to be aware of the content of data, or to be able to find it. It is entirely possible that data exists which no one has a use for at the current time, but which may become useful at a later date. If would be difficult for potential users to judge this, but again geoportals may have a role to play (see section 1.2.5 to 1.2.8) as a user-friendly service providing standardised metadata (and further information which may be helpful to users), so encouraging browsing of potentially useful datasets by researchers.

2.2.3 Effectiveness – Purpose

The purpose of the product, the type of application or the type of decision; all these factors influence usability. From the definitions of usability at the beginning of this chapter, the context of use was highlighted as being extremely important. The clear implication was that data considered usable in one situation may not be usable in another. Effectively, usability was not absolute, but a relative term only applicable when a wide range of information was available as to the task in hand. The context of use is one of the most important aspects of usability, and one which has been neglected in the past. However, the importance put on the purpose of the data has grown as the pace of change and development of new applications has increased (Brown et al, 2011b), such that the data producers have been unable to predict how their data would be used and to what purpose. This also makes classification of datasets much more difficult, in that a producer cannot simply apply the stamp of usability to the product and consider their work complete. They must look at their product from the user's point of view (an often difficult task, particularly if the user group is not clearly defined, or changing rapidly) and address issues that may not be relevant to the dataset at the time it was created. As far back as 1985, Gersmehl noted a similar three-fold duty of map producers: to the data; to the map reader; and to any third party who might be affected by a foreseeable misinterpretation of that data. Unfortunately this duty was not universally embraced.

As an example of how crucial context is to GI data usability, Pendlington and Capstick (2012) looked at the context of use of potential new 3D Ordnance Survey (OS) products. They used semi-structured interviews to find out what current users actually did, rather than what new products they wanted. The interviews provided leads for more interviews, and gathered a considerable amount of information on customer thoughts and experiences, as it put customer desires in context. They found, not surprisingly, that different customers had different needs, but also found some consistency in the requirements of this audience. Accuracy, currency and geometry was found to be universally important, but texture and appearance less so. The most useful information was number of storeys, building volumes, building heights and building materials. This opened up the data to more uses, such as in development planning (improved communication and greater transparency) and sustainable development (PV cell location, green roof siting, wind canyoning forecasts, etc). The new products could therefore improve the accuracy of analysis and reduce the number of site visits required, hence reducing costs. By examining the context of use, the new product could be tailored to improve decision making, communications and efficiency, so reaching a wider audience and becoming, effectively, more usable. The context issue is a theme that pervades a wide range of elements related to spatial data usability.

2.2.4 Effectiveness – Utility

Utility is a key usability attribute (ISO, 1998). The ability to use a product or data with minimal effort, training or learning makes it much more attractive to users, and saves both time and money (Tsakonas and Papatheodorou 2008) and utility, or ease of use, can be assessed by the levels of speed, completeness and correctness in the user's performance (Bugs et al, 2010). However, data producers have a very difficult job of judging the skill levels of the users of their product. Not only could novices, intermittent users or expert users be involved, but these skills, and the groups involved, change all the time. This is particularly true of internet-based services, where the range of users is large and varied, but this also enables usability engineering to be of most benefit to most people (Nivala et al 2007).

It is difficult to accommodate the needs of all potential users when designing any product or service. However some assessment of their needs should be attempted, otherwise a part of the potential audience will be lost. Nivala et al (2007) noted that there were now technical solutions which meant that all users who use a system need not be provided with the same system properties if they were using it for different purposes. Instead, they could be offered a variety of choices depending on the context of use and on the users' differing levels of skills or abilities.

2.2.5 Effectiveness – Novelty

New data or a new application of data can spark considerable interest that slowly fades as the novelty wears off. Google Earth provided a good example of a new product that exploded into public consciousness with its launch in 2005, albeit with a massive press campaign, and was believed to be the primary driver in a sudden increase in demand for geospatial data and platforms (Scharl and Tochtermann, 2007). Interest in this product was maintained with periodic additions of new datasets, such as sea bed information, the surface of the moon and astronomical data.

2.2.6 Effectiveness – Popularity

If everyone else is using data or a product, others tend to want it too. The earlier example of Google Earth is a good example, with Google's official blog (Google, 2011) reporting the one billionth download of Google Earth in October 2011.

2.2.7 Efficiency – Cost

One of the truisms of GIS is that obtaining data is the most expensive part of a project, in terms of both cost and time (Ubbens 1989), with Frank et al (1991) estimating the ratio of hardware/software/data costs at 1:10:100. Despite this there is still no commonly adopted method of determining, in advance of purchase and use, whether a dataset is worth the cost.

High cost may influence usability, and some organisations (such as charities or non-profit organisations) may be unable to afford to use the very expensive commercial data provided by some companies. However, the reverse may also apply in some situations, with high cost being perceived as being of better quality and offering exclusivity and therefore offering a competitive edge over other consumers. In contrast, some data providers, such as OpenStreetMap (OSM) are able to offer a vast variety and volume of information free of charge (Zielstra and Zipf, 2010).

Received wisdom holds that if cost was the main determinant of data use, volunteered geographical information (VGI) or crowdsourced data would be better and used more compared to the equivalent professional geographical information (PGI) wherever the option was available. Parker et al (2012) found this was not necessarily the case, and that when risk was high, users used whichever source they believed most likely to supply their information needs, whether free or at cost. This study found that individuals undertaking leisure activities seemed more willing to spend resources (such as time and money) for information where there is a risk associated with their activity. No broad comparisons were drawn with commercially risky activities, and although the comparison seems at first sight to be intuitively correct, would require more study for confirmation. One of the characteristics of the effectiveness of data is the added value it provides. Although the cost of data is relatively clear cut, the benefits it brings are not (as noted under the Added Value element, Section 2.2.1).

2.2.8 Efficiency – Integration and convenience

This element refers to the ability to access and to mix data in order to achieve added value or to examine relationships in data that have previously not been combined. Convenience dictates that data available in a popularly-used format will have a greater chance of being used by a wider range of users, while that held in a non-harmonised format (particularly without metadata) may reduce opportunities for it to be used outside its original field. Non-technical barriers to using data from diverse sources include licencing, copyright and cost (Vandenbrouke et al, 2009), factors that overlap with other elements. Governments have also recognised the potential benefits of greater integration (especially between the public and private sectors) and in making spatial data freely and widely available. They also recognise the significant barriers to data sharing and usability that exist, including the lack of accepted standards for many aspects of data recording, storage and transfer, as well as organisational issues associated with ‘silo’ mentalities of user organisations.

In summary, there are two main approaches to mixing data from different sources: data standardisation and data integration (Peng, 2005). Data integration uses tools (such as service chains and distributed operations) to translate the data into a usable form; data standardisation forces the original data to conform to certain standards (such as those set by the NSDI or INSPIRE). Although discussed under separate headings, both approaches overlap, and neither is mutually exclusive. Whatever the approach, sharing the data and using the same datasets for different purposes are more efficient ways of uses of that data.

2.2.8.1 Data standardisation

As mentioned above, one approach to achieving interoperability and to address the various issues relating to data sharing is to set strict standards and formats for the original dataset. Many governmental bodies have set such standards to encourage wider data use within their own countries, but with users requiring data from yet-wider sources, including those from different nations, achieving the ultimate aim of all data conforming to the same strict standards and structure is still a distant aspiration.

Many of the standards issued by the ISO, such as those relating to metadata (see Section 2.2.20) have been spearheaded by the Open Geospatial Consortium (OGC) – an international group of private companies, government agencies and academic organisations which aims to facilitate interoperability between geospatial technologies through education, standards, specifications and other initiatives. OGC standards and specifications empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications (OGC 2004). They have also been applied to various geospatial web services.

To facilitate data use within countries, many governments have set up national spatial data infrastructures (SDIs), the definitions of which are many and varied. A simple definition from Hobona et al (2008) for a pan-European geospatial research test-bed was of a collection of technologies, people, policies and frameworks for facilitating the sharing of geospatial resources. This definition was similar to that proposed by Crompvoets et al (2004) who also emphasised the facilitation of exchange of data but tilted away from being data-oriented to having a more user- and application-oriented focus, whereas de Man (2006) took a more holistic view and stated that SDIs could be seen as networked infrastructures, socio-technical actor-networks, common pooled resources and communities of practice. Vandenbrouke et al

(2009) proposed a definition somewhere between these two approaches while including the actual use of the data, stating that an SDI was a set of technological and non-technological set-ups (components) within and between organisations (network) to facilitate access, exchange and use of spatial data (narrow objectives), thereby contributing to the performance of business processes (broader objectives).

Despite the lack of a fixed, agreed definition, the term SDI is now established in the geospatial field and seen as part of the trend away from data-oriented towards service-oriented structures. The aim of such national SDIs was to create a single source for accessing all the geographic and special resources that were available. These SDIs were not a single national repository, but a kind of resource library, where resources were linked electronically in a distributed network (Crompvoets et al, 2004).

In Europe, the INSPIRE programme was set up to aid the creation of a SDI for all the countries of the EU. INSPIRE is an example of a second generation SDI, being service-oriented rather than purely data oriented (Crompvoets et al, 2004), changing emphasis from data to information, and moving towards a more open generation of SDIs aimed as much at non-specialist users and the general public as specialists and expert users (Craglia et al, 2007). The INSPIRE directive specifically states that access should be provided to the data infrastructures (UK Location, 2011a) and in this country UK Location includes a point of access through data.gov.uk (HM Government, 2013) to provide a basic search service to UK data users.

Setting up a SDI involves many of the usability elements outlined in this paper, many of which overlap. The process is complex and opinions differ as to whether the SDI approach is the correct way to proceed. For example, the Crompvoets et al (2004) study noted many pitfalls with SDIs, including poor management and decreasing interest once the initial SDI was set up. It also noted that interfaces to SDIs were not always user-friendly, and that the terminology was too discipline-specific and too focused on the data alone, particularly for non-expert users. Another pitfall was that knowledge is often seen as power, and de Man (2006) noted that bureaucracy and politics can have a considerable influence on the use and success of SDIs, as access can be restricted and controlled, thus excluding some from power in order to consolidate the power of others.

2.2.8.2 Data integration

It is not only integration allowing use amongst a wider community that is important, but that data can be used with other, perhaps previously unrelated, data. The mashup ‘industry’ was born from using diverse data sources to create new, interesting information, but if different data sources cannot be integrated, such opportunities will be lost. The general view was of users adapting data to their own use on a case-by-case basis, effectively creating a duplicate of the original, but altered to fit their specific purpose. One of the main drivers behind all the different approaches taken to improve integration was to avoid the creation of similar, multiple datasets of the same base data. Riedemann and Timm (2003) for example considered the best approach to be a distributed operation web service (synonymous with Cloud Computing) which enabled real-time data transformations and so prevented duplication of effort without the data provider incurring any development costs. These web services need not alter the original base data, an important consideration for many organisations.

The lack of supporting metadata for web services was pointed out by Bucher and Jolivet (2008), who emphasised its importance for future discovery and use. Developers of services may not be aware of all the potential uses of their software, therefore need to state clearly what their code actually does, using unambiguous vocabulary where possible, thus increasing potential future use. They believed that developers were not willing to build and share descriptions of their resources unless they were forced to, or gained benefit from it, therefore having a module that automatically exploited existing metadata to display available services would improve their use and make chaining easier.

All of the above approaches require some way of a system ‘recognising’ the features in the dataset. Just as semantic similarity is central to many cognitive processes and plays an important role in the way humans process information, issues of data semantics and metadata content are important to data quality and usability (Schwering and Kuhn 2009). Some conceptual similarities are therefore required between the data itself and the tools used to interrogate the dataset (Fisher et al, 2010).

It should also be noted that the UK Location (2011b) guidance documentation stated:

> “Many on-line web mapping services are heavily tied into vendor software that require the web mapping service to access data on a local system in a specific way. These mapping applications can only use those datasets that are specially prepared for them. Although this has helped people become familiar with such applications, it limits the ability to combine data from a diverse range of sources” (UK Location 2011c, p. 11).

As part of its commitment to interoperability, UK Location guidance suggests data producers use an OGC Web Mapping Service interface so users can view location information published by a wide range of data providers, and also suggests using 'readily-available' open source products wherever possible in order to maximise the use of the data by the widest audience possible.

2.2.9 Efficiency – Searchability

Searchability (or findability) is a key requirement of data, as identifying data for use can be a challenge, particularly when that potential use was not considered by the data producer. Having sufficient and good quality metadata associated with any dataset is vital to searchability. A more detailed discussion on metadata is found in Section 2.2.20.

2.2.10 Efficiency – Security

Factors from this element may also be found in the elements of trust, authority, and reputation (in the upcoming sections relating to the usability characteristic of 'satisfaction'). Users needed to know that the data they were using was sound and likely to be free from tampering and hacking (Hunter et al, 2003) and these issues impacted on the usability of VGI when compared to 'official' GI.

2.2.11 Efficiency – Speed of access

Slow access speeds can frustrate users, and frustrated users could look for alternative sources of data with faster responses. Animations and other novel or sophisticated visualisation techniques may aid interpretation and make information appear more accessible (and therefore usable), but this may be cancelled out by the resulting increased download times resulting in a negative experience. This conflict between accessibility and screen loading and refreshing times illustrates the overlap between usability elements, as what may appear to make data more usable on one hand (a highly animated 3-D landscape scene, for example) may actually make the information less usable in another factor (for example, an extended screen load time). Noting these competing priorities, Nivala (2007) suggested adding another, small animation in such circumstances to indicate to the user that something was processing or loading (and in generic IT products this animation often takes the form of a running egg-timer, rotating clock hand, travelling dots, or similar).

2.2.12 Efficiency – Standardisation

This element refers to the use of accepted symbolism and feature definition in a product, such as the use of completely novel (or completely inappropriate) map symbols. Lack of standardisation could result in a data product not being widely accepted in its subject area. Testing on a sample audience would inform data producers if users found their symbolisation, for example, clear and intuitive. Unclear, indistinct or inconsistent symbology would create uncertainty and confusion amongst users. A simple example would be if a map was supplied with land in blue and water bodies in green or brown, contradicting the conventional approach. The rationale behind the colour choice would have to be strong, and such a choice would have to be acceptable to the user group in order for the map to be used.

2.2.13 Efficiency – Legal issues

This element includes intellectual property (licensing, copyright, fair use, etc), ownership of data, liability and privacy issues. Geographic data can fall into any one of a plethora of categories relating to its use, ownership or licensing status. Some data producers enforced strict licensing terms to defend their intellectual property, and Ordnance Survey has been involved in some high-profile cases (BBC, 2001). As online material became more available (not just in map data cases, but with music, film, computer games, etc) the perception with a substantial proportion of the population was that all the data on the web was free to take and free to use, despite this not necessarily being the case. The confusion between the use of the word 'free' in FOSS software terms being interpreted as 'free beer' (ie something for nothing) rather than the more correct 'free speech' (ie open source to use and develop within certain limits) meant that a lot of geographical content (on the web especially) was in a grey area, from a legal standpoint. As McConchie (2008) pointed out, at first glance the geospatial field has many web map services, many which appear to be falling over themselves to provide more free data and services online. This 'freeness' is put into context by the example of Google Maps, which makes its data freely available (and is much used as a result), but can only be used in ways sanctioned by its Terms of Service agreement (Google, 2012). For example, one of the terms forbids the creation of new content based on its maps. Do mashups represent 'new content?' If so, many GI end users may find themselves breaching those terms, and an organisation wanting to use a mashup downstream as a business input would be in some difficulty regarding the legal status of subsequent outputs derived from that content.

The legal aspects of GI have not been a focus for this thesis, but its importance and influence is acknowledged throughout this research. Indeed, the release of UK map data under the OS OpenData brand reflected a change in the legal status of much of that data. Although not part of a map itself, legal information is an important component of metadata, where clear licencing information, or guidance of legal use, etc, could remove much uncertainty relating to data use. Recent trends, including the aforementioned expansions of OS OpenData products, indicate a change in the attitude towards licencing by data producers, with some indications that they are changing their licencing to encourage the use of their data, rather than imposing strict restrictions on its further use. This can be seen in the increasing amounts of FOSS data being made available.

Onsrud (2010) believed that addressing the legal aspects of a dataset was required in order to achieve completeness. As incomplete data could not be of high quality and poor quality would affect usability, legal aspects had a high impact on data usability. Onsrud (2010) also suggested licence generation could be embedded in automatic metadata generation processes, again highlighting the importance of metadata to usability.

2.2.14 Satisfaction – Authority

The perception of quality inferred by being officially sanctioned may enhance usability by promoting confidence amongst users (Goodchild 2008), hence the overlap with the following element: trust. It could be argued that Ordnance Survey data is held in such regard. Such authority gives advantages over other products that are not officially sanctioned (Hunter et al 2003). On the other hand, users may have some scepticism regarding VGI, though Parker et al (2012) pointed out that recent or current information provided from established community members through VGI, especially in subject areas or at scales (in time and space) where traditional sources were unavailable, were perceived by users as carrying more authority than that of other VGI sources.

2.2.15 Satisfaction – Trust

Trust in data has a major impact on usability, but is difficult to define and measure, having an emotional component that varies from person to person and user to user. Trust was described by Hunter et al (2003) as arising from the knowledge that a product was developed by a particular organization, with official sanction and adhered to standards and/or industry best practice. Aids to trust also included the provision of full metadata. An interface which appears ‘professional’ also engenders trust, which influences the decision to rely on a system, despite using data of unknown quality. An individual’s propensity for trust was a factor, but interface design and appearance did affect perceptions could over-ride any caution regarding the data with Harding et al (2009) pointing out that some users put full trust in the system they were using while having no actual knowledge of the accuracy or the quality of either the data being used or the system using it. Other studies, as reported by Skarlatidou et al (2011) suggest that a user’s perceptions of trust of online environments influenced their inclination to engage, use and to accept these systems, which in turn influenced how they perceived their experience as a user.

The rapidly increasing use of online maps gives added urgency to the need for investigating this area as their potential audience expands widely across the general public. Skarlatidou et al (2011) stated that the GIS community should consider investigating ways to improve the spatial literacy of non-expert users in order to reduce their reliance on design and branding as indicators of trust in data, and so enabling them to make a more informed assessment when viewing online maps. Although improving the geographic awareness of the population would be a good thing *per se*, a cynic may take the view that professional geographers would rather raise the entire population to their own higher levels of spatial awareness rather than address the usability issues inherent in their current presentations and practices.

If trust is an important factor in data usability then there must be concerns with the data produced from non-professionals, such as the public. This data, often termed VGI (volunteer geographic information), CGI (collaborative geographic information) or crowd-sourced data, has none of the characteristics outlined by Hunter et al's (2003) definition. Trust in VGI compared to PGI (professional geographic information) was found to differ widely in Parker et al's 2012 study, with user group members found to trust the other members of their own user group, and their inputs, more than those of other groups, and in a detailed discussion on maintaining trust and credibility with regard to VGI, Flanagan and Metzger (2008) noted the need to identify the motivation of individual contributors, a difficult task.

Bishr and Kuhn (2007) looked towards using trust as a proxy measure for data quality from web-based contributors. In simple terms contributors to VGI datasets would be given 'trusted contributor' status in a similar way as sellers in eBay were graded with stars that reflected their sales volumes and customer feedback grades. The technology now exists to have both feedback and messaging opportunities attached to base data or on the portal, and both actually exist in non-spatial data applications, though adoption by the spatial data industry has been slow. The UK government data.gov website provides an example of where lists of datasets have comments and suggestions from users, with one Land Registry information page (https://data.gov.uk/dataset/land-registry-monthly-price-paid-data, accessed 5 January 2016) showing a comment from August 2014 suggesting latitude-longitude data be included with future releases.

2.2.16 Satisfaction – Caveats on use

Statements of caution when obtaining data are rare, yet clear limits of use are important to ensure data are not used in completely inappropriate ways. An example where a caveat on use of certain data would be helpful to users is provided by police crime maps (noted by Tompson et al, 2014) and illustrated here by using crime maps from South Wales Police from around the University of South Wales. Crimes in the maps are located by means of points, as shown in Figure 2.1.

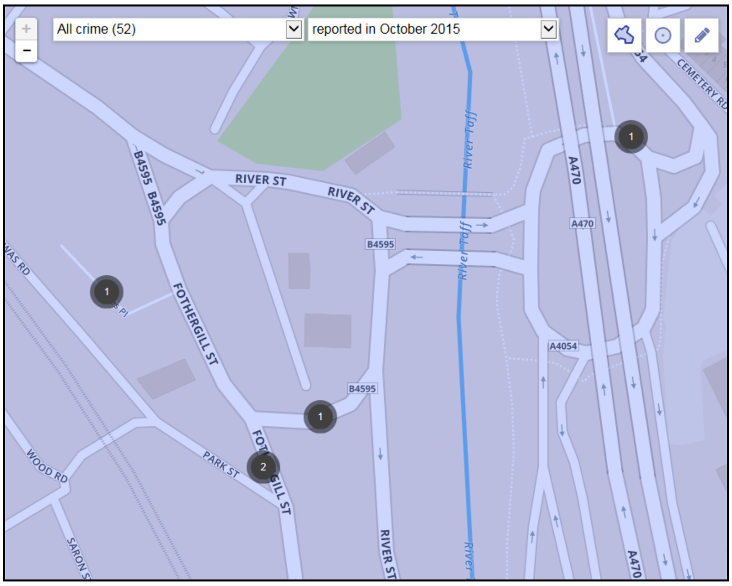


Figure 2.1: Crime map showing point locations of crime. (https://www.police.uk/south-wales/56/crime/). Accessed: 16 December 2015.

The use of point locations infers a level of precision in these maps and it may naturally be assumed that crimes actually occurred at those locations (Coote and Rackham, 2008), but the crime data is obfuscated using geomasking in order to deliberately reduce spatial accuracy. However, an older version of the South Wales Police website included the page as shown in the screen shot at Figure 2.2, including an important caveat (circled in the image).

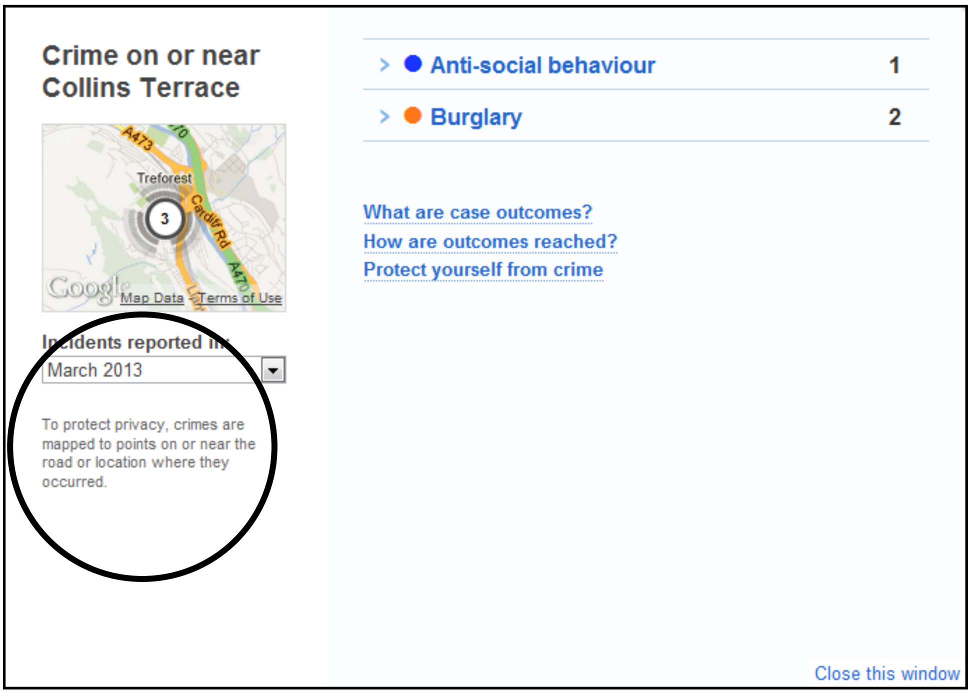


Figure 2.2: Screenshot of crime detail webpage (https://www.police.uk/south-wales/56/crime/), with qualifying statement circled. Accessed: 30 May 2013.

Tompson et al (2014) indicated that most crimes are placed on the map at the mid-point of the road in which the crime was reported. A prospective house buyer, therefore, consulting the map, may be put off to find a crime (or crimes) located outside their front door, despite the actual location having been some distance away. Conversely, a person looking to buy at the end of a street could feel reassured that any crimes in the area were on the map several hundred metres from their property, not realising that the crimes did in fact take place in their immediate vicinity. It should be noted that the screen with the clarifying statement no longer appears on the crime map web pages, leaving users with no explanation as to the placing of the points on the map. Tompson et al (2014) saw considerable promise of the geographical use of crime data, but only at suitable geographical resolutions, as the type of maps typified by Figure 2.1 implies a level of accuracy and precision which was not justified.

2.2.17 Satisfaction – Certification and standards

Certification is required in cases where (for example) certain official air or marine charts are required to be used, by law. Published organisational standards apply to some products, such as those from Ordnance Survey (2013). There are no standards regarding the accuracy of, for example, OSM's information, therefore caution must be exercised when using it.

2.2.18 Satisfaction – Legal defensibility

Authoritative data sources often have this status. For example, the US Environmental Protection Agency places a high emphasis on its data on environmentally-degraded land of being capable of being defended in court (Hunter et al, 2003), and Bielecka (2003) noted that the data held in the Polish spatial data infrastructure included details of land ownership, with the importance of keeping this legally-sensitive information accurate. Beard (1989) gave the example of using generalised maps for property tax assessment and property ownership purposes, where some small pockets of land could disappear from the maps due to the generalisation process, but continued to exist 'on the ground,' sparking property disputes.

2.2.19 Satisfaction – Producer reputation

Reputation and Authority are similar, though even data producers that do not have the authority of official sanction may enjoy a positive reputation as, likewise, not all officially-sanctioned producers will have a positive reputation. This could include small companies, online bloggers or individuals within an online community. Data providers with a ‘good’ reputation may be seen as providing more authoritative data.

2.2.20 Satisfaction – Metadata

Metadata is information about data; structured information describing the information resource (Craglia et al 2007). The importance of metadata is reflected in that it has its own standard (ISO 19115:2003, 2003, Geographic Information. Metadata.). The Standard provides a framework for metadata, defines metadata elements, provides a schema and establishes a set of metadata terminology, definitions and extension procedures. As well as enabling data producers to characterise their geographic data properly, it also facilitates retrieval and use, through easier location, access, and evaluation of the data, by enabling users to determine if the geographic data held will be of any use to them. It states the essential requirement that a basic minimum of metadata must be maintained, and that these core elements must at the very least serve for catalogue purposes, and should include:

- Dataset title
- Reference date
- Who created the dataset, and/or who was the responsible party
- Language
- Spatial resolution
- An abstract (summary description)
- Extent information (including vertical and temporal, as appropriate)

A recently- updated geographical metadata standard (BS EN ISO 19115-1: 2011) noted the intention of taking greater account of web-based services, removing the concept of core metadata, and widening some of the definitions used.

These rapid and frequent changes show how the development of technology has outpaced the setting of standards. The development of new standards was seen by Fisher et al (2010) as lagging behind developments and new geospatial issues. This would not have surprised the many researchers who saw the standards process as inherently conservative, proceeding by consensus, and therefore not keeping up with the most recent research (Goodchild, 2007b).

2.2.20.1 Components of metadata relating to geospatial data

Fisher et al (2010) viewed metadata standards as acting to restrict the growth of creative uses of geographic information by making no provision for informing users how best to exploit the data. They pointed out that that INSPIRE says producers should not publish their rating of 'usefulness' as it would do more harm than good to users. Instead, INSPIRE suggested leaving such information to be formed via word of mouth ('informal user feedback') as to whether the data is useful, good value, and so on, but noting that word of mouth also includes forums, press articles and the like. Comber et al (2007), however, suggested metadata could be expanded to make it more user-focused. This study asserted that metadata standards were still grounded in data production and did not provide information to help users assess the relative uncertainties associated with using data for their application. They saw the INSPIRE initiative as opening a gap between users and producers, and believed it was better for these two parties to move closer and engage in meaningful dialogue. They suggested ways to achieve this aim could involve including the following in metadata:

- The socio-political context of data creation, actors and their influence;
- Critiques of the data such as academic papers;
- Data producers' opinions of class separability;
- Expert opinions of relations to other datasets;
- Experiential metadata;
- Free text descriptions from producers;
- Tools for mining free text metadata.

All the above suggestions were intended to improve the usability of data and address the paradoxical situation that on the one hand users of data have easier access to more data than ever before, but on the other hand they know less about the meaning behind that data. The first bullet point, above, gives the context of the data production, at which point the traditional metadata process often ends. The other points are intended to give users, or potential users, the fullest information that can help them assess the usefulness of a dataset relative to their problem and understand the limitations and uncertainties associated with it and of any integrating activities. Inclusion of experiential metadata, and user feedback, has been proposed by other authors (including Comber et al 2007, Fisher et al 2010), including a proposal for a wiki-based solution that would allow different user communities to be differentiated and provide a framework within which new, potential data users could learn from the experience of others.

Metadata is one usability element of a dataset that is strongly inter-related to several others such as quality, trust, reliability, validity and integrity. Hunter et al (2003) stated that scientific researchers would consider it unthinkable to use data without sufficient metadata. They would require, for example, information on the survey method or data collection method, and so on. Full metadata would also include a description of the purpose of the data; documentation confirming that the data had been produced to meet the needs of certain users; and any caveats on its content and use. Unfortunately, typical metadata production only involved providing some specification elements (such as the title of the dataset and an abstract, for example) as metadata for discovery, and perhaps the results of quality inspections as metadata for evaluation. This was the point where the majority of data producers stopped, even though they could go further by providing the first indication of use, or the application, problem or need that triggered the data production in the first place (Toth and Tomas, 2011).

Lack of metadata means that some information may be lost or missed for future use through being unsearchable and therefore unfindable. The UK element of the INSPIRE initiative includes a Discovery Metadata Service (UK Location 2011c), based on the creation of discovery metadata as part of the provision of the data and services it relates to by the Data Publisher. In the past, the task of creating metadata was often seen as part of a later administrative activity, and was frequently created by someone removed from the creation of the data itself and thus lacking knowledge about much of the data, such as its provenance and the constraints surrounding its collection. UK Location encourages discovery metadata to be produced as part of the data production process itself, as part of the same toolset, and stored in parallel with the data. On the other hand the presence of metadata was suggested by MacCormack and Eyles (2010) as a possible proxy of data quality (though not the only indicator). In their study of borehole records, they noted the higher quality records were those obtained from engineering and construction reports which contained a great deal of detail. Lower quality borehole records typically came from large databases which often provided general information with little or no accompanying descriptions. Presence of, or lack of such metadata was seen as a quick and easy way of establishing data quality.

Bucher and Balley (2007) provided some examples that illustrate the importance of metadata in such service chains. Firstly, the metadata allowed relevant data to be searched and found. Then it provided information on any software required to read it (for example, whether the dataset was in csv format, plain text, etc), and to identify it correctly (for example, whether it consisted of points, lines, polygons, networks, etc). The semantics of the dataset were important, too. In the case of line data, for example, where each line represents a road, each line has an attribute. The data producer added a ‘weighting’ to the line to represent volume of traffic. A subsequent user, with no metadata to consult, could assume the weight represented speed, thus generating incorrect results. Without sufficient metadata, subsequent users could only make assumptions which could have major consequences. Perhaps a more scientifically correct approach would be to decline to use the data on the grounds of having insufficient information. Looking at spatial data for military planning, Doherty (2010) emphasised the importance of metadata by asserting that building usability into data creation was critical to success, part of which involved ensuring that metadata was supplied and contained, at the very least, information on time, date, source, location and scale, with the ability to tailor detail appropriate to the users and their goals.

2.2.20.2 Geospatial metadata creation

Creating metadata has been viewed as a thankless task, often deemed to be a tedious burden at the end of a project (Ellul, 2013). As an example, Ellul et al in 2010 noted the lack of enthusiasm for metadata creation amongst data collection teams on a multi-national environmental project, suggesting they did not realise the importance 'further down the line' of metadata and metadata specifications. The data producer knew what the data was intended for (and in the past the producer was also usually the main user of that data) and as a result did not see the need to document the information, therefore the metadata was not fully completed and contained many errors (in the author’s words, "sloppy and patchy"). Bucher and Balley (2007) noted the future aim of generating metadata elements automatically, which would ease an administrative burden on data producers, reduce time spent examining the data by users and potential users, and also improving the quality and completion of metadata provided with each dataset. Batcheller et al (2007) described an automatic method of metadata transfer within an ArcGIS environment, freeing up the user for more intellectually challenging metadata tasks. Ellul also agreed that further automation of metadata creation was required, along with tighter integration of metadata and the data itself, with Onsrud (2010) suggesting that standards-based metadata needed to be created in under 10 minutes, with a user interface which automatically guessed each field based on information and terms taken from the file, allowing the user to quickly and easily correct and complete as required.

The tools required to achieve closer coupling of metadata to the data itself and automatic generation of metadata had not been created, but Ellul et al (2013) recently developed such tools using the FOSS (Free Open Source Software) packages QGIS and PostGIS. By using these tools all the mandatory INSPIRE elements can be automatically included plus several optional elements. To aid in GIS analysis a metadata layer can be added to a map, to provide a brief overview of the state of the datasets at each location. This development still requires work on the user interface to make it appear more professional, and once this is done it is planned to open the source code. Future work includes allowing users to comment on the data and metadata and describe how they have used the data, supporting Comber et al (2007) and Fisher et al (2010) who suggested experiential feedback as a useful metadata content, as described in Section 2.2.20.1.

2.2.20.3 Improving geospatial metadata

Recent steps towards providing experiential metadata have been taken. Developments on the data.gov website (HM Government, 2013) have not only improved the interface, but allow for comments to be posted, and example screenshots are shown in Figure 2.3 and 2.4. These comments are not directly tied to the data, therefore may not be considered, in the strictest of terms, as metadata. However, it still provided information about the data and how it was used.

Other approaches looked at the structure and format of the data itself, in much more basic terms, to allow the data to be used and understood by a wider group of users. Kelly's (2010a) study on adapting GI data to address problems of mapping in a non-visual manner, for those with visual impairment, was one example. The study noted that non-GIS groups did not have the right background, training or awareness to know what data to ask for (that is, they lacked knowledge of underlying vector/raster models, etc). However, GIS experts needed non-GIS people to suggest problems which novel uses of 'their' data could be used to address. In this case it was how to make reasonably detailed vector information available on small mobile devices, and how to extract the information from the whole dataset to make the end result meaningful and usable by the vision-impaired. This example emphasised once again the importance of context, as such a system may be extremely useful and usable for certain of these stakeholder groups, but not for other groups requiring a personal navigation system.

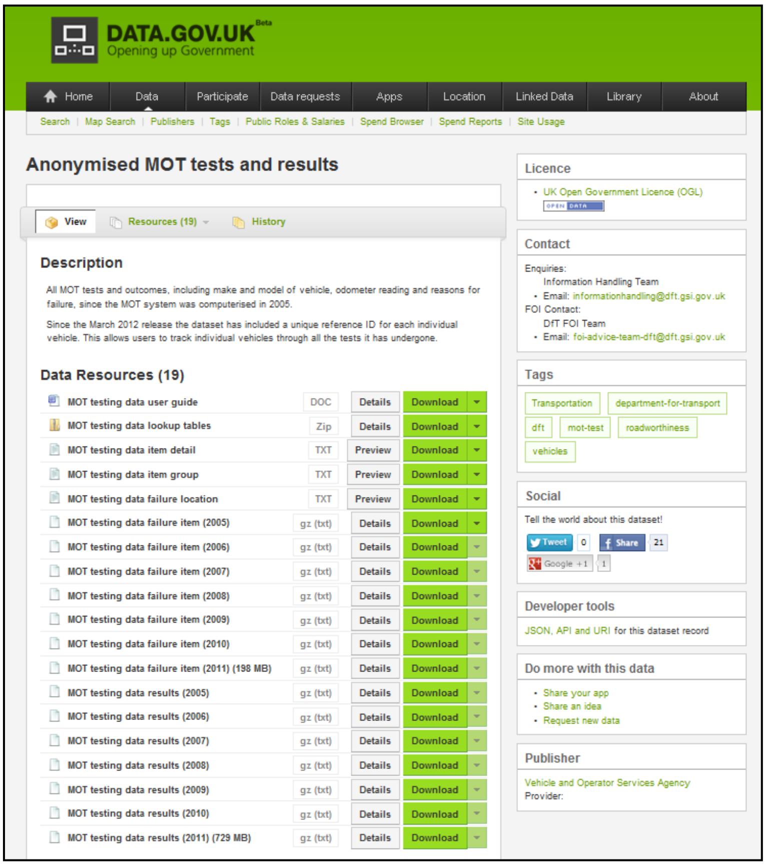


Figure 2.3: Screenshot of data.gov website showing example of resources available and illustrating the interface.

These points effectively summarised the ideal situation with regard to metadata, and matches several standardised approaches, such as the widely-used Dublin Core (http://dublincore.org/), which in turn has informed other schemas, many of which include Dublin Core standards for purposes of interoperability.

The call for more user information in metadata was also made by Lush et al (2013) who surveyed users, the majority of whom supported an all-in-one, drill-down interrogation facility for metadata that would provide as much information as possible, presented in one place, in a format that allowed easy comparison and closer investigation, that combined the following:

- dataset producer information;
- producer comments on dataset quality;
- dataset compliance with international standards;
- community advice;
- dataset ratings;
- links to dataset citations;
- expert value judgements; and
- quantitative quality information.

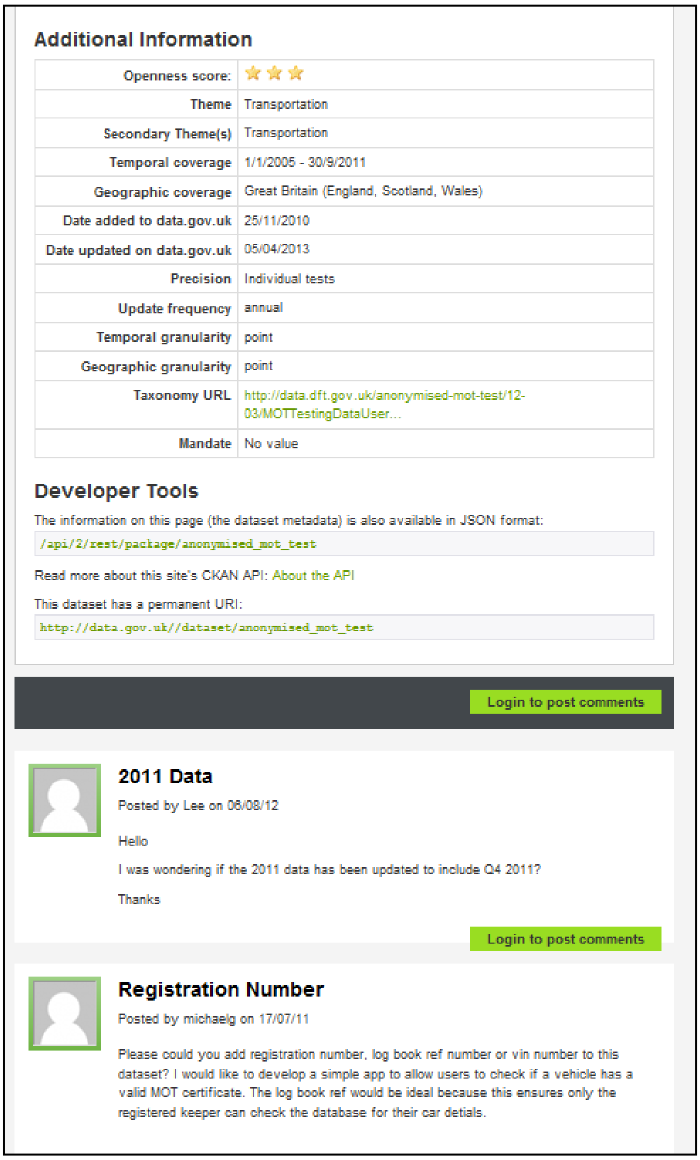


Figure 2.4: Screenshot of data.gov website showing option for posting comments, with example of comments posted at time of viewing (31 May 2013).

De Bruin et al (2001) pointed out that even with full metadata available, any comparisons or assessment of usability were usually carried out post-purchase, as getting suitable samples before purchase was problematic. De Bruin suggested the approach taken by software companies could be used, where they provide a small amount of sample data for evaluation before purchase, or provide evaluation software with limited functionality. This would enable users to make a proper, relevant fitness-for-use assessment at a time when it was actually required, in order to make a purchase decision

Part of the problem with generating metadata in a geographic context as pointed out by, amongst others, Sefanakis (2003) was that geographical data was distinctly different from the alphanumeric data used in traditional business, being more complex (with space, time history components, etc), collected using different standards and resolutions, and continuously updated and changing. Such data would have some structure, but not as rigidly fixed as, for example, financial data. In Section 2.3 the topics of crowd sourcing and VGI will be discussed along with associated implications for metadata and ontologies. Briefly, where metadata is concerned, ontological structures could be used more to aid searchability and information sharing, rather than less-structured (or completely unstructured) free-text classifications or loose 'folksonomies' which are difficult to categorise and make search and discovery difficult and time consuming.

2.2.21 Satisfaction – Visual appearance

This characteristic has several aspects which are difficult to treat separately when looking at data usability characteristics. There is therefore a considerable overlap between the following three sub-elements: data visualisation; interface design; and human-computer interaction (HCI).

2.2.21.1 Visual appearance – data visualisation

Data visualisation refers to how data is presented, rather than the 'look' of a system's interface (which is dealt with separately). Geographic visualization includes not only the presentation of graphical data, but also control of the user's navigation in the sense of where to go and where to look (OGC 2011b). This key sub-element has been the subject of much research. It was recognised by, for example, Wachowicz et al (2002) and Wachowicz and Hunter (2003) as being critical to the usability of data. Although human perception is an important aspect of many aspects of usability (for example in the tactile feel of an interface, or the audio feedback given from equipment) visual perception is vital in enhancing usability and aiding the decision-making process (Baptista et al 2004).

Some visualisations seem to be able to bridge the gap between producer and user thus improving the chances of the data being more fully understood and used. This may have particular relevance to non-expert users, who may have a greater likelihood of not being able to interpret geographic information easily. Recent work by UCL and London City University suggests that use of 3D and animations can encourage greater engagement with the general public, as well as with more expert users. Examples include the use of 3D animations at public meetings to illustrate the visual impact of fish farms and associated support craft in Loch Linnhe in Scotland (Wang et al 2013). Detailed datasets were used to create an integrated onshore and offshore topographic and bathymetric landscape, generalised to provide a fast-responding impression of proposed developments. The underlying data was of sufficient quality that it could also be used to inform professional and scientific studies, and in Wang's research were used to investigate sea louse dispersal patterns. Care had to be taken with such an approach, to ensure that any animations or simulations (especially those purporting to describe the future) were not stated to be irrefutable fact. Monmonier (1996) urged caution whenever an audience was asked to trust blindly in representations of the future that act like a crystal ball, noting that the professional geographer or scientist would always qualify such representations, but less scrupulous operators with vested interests may choose not to.

Results from Cinnamon et al's study (2009) indicated that speed of animation was critical to perception and that control over frame speed could enhance usability for users. Midtbo and Nordvik (2007) urged designers to be cautious in their study into map panning and zooming. They noted that although people seem to find map animations attractive, little evidence was found that they aided wider usability. They noted that techniques such as a sliding zoom was preferred to stepwise zoom, and likewise with slide movement rather than stepped movement, with users able to track features better. Another conclusion was that the cartography between scales or zooms should not be changed between zoom levels in order to avoid confusing users (although the Digimap interface does just that, although designed for more proficient map users rather than the general public).

Other developments indicate the work being done in the information visualisation (InfoVis) community, applying their geographically unconstrained ideas to GIS in order to engage more than just the traditional cartographic audience. Dykes (2013) suggested, for example, that public accessibility can be increased through the use of sketch-graphs which appeared less formal than traditional graphics plotted by default spreadsheet software, though evidence of this, other than anecdotal, is yet to be obtained. Complex data interactions can be illustrated by animated, dynamic visualisations, such as that of Olner et al (2013).

Although the drive for more realistic visualisations is strong, a balance has to be struck with computer response times, another usability factor. Lange (2011) questioned whether it was worth continually striving for better realism, as, just like maps, landscape visualisations were still representations or illusions, whether of the present, future or past. Sheppard and Cizek (2009) also cautioned against treating modern developments in visualisation only as a question of spatial data and geographic information science. They recognised that the realism of Google Earth, for example, also invoked emotional and intuitive responses. The perennial issues of data availability, data precision, data quality and the level of uncertainty in the data were also considered by Lange (2011), who noted that these issues were typically not addressed in novel visual representations.

2.2.21.2 Visual appearance – interface design

Interface design overlaps with the technical design of appliances and devices as well as with the interface with the data itself but is still relevant to the usability of data itself. This element deals mainly with the interface from the designer's point of view. The next sub-element will take the users' perspective.

Shneiderman and Plaisant (2005) compared the development of computer technology with that of photography or automobiles: initially they were usable only by a small number of enthusiasts who took considerable efforts to master the technology. Now, as the interface has improved and the technology is more commonplace, such factors are no longer deemed as important. A question remains however: is this a result of the interface being so well designed, or of users being so practiced that use becomes almost automatic and subconscious? As Shneiderman and Plaisant stated:

> "Successful designers go beyond the vague notion of 'user friendliness', probing deeper than simply making a checklist of subjective guidelines. They have a thorough understanding of the diverse community of users and the tasks that must be accomplished. Moreover, they are deeply committed to serving the users, which strengthens their resolve when they face the pressures of short deadlines, tight budgets, and weak-willed compromisers (Shneiderman and Plaisant, 2005; p. 31)."

Shneiderman and Plaisant (2005) believed technology designers must reach beyond the 'early adopters' to be successful, and understand the diverse community of users and diverse range of tasks to be satisfied. The changing attitude of technology designers was illustrated by their catering for the inclusion of users with disabilities in their designs. Slowly, it was suggested, the attitude of data producers was also becoming more customer-centred, with their products being designed for a wider, more diverse, audience. In an ideal world universal usability should be the ultimate aim of the data producer.

In further discussing the theory of usability through interface design, Shneiderman and Plaisant (2005) raised two main challenges: first, that theory should be more central to research and practice, thus guiding research and understanding relationships between concepts and generalising results; and second, that theories should lead rather than lag behind practice. This contrasted with reality, where theory is often formulated after development, to explain rather than predict. As Shneiderman and Plaisant (2005) pointed out, effective theory should suggest novel products and help refine existing ones rather than simply explain why something was successful or not with the benefit of hindsight.

The variety of devices used to view geospatial data also sets a challenge as to usability aspects. The same data cannot be assumed to be universally usable across platforms nor on every type of device (as, for example, laptops, tablets and mobile phones all have different sized screens viewing differing levels of detail and also having different technical properties and functions). Nivala et al (2007) gave an example of a difficult to use web map application which, when redesigned with usability aspects in mind, increased its volume of users. It would appear from this study that when several companies provided applications with similar technology, the one which designed the most usable application had the advantage in the battle for market dominance. Making a geospatial service easy to use was a critical requirement for success, especially as the typical user of such an application would be a private, non-professional map user. The interface must therefore be designed accordingly, but also use terminology that would be understood by non-experts. The use of map-specific terms such as layers, topology, etc should not be considered as universally understood by all users. Many authors (including Boulos, 2005) noted the consistent terminology, design and tools used throughout Google Map products, and the various levels of help and assistance offered, which ranged from ‘How to Start,’ through ‘Helpful Hints,’ to higher-level technical information, so providing greater usability to a wider range of users.

Although the above statement is primarily about designing physical entities, a similar customer-centred attitude from data producers is slowly developing. The diversity issue is particularly interesting. In designing physical objects with, for example, disability in mind, designers realised that the wider community also benefited. Dropped kerbs on pavements were originally put in place for wheelchair users, but are appreciated by parents with pushchairs and delivery drivers wheeling goods into premises. This helped streets and pavements become universally usable. Such examples from other areas indicate that improving usability for one reason may have positive knock-on effect in other areas.

Sopan’s (2012) health study noted the requirements for a flexible tool that could use all the different data formats and geographical resolutions used by contributing US states. The researchers asked whether such data was suitable for use by the general public, especially when little metadata was provided explaining the issues. The visualisation tool they proposed also enabled users to access the raw data. This would aid professionals or trained users in examining the provenance of the data, therefore increasing user confidence in its use.

Although the *functionality* of the interface has an obvious contribution to usability, Skarlatidou et al (2011) found that a good-*looking* system also promoted trust amongst its users. Trust was another element of usability, which was looked at in more detail in Section 2.2.15).

2.2.21.3 Visual appearance – human-computer interaction (HCI)

Usability studies have traditionally concentrated on HCI and ergonomic factors while ignoring the influence of data. HCI can, however, affect the way the data is perceived and used. For example, Onsrud and Calkins (1993) noted that the method of presentation of geographic data could have a major influence on how its usability was perceived. With today’s plethora of visualisation platforms available such comments are still relevant, with screen size having a considerable influence on the information presented. Not only is too little information a problem, but on small screens too much information can result in visual clutter obscuring important details. Onsrud and Calkins (1993) also noted a communications gap between the designer/producer and the user, particularly involving feedback of problems.

With its considerable body of literature HCI has a relevance to a number of themes related to geospatial data usability. What enables a complex piece of technology to become almost universally used and accepted, where others fail to become mastered by the population? To what extent is interaction with the interface the cause of acceptance or rejection? Hunter et al (2003) noted how the ‘feel’ of a product was highly subjective, yet could result in its success or failure. They looked at how Google Earth became so popular despite lacking metadata, carrying no authority and having large areas with degraded data. With a well-designed interface, along with easy-to-use tools and easily understood, selectable layers, Google Earth enjoyed high levels of usability through being cost-free, quick, convenient and easy to integrate with other data (to make mashups, for example). Hunter et al (2003) also believed that a good interface could help reduce errors in use, though variations in skill levels meant that use error could never be eliminated completely. Use error caused by issues of poor interface design or function would have a considerable effect on the perceived usability of the spatial data used.

When referring to users interacting with systems and processes, Bainbridge (1983) noted some characteristics that could have wider relevance. Outlining one “Irony of Automation,” she asserted that without some underlying knowledge of the process being used (of an automated process, in her example), users cannot generate successful strategies for unusual situations. Sharples (2009) took this further and believed that it was only when a user enthusiastically explored the complexity of a system could they understand how the system actually worked, and thus harness its full potential. Swap the word 'system' for 'data' and such a view could be equally as relevant in this subject area. Sharples noted that by achieving full understanding of what they were using, users could use the system for complex tasks the system was not specifically designed for. Again, the same could be true of those using data and information in data-rich environments.

Although investigating at systems rather than data, Haklay and Zafiri (2008) looked at how GIS was used in various situations, whether at work, in education, or at home. They conducted a screenshot study supported by a questionnaire, designed to explore how GIS users organised and customised their GIS interface. The questionnaire was a relatively cheap method of reaching a large number of users quickly, and could solicit opinions on satisfaction (rather than solely observing and noting behaviour). Their study analysed the number of toolbars (active and inactive) on the screen; the screen area occupied by map; the software packages used; the number of applications running; and the total size of the map image. They found that users sacrificed map area to accommodate other parts of the interface (such as toolbars and layer menus), so reducing the productive screen area. These findings could be relevant if data producers designed their visualisation for a larger full-screen area, not knowing that the actual visible, usable area for their data could be around 40% smaller than their estimation, thus losing detail and legibility.

Wilson (2010) noted some further usability issues regarding visualisation of geospatial information used by electric and gas utility field workers. As well as dealing with high volumes of data which changes frequently, key usability elements of positional and attribute accuracy were also to the fore. However, issues of data coverage, with data, maps and diagrams provided to field workers that did not cover the entire utility network in an area being considered unusable. Coverage, currency and accuracy were seen as the most important usability elements in that particular context. Presentational problems were also important, with the interface being vital. The study looked at the contribution data made to the HCI, noting that visual clutter overwhelmed users and hid important objects. The solution for this context was to present thematic views, where data relevant to the user's current task was visualised and less relevant data filtered out, thus maximizing the usability of the geographic information provided.

Achieving a suitable balance on a map between too much and too little detail is difficult, and it is not just too much information on a small GUI that is a problem. Lack of information could be due the restricted amount of it that can be physically accommodated on the space available. The choice of scale also limits the ability to present a more complete description of the information, forcing the sacrifice of positional accuracy for graphic emphasis. Such taking of cartographic license could have repercussions. This is due to many users assuming (through convention) that the location of an object on a map bears some relationship to the object's true position on the ground. Beard (1989a) cited examples from Gersmehl in 1985 relating to dots on soil maps in USA which violated this assumption and therefore introduced the possibility for error.

2.2.22 Satisfaction – Quality

Much of the literature on data quality considered usability to be one aspect of quality, but when data usability is being considered, the quality of the data makes a considerable contribution as to its usability. The international standard for geographic information quality (ISO, 2013) does not list usability as data quality element, nor does the US Federal Geographic Data Committee (2015a). This thesis also takes the view that quality is an element of usability, an element with many sub-elements and further subdivisions. Table 2.1 grouped geographic data quality into three sub-elements; Table 2.2 provides a more detailed breakdown into quality attributes, many examples of which will be found in the Results, Analysis and Discussion chapters relating to specific issues found in the case studies conducted for this thesis.

As with ‘data usability,’ the definition of the term 'data quality' means different things to different users and depends on the context. For the purposes of this thesis data quality is described as being made up of a series of data attributes (as detailed in Table 2.2) which, when considered together, provide an indication of quality of that data.

Frank (2006) concluded that a definition of separable dimensions of data quality cannot be achieved, therefore the task of pinning down what represents quality in general may never be complete, though assessments of quality for specific tasks were possible. This assertion did not stop other researchers continuing to make efforts to make general assessments of data quality. For example Coote and Rackham (2008) based their definitions of data quality on the international standard on geographical data quality principles ISO 19113:2003 (ISO, 2003), which defined quality as ‘fitness for purpose,’ a relatively informal and broad definition, which takes user expectations into account. This definition was almost synonymous with that of data usability but not sufficiently precise in the context of the current study to be accepted in its entirety, although components of the Standard provided a useful quality checklist as outlined in Table 2.2. Talhofer et al (2011) added that user satisfaction was the final criteria for product quality evaluation (reflecting usability), but this was not formally included in the Standard.

Good quality data does not necessarily equate to highly usable data. Frank (2010) noted the common misconception that the highest quality data was always preferable, with users forgetting that better quality meant more detail and therefore more data, longer data transfers and processing times, the increased possibility of map clutter, and so on. Bielecka (2003) also noted that high quality data did not necessarily equate to high levels of usability, giving the example of the large amount of data that the Polish Spatial Information System tried to make more widely available for cross-discipline research. It appeared that with so much data available no single person or group could hope to make full use of it due to the sheer volume that was being produced. The 'data tsunami' (as termed by Swan, 2015) is a common issue, for example found in the UK government's Armchair Auditor initiative, where potential users were swamped with vast amount of data and failed to analyse anywhere near the levels that were hoped for (BBC, 2012), or concerning high quality Israeli census data (as assessed by Benenson and Omer, 2003) which had not been exploited as predicted. All the examples indicated that user skill must be sufficient to exploit such data and that infrastructure and resources must be available to make use of it.

Quality sub-element of usability	Quality attribute	Quality sub-attribute
Completeness	Commission	
	Omission	
Logical consistency	Conceptual consistency	
	Domain consistency	
	Format consistency	
	Topological consistency	
Accuracy	Positional accuracy	Absolute external positional accuracy
		Gridded data positional accuracy
		Relative internal positional accuracy
	Temporal accuracy	Accuracy of a time measure
		Temporal consistency
		Temporal validity
	Thematic accuracy	Non quantitative attribute accuracy
		Quantitative attribute accuracy
		Thematic classification

Table 2.2: Data quality attributes
(based on ISO 19157:2013).

Goodchild (2006) suggested that the quality of GI was measured by the difference between the data and the reality they represented. The quality of the data therefore became poorer as the data and reality which it represented diverged. In these terms, quality can be ascribed to a specific feature (for example, positional accuracy), or described in respect to the feature set (for example, the completeness of data). It should be remembered that all maps are actually a representation of reality, which means that all maps are necessarily unreliable and inaccurate (Monmonier, 1986). All locations are described with a certain error, whether geographically or temporally, that is with an error in space (location) or time (perhaps out of date), or both (Frank et al 1991). Expert users understand these concepts of inaccuracy, but other end users may not, especially as the visualisations of such data (such as maps) may lack intuitive cues or any information regarding data quality (Beard 1989a).

2.2.22.1 Completeness

Issues of quality are frequently overlapping or interconnected. Completeness, for example, can be affected by errors of commission or omission. Jackson et al (2013) compared school locations using national, official (government) data and that from VGI. Some schools were included in some datasets, some were missing. Investigation showed that the VGI data depended on a large upload of data some time previously, after which several schools were closed or new schools opened on different sites. Some data was temporally invalid, leading to errors of commission (some old and new locations were both included for some schools) or omission (some new schools were not included in the VGI dataset).

2.2.22.2 Logical consistency

Logical consistency assesses whether data is consistent with its definitions, including whether network connections are missed, whether boundaries of land use make logical sense or not (for example if a map shows the edge of a nature reserve extends to the centre line of its boundary road, which is not logical).

2.2.22.3 Accuracy

Accuracy refers to how well a feature in a data set matches the feature in the real world. Positional accuracy refers to degree of matching from (for example) a coordinate system to the feature on the ground, or to how well a data point matches a feature (does the point lie within the real world object, for instance). An example of a temporal issue was given in Section 2.2.21(a). Thematic accuracy refers to classification or feature attribute factors.

Goodchild (1989) had already noted that all spatial data were of limited accuracy, far exceeded by the precision levels of GIS, which in turn gave a false indication of accuracy. For example some GIS gave unrealistically precise latitude and longitude measurements to 14 decimal places. Goodchild asserted that the means to characterise accuracy and track uncertainty through GIS processes were inadequate, and also noted that despite the term 'uncertainty' being much used in the geographic research community it did not occur in the relevant ISO standard (Goodchild 2007b). Toth and Tomas (2011) also noted the misuse of some of the above terms when used in metadata (perhaps illustrating the gap between the actual producers of the data and those tasked with creating the metadata), including confusion between the words ‘accuracy’ and ‘precision,’ indicating the need for data providers to define these terms. Using the terms interchangeably ignored that the first related to measurements while the second referred to the properties of the measuring instrument.

Geospatial data were also inherently unreliable due the world constantly changing and nature itself rarely being distinct and clear, hence the data may not be totally accurate (Frank, 2006). Nature can be fuzzy or gradual but to make it more easily understood generalisations were made and this, by definition, creates error and uncertainty. Levels of error and uncertainty vary from dataset to dataset, having been affected by the methods of measurement and sampling, processing and so on. With the realisation that not all geographic data was of equal quality, there was a need (as recognised by Maffini et al, 1989, and others) to deal with this issue in a proper manner. Completeness of data was also seen by Onsrud et al (1989) as one of many factors of data quality, though Maue and Schade (2008) viewed completeness as one of its key components. They noted that the spatial heterogeneity of completeness was normally neglected and rarely communicated despite playing an important role in the overall quality of the data. One reason for the differences in completeness was the increasing amounts of spatial data coming from piecemeal sources, reflecting the rise in VGI, etc. They suggested various visualisation techniques with which to represent the various degrees of completeness and quality, from blurring or ‘fogging’ unmapped areas (as suggested by MacEachren in 1992) to reducing colour saturation of some map categories. This also raised the interesting question of how to grade completeness. Is completeness binary? Is an area simply complete or incomplete, or are there grades or levels of completeness? These questions have arguably yet to be fully answered and are subject to ongoing research.

Inaccuracy is another component of GI data quality, and may be generated by data collection (source error) and in processing (process error) (Beard 1989a). With traditional map production process error generally ceased with the final compilation and publication of a map, but with GIS the potential for process error remained as easily carried out manipulations could potentially contribute new errors to the data. Goodchild (1989) concluded that each step of any processing of spatial data introduced error of various types, while Brusegard and Menger (1989) noted that GIS had the potential for users to multiply and cascade errors in ways not understood by them at the outset of the process. This is especially true of the vast quantity of geospatial data, of variable accuracy and quality, created and contributed by users Goodchild (2008). Goodchild however also asserted that in user-generated content, VGI and mashups, some inaccuracy was almost expected, and generally ignored. This provided another indication that in some situations the level of data quality was not the major factor in its usability, and again emphasised the importance of context of use.

2.2.22.4 Non-locational accuracy

Non-locational accuracy, alternatively termed ‘attribute accuracy’ is a subset of the accuracy sub-element. Geographical objects and data also possess nonlocational characteristics which can be sources of inaccuracy and uncertainty. The description of a real-world entity (such as a woodland) could be realised in many different ways: coniferous/deciduous; oak forest; commercial plantation; orchard; etc. Error, uncertainty and unreliability could creep into these descriptions for many reasons, similar to those errors associated with locational characteristics. For example, if classification is done by remote sensing, the software used may have mis-classified a specific oak forest as the more general term deciduous woodland. A field sample may have missed certain species that make up a small proportion of a forest, meaning the forest is classified as a feature consisting of one species. It is possible however, as stated by Guptil (1989), to ascribe categorical accuracy to such data and provide this information to potential users.

The need to identify principles of uncertainty and model them mathematically was the conclusion to Talhofer et al's 2011 study into spatial data analysis and data quality, using a case study looking at measuring terrain complexity to identify cross-country routes for army trucks in the Czech Republic. This study also pointed out the problem of defining quality, noting once again that the context of use was one of the main determinants in ascertaining spatial data quality.

2.2.22.5 Communicating error

Error could be introduced in any of these categories, some could be obvious at first glance of a resulting map, others may be well hidden, with the potential within a GIS for a cascade of such errors to result in erroneous information which users would assume as accurate and definitive. The generalisation of maps can cause many such errors, with Beard (1989) pointing out the hazards of such maps, especially where they were not accompanied by information on the source material, classification, interpretations and degree of generalisation. Without this information users could easily use the data inappropriately. Gersmehl (1985) noted that some generalised maps in the US caused legal action involving individual property rights and property taxes caused by the generalisation process ignoring small pockets within larger areas.

The quality elements as itemised in Table 2.2 form part of a long list of interlinked factors which offer an indication of quality. Other factors not mentioned in the table, or in international standards, for example, may also contribute towards data quality, and hence usability. For example Petrovic et al (2011) found that the variety of scale, accuracy and detail in the data that made up Slovenia’s NSDI had significantly affected its usability. Beard (1989) raised the possibility of another type of error: use error, when maps compiled for one purpose were used for other purposes for which they were not suitable. Mashup creators and VGI users, less well versed in the conventions of mapmaking, may fall foul of this error. How users are informed of such issues has been the subject of much study.

Many researchers have outlined potential solutions to the current challenge of communicating all the different types of accuracy and reliability information to the user. Maffini et al (1989) suggested being more explicit about error, both in source data and its derived products. As error and level of accuracy will vary depending on the subject, the method and the context, these differences must be communicated to users to enable them to make more informed judgements about the geographic data they were using. This attitude was supported by the work of De Bruin et al (2001), who suggested a decision-making method for choosing the best data set, taking into account the uncertainty due to error in each set. Frank (2006) argued that error, uncertainty and incompleteness were necessary and important aspects of how people organised and used their knowledge, and recommended they be taken into account when designing GIS and using geographic data. Maue and Schade (2008) suggested a quality layer for each dataset, but noted that presenting a choropleth of quality may itself imply a clarity and precision which did not exist, before proposing the use of a more complex regional quad-tree approach.

Brusegard and Menger (1989) assumed that solutions would be available for these issues of accuracy, error and reliability because these types of issues were common in GIS. The authors wondered if such thinking actually occurred within the GIS development community, as there seemed to be no standard tools or techniques available to deal with them. There seemed to be little investment in the GIS industry towards addressing the issues of error at each link in the process chain, nor in altering the design (or the designers' attitudes) of standard datasets to reflect their use for a wide and unpredictable range of purposes. It may seem counterintuitive that users would accept data which acknowledged inherent inaccuracies and errors, but there is one glaring example of unreliable GI data being highly used: Google Maps. Goodchild (2008) suggested that users assumed from the outset that the data was unreliable and not 100% accurate, but that it provided a useful, general indication of the geography. Users may recognise that Google Maps, and other data, may have such a high number of errors or require such a level of pre-use processing that it may not be practical for use in high quality decision making (Wachowicz et al 2002), and act accordingly.

2.2.23 Other factors contributing to geospatial data usability

Other factors which are considered to make a major contribution towards the usability of GI data do not feature in the official International Standards. Context and organisational issues (particularly organisational culture) are two such factors, and will be discussed here.

2.2.23.1 Context

Context is one of the key issues regarding geospatial data usability. Instances from the literature will be used to illustrate the influence of context on usability. Issues with data volume will form the first series of examples. It may be assumed that the only issue surrounding data volume was obtaining sufficient data for a task. On the contrary, in their paper introducing a visualisation tool for US government health data, Sopan et al (2012) implied that government departments (not only in the US) could not simply upload a high volume of health and demographic data to the web and expect the public to make use of it in an informative way. The amount of pre-use conversion required for the data used in their study would make this impossible (or at best unrealistic) for an untrained or non-geographer user, and they asserted that any government or large data producer should have known this beforehand. Several examples of excesses of volume were provided in section 2.5.10.3, including: Bielecka's (2003) example of so much high quality data being available through the Polish Spatial Information System that no individual or organisation could cope with the volume produced; the UK Armchair Auditor initiative (BBC, 2012) where users were swamped with high volumes of differing data; or Benenson and Omer (2003) reporting on underused Israeli census data due to volume. In terms of data volume, therefore, levels must be appropriate in the context of the task, and the appropriate tools and background information available (via metadata, again highlighting the importance of this factor) in order for the data to be searched, identified, downloaded (or processed as appropriate) and interpreted. With the UK Armchair Auditor initiative as a specific example, this involved the government releasing the contents of a government spending database (Coins) which ran to millions of lines of raw data. The government acknowledged there were no user-friendly tools readily available for users to access this data, but that its mere presence on the web would result in applications and tools being created (but not necessarily by the data producers or providers, but unknown third parties) to query, slice and analyse it. The data.gov website (UK government, 2010) acknowledged that at the time of release some expertise in constructing SPARQL queries would be required to extract information from the raw data, but that web-widgets would appear to do these tasks. Very few reports have since been made concerning information obtained from the Coins database by anyone outside government.

The quality and usability of information used in smartphone augmented reality (AR) applications was looked at by Yovcheva et al (2012). Despite over 500 different AR applications being available and annual downloads expected to reach 400 million by 2014, perceived usability and utility were low. This study found various causes, many of which tied in with the usability elements outlined in the Background chapter, but which varied with the specific applications involved. Issues included:

- Having too much information on the screen, with tags, dialogue boxes, north point and descriptions all overlapping and obscuring the image (annotation overlap and real-world occlusion);
- Out-of-screen annotations (therefore the user missed a lot of information);
- Illegibility (text too small);
- Ambiguity (floating tags vaguely located, especially advertising tags, making it unclear what they are indicating).

What seemed to be required was a system of filtering to maintain the quality of visualisation, as there was no aesthetic relationship between the information and the background. This filtering would be based on the context of use, as defined by the user's expressed interests. It was the context that highlighted the usability problems, in that the clutter was caused by information not required by the user at that time. Future studies would be expected to identify a list of user requirements that changed according to context, and a set of design guidelines for meeting these requirements while avoiding the issues outlined in the previous paragraph. Although non-expert users may have perceived a purely interface problem, the real issue was with filtering and selecting data according to user needs and context.

Similar issues were addressed by Taigel et al (2013). By restricting the information available in their AR application, which was designed to communicate ecosystem services, only the data relevant to this topic was visualised. They found the technology worked better as a communication tool where there were wide open vistas, such as over open farmland. Walks on urban tours became confused when points of interest (POIs) appeared on the interface but the actual feature was not within line of sight. Adjusting the radius for POIs to be picked up mitigated this. Usability was also restricted by interface issues such as screen glare, battery life, signal quality and text size. However, users did not all appreciate having their attention constantly diverted from their surroundings, therefore in some circumstances less information was considered better. This example illustrates several issues regarding context. Firstly, using the same data and the same interface but in urban and rural contexts resulted in different perceptions of usability; secondly, personal perception plays a role in perceived usability, with some users experiencing less satisfaction than others due, it seems in this case, to personal preferences. Once again the difficulties in assessing usability were made apparent, where geographical, personal and interface factors all combined to produce a complex picture. No quantitative study was made of the usability issues in this case, again highlighting the lack of a clear methodology for assessing the usability of geospatial data.

Issues with different data formats in different contexts also highlight how usability can change according to user demands. A report by Kelly (2010b) noted the differences between a full-blown GIS and a simple pre-rendered map, contrasting the ESRI Shapefile and the OpenStreetMap (OSM) XML format, but noting that the gap appeared to be narrowing with more simplified vector products becoming available. The ESRI Shapefiles use several different files in different formats (.shp, .shx, .dbf) which provided a lot of information, stored efficiently and easily accessed by computer, but which were not in structures convenient for exchanging and interchanging data. Kelly also noted 14 different types of geometry used by Shapefiles. Shapefile version of OS Vector Map Local had street names in an entirely separate layer from the streets (somewhat inconvenient for a user wanting to access streets with their names). OSM had everything in one file, and though OSM XML was inefficient and slow, it was human-readable (in that the logical structure of data was obvious without formal documentation). It had only two geometry types (nodes and ways), and simple freeform text attributes. Kelly speculated that 'professional' map data was always intended to be accessed via a GIS, whereas OSM never prioritised its use by GIS. Interchangability of each other's data would never, therefore, have been considered. Kelly concluded that, similar to the previous paper, 'kitchen sink' file transfer formats for vector export should be avoided, as too much unrequired information would be involved. Instead, at the design stage, developers should proceed on the basis that users should not be required to use a GIS to read vector data, and that usability of data should be the main concern, rather than focusing on the technicalities of internal storage format as is the case at present.

In summary, the usability of geospatial data cannot be assessed without context. Geospatial data usability is not, therefore, a value inherent in the data: it changes depending upon how the data is used. The implication for this thesis is that the datasets to be assessed will require their usability to be assessed in a particular context, and that the results of that assessment will only have direct relevance to that context. This aspect was used to inform the approach to this thesis, and highlights the difficulties in making general conclusions from specific observations where geospatial data usability is concerned.

2.2.22.2 Organisational issues

One issue which has a considerable contribution to usability, but which will not be considered as one of the foci of this thesis (due to being unconnected with data issues) is that of the user's organisational culture. For example, in a project to share data on coastal erosion along the Italian Molise coast with a variety of local, regional and national stakeholders, Caiaffa et al (2008) noted that despite using only data certified for their provenance and reliability, accompanied by full metadata, and on a system open to all interested parties, usage levels were low. This was due to institutional resentment and the internal politics of the organisations involved. Such findings could be applied across the social and cultural sphere, where technical barriers to use are absent, but perceptual and cultural problems remain.

2.2.22.3 Appropriateness

A further element, subtly different from that of context, is the appropriateness of the dataset for the task. This element ties together many practical usability aspects, such as scale, resolution and precision. For example, if the data is provided at one particular scale, it may be unusable at others, as per Yovcheva et al's 2010 study into spatio-temporal data in virtual globe environments, which highlighted the need to have maps and data at a variety of appropriate scales when users were required to work on a small study area.

The factors covered in this section give an indication of the almost ecological way in which characteristics and issues relating to data usability are interconnected and dependent on other characteristics. Such overlaps are the norm for usability issues, as will be seen throughout the remainder of this thesis.

2.3 Crowdsourcing, geospatial data quality and usability

Web 2.0 is a broad term used to distinguish the move away from the web simply disseminating information to users, towards the users actually creating data, manipulating it, analysing it and presenting the resultant information. Social media sites (such as Twitter and Facebook) and other user-generated information sites (such as those termed ‘wikis’ after the Wikipedia website) are examples of Web 2.0, as their content is mostly created by the users themselves, often as a community. Sir Tim Berners-Lee (IBM 2006) did not like the term, believing the person-to-person connectivity signified by Web 2.0 was actually the aim of the original Web creators all along (BBC 2005). Taking on board such sentiments it is argued here that the term Web 2.0 was a useful shorthand way of signifying the practical changes from the early days of the Web, and can be used to comment on how such changes have been perceived by users, commercial interests and governments.

The use of Web 2.0 in the field of GIS gave rise to VGI (volunteer geographical information), a term defined by Goodchild in 2007 as a special case of user-generated content, encompassing sites such as OpenStreetMap and Wikimapia. The new concepts of CGI (collaborative GI), and PGI (participative GI) also reflected the wider range of potential contributors, while adding to the terms used in other subject areas such as 'citizen science' and 'citizen sensors' (Goodchild, 2007). Problems highlighted by Haklay (2010b) was that there has been no systematic analysis of the quality of VGI, and that one early perception of VGI was that of NIMBY (not in my back yard) geographical information, as the public only got involved to stop developments that affected them, and such involvement was informed by user self-interest (Haklay 2012). He also argued, however, that this was not borne out by the current evidence, which pointed to VGI as a possible source of valid geographic data with a whole host of applications. Veregin (1999) expressed concern with VGI quality as their data did not have to conform to any quality standards, in contrast to that produced by national mapping agencies. More recent concerns have been expressed regarding the absence of quality standards and of professional oversight in the rapidly-increasing volumes of VGI data becoming available (Feick and Roche, 2012).

For example Newman et al (2010) reported that many organisations had developed websites to support their volunteers and facilitate data entry and dissemination. They were using these volunteers to contribute information, sometimes termed 'citizen sensors.' In this case individuals could contribute data to web maps such as 'Invaders of Texas' and the 'Invasive Plant Atlas of New England.' Many of the sites used Google Map technology, or interacted with Google Earth applications to provide a professional-looking and familiar interface to users. The professional appearance of the interface also raised user expectations, therefore creating a demand for fast performance and an easy and quick way to post information. Such sites (and other, more well-known sites such as OpenStreetMap) must be usable by as wide a spread of the population as possible in order to be successful, and engage a range of interest from those simply wanting to input as well as those with more time and knowledge to explore further. Some basic usability issues were apparent in these map sites, such as the use of technical terms such as 'layers' and 'legend' which were particularly difficult to understand by non-geographers.

Goodchild and Li (2012) noted the ongoing discussions regarding trust, credibility, quality and coverage of VGI, emphasising that VGI is more likely to be trusted than other forms of user-generated web content due to the long-established view (as noted by Monmonier, 1996) that geographic representations are perceived as objective facts, more so than the written word and other representations. VGI is not the only type of GI which causes concerns over usability. Another example of the importance of usability was given by Zhao et al’s (2009) project to increase the visibility and usability of some US government data. The project took US National Agricultural Statistics Service (NASS) crop data, which was held in spreadsheet form, and integrated it with relevant geographic data to make it possible to discover, retrieve, analyse and visualise in a geographic context, thus improving the usability of the data over its previous tabular format. This new system improved the accuracy and speed of response of the decision support system.

Web sites consisting of user generated (UG) geographical content are increasing and becoming more established in society, such as Wikimapia (wikimapia.org/) and OpenStreetMap

(openstreetmap.org/). These websites allow anyone, in theory, to contribute to a map of the world. Crowdsourcing and editing are intended to be more accurate than information provided by one individual, on the basis that multiple contributions will eventually achieve the correct outcome, though in some cases it would be down to the viewer to be aware of any limitations. The possibility of vandalism, mischief or purposely erroneous information being included is rarely highlighted, but is a risk with any UG content, and Goodchild (2008) suggested that protocols should be built in to take these into account. Google suspended their Map Maker after an offensive image was posted on a map of India, and kept it offline until they reviewed ways of preventing a recurrence (Guardian, 2015). OpenStreetMap (OSM) and Google Maps allow users to create or move locations of objects, for example enabling people to ‘correct’ the position of their own homes. Such editing may in fact change the relationship to surrounding objects so that the overall picture actually becomes less accurate. On the other hand, such sites could enable a new road to be mapped before a full, ‘official’ ground or aerial survey takes place, using the local population as citizen surveyors.

Maue and Shade (2008) noted some quality issues, particularly relating to completeness, which seemed to apply specifically to VGI, reporting web maps with missing features (feature incompleteness), lack of thematic attributes where, for example, a street is shown without a name (thematic incompleteness), and incorrect geometry/topology with, for example, lines not meeting (spatial incompleteness). The point of VGI is that it depends on volunteers, and therefore the level of coverage and completeness is generally dependent on the number of enthusiasts in any particular area. In areas without a population of keen volunteer mappers, there may be no coverage at all, and this was borne out by studies which noted that rural areas (Zielstra and Zipf, 2010) and areas of low socio-economic status within cities were losing out on VGI map coverage (Mashhadi et al, 2013). Steve Coast, founder of OSM, asserted that “nobody wants to map council estates but these are places that people aren’t that interested in visiting anyway,” (GISPro, 2007). This seemed to miss the point about OSM’s aims of providing a road map of the world. Maue and Shade (2008) did point out, though, that VGI can produce maps of a very high standard for some areas. Haklay followed this up, noting in 2008 that online communities in general were not necessarily inclusive, and that OSM in particular effectively shuns socially marginal places, and therefore socially marginal people, thus causing problems of coverage and completeness.

Zielstra and Zipf's 2010 study compared TeleAtlas and OSM road data in and around Germany’s five largest cities, and five other medium-sized cities. They found that in cities TeleAtlas had mapped considerably more roads, but OSM included many more small side streets and pedestrian paths. The completeness of OSM coverage dropped sharply with distance from the largest cities, particularly so from the medium-sized cities. The conclusions from their study included comments on usability, in that coverage of OSM-type data in rural areas was too poor to be a realistic alternative to commercial equivalents, despite being an extremely cost effective (that is, free to obtain and use) alternative in densely-populated urban areas. Once again, their research stressed the importance of the application in hand, and highlighted that the context of use was seen as the key determinant of usability.

Maps using data sourced by VGI may also have a degree of variation in quality within the map. Volunteer mappers may have mapped less popular areas, but at a much lower scale than in densely-populated urban areas, where more sampling points were taken more frequently. The representational variation over the map scale and the minimum unit of measurement is not easily recorded or presented to users (Comber et al, 2007). The map results may be valid, but the dangers inherent in assuming a standard level of coverage, coarseness and sampling interval and carrying these assumptions unnoticed into analysis or decision making, may not be obvious to untrained or unaware users. This issue was confirmed by Parfitt (2012) who pointed out that when analysing the location and extent of VGI projects monitoring biological diversity there was a strong bias towards the projects being located close to human settlement.

2.3.1 Data quality: crowd-sourced versus ‘official’ data sources

The lack of VGI and other data (such as Google Map point of interest data) in rural areas means national mapping agencies are often the only source of data for such locations, and Butchart et al (2013) used Ordnance Survey Open Data products to develop a smartphone mapping and data-capture app for use by higher education students, pointing out that insufficient alternative free-of-cost data existed for the area covered by the study. In some specific situations rural VGI was more usable than the PGI sources available. Parker et al's (2012) study noted that recreational kayakers used VGI for situations where information at the required scale was not available from PGI sources, but still required PGI where it was seen as more reliable. The kayakers used PGI for information on topography and to calculate distances down stretches of river (and other static, objective features), but used VGI for riverbank heights, launch points and river access points ie fast-changing subjective data), obtaining a level of detail not available in conventional PGI using information provided by their own sporting community. In a later study, Parker et al (2012) confirmed these broad conclusions, adding that the channel through which the information was received was important, with regularly updated, interactive channels having a higher chance of reflecting the current situation and therefore being used more.

Inconsistent coverage issues may not be specific to VGI maps, but were found much less frequently in the products using data from national mapping agencies or from established commercial concerns. Several comparative studies attempted to quantify such differences particularly (as Zielstra and Zipf pointed out in 2010) as questions were often raised about the quality and reliability of VGI, though rarely asked of commercial concerns. In addition to the specific issues found by the Maue and Shade (2008) study, Newman et al (2010) noted some wider points applicable to PGI and VGI, particularly the gap that needed to be bridged in order to reach citizen science standards of accuracy and precision. In examining the ways in which citizen science usability research can advance GIS in general, the need for education of users in the fundamentals of spatial literacy was obvious. Newman gave the example of a common misconception sometimes held by non-geographers: that if a map did not show the presence of an invasive plant in a certain area, it did not necessarily mean there was actually none present. This raised fundamental issues, as reported by Monmonier (1996) of non-expert users viewing maps as containing 'gospel truth,' and highlighting the need to inform users about accuracy, precision and uncertainty, and also the need to distinguish clearly between content that is 'blogged' and that which is of a scientific standard.

The term 'Volunteer' in VGI implied that contributors operated with purely altruistic motives (Brando and Bucher, 2010) highlighting the fast VGI response to natural disasters such as the Haiti earthquake. In this thesis we have seen that useful VGI is often provided to, and used by, fellow members of a particular community, such as kayakers reporting river conditions and riverbank entry points (Parker et al, 2012). Even with the best intentions, however, contributions may be of low value. Malicious postings or vandalism have featured in other UGC and VGI sites, such as Google Map Maker, where content is often anonymous. Wikipedia (2013b) provided a list of Wikipedia hoaxes, with some apparently created to catch out lazy journalism while others appeared to have financial, political or self-promotional intentions. Similar motivations may apply to map wikis. Bishr and Kuhn (2007) noted the self-regulating anti-vandalism aspects of having a large body of contributors, with the 'crowd' quickly repairing any damage whether intentional or accidental. Coote and Rackham (2008) noted that community users were tolerant of errors, but expected them to be corrected relatively quickly. There was very little empirical evidence of the success or otherwise of this approach.

2.3.2 Representativeness of crowd-sourced data

There was also the question of whether the wiki model was actually that of a community. Real interaction between contributing members was rare, with little opportunity to establish relationships between individuals (de Man, 2006). Without this little social trust would develop between members, and without social trust the community would be more prone to decay over time. Similarly, many of the geographic wikis lack the dynamics of social networks or web-based communities. One exception was OpenStreetMap, with its mapping parties, but in general there were few opportunities for true collaboration. Issues regarding working collaboratively were considered by Yovcheva et al (2010) who looked at developing a truly collaborative, web-based virtual globe application with synchronous use. Perhaps surprisingly (considering the intention to have a 'community' approach), users strongly believed that different access levels were required for different users and that completely unlimited access to datasets for everyone was not a good idea.

Bishr and Kuhn (2007) also asked if it was possible to make collaborative GI more usable for a wider base of users, and raised three sub-questions:

- With such a large flow of information, how can it be ensured that the high value contributions were embraced and used and the low value (or fraudulent) ones were discarded?
- How could metadata be provided for this type of geographic information?
- How could the semantics of collaborative GI be made explicit to enhance the overall usability of the data?

Some researchers have suggested answers, but more have confirmed the importance of the questions.

2.3.3 Metadata of crowd-sourced geospatial data

The lack of metadata was identified by Brando and Bucher (2010) as a main restriction on the usability of VGI. Without it, users could not be expected to understand the data content in any detail. They acknowledged the role of VGI in disaster response, where local contributors could provide more up to date information than traditional agencies when the initial response may not call for high levels of accuracy. Again, context was key, and in the correct circumstances VGI could be considered extremely useful and usable. According to Aditya (2010) neighbourhood groups (in Indonesia, in this particular case) rarely had useful and usable means available to help analyse the geographic data collected by their local community. In common with findings of other VGI and PGI studies relating to community groups, they lacked the resources and knowledge required for data transfer and translation. Additionally (in the Aditya study) the data could not be integrated with government data. Similar issues were raised by Wiemann and Bernard (2010) who noted the near impossibility of incorporating user generated geospatial data into existing SDIs due to the use of isolated VGI applications with widely different formats and structures. This effectively restricted the audience for the data meaning it was not necessarily available for scientific research. Some more recent research looked at how such data could be used in one-off exercises: Klinkenberg (2013) noted the use of VGI in building the Atlas of Plants in British Columbia; how VGI was used in the aftermath of natural disasters such as Hurricane Katrina (Miller, 2006); and after the Haiti earthquake (Poore and Wolf, 2010; Sweta and Bijker, 2013).

It would appear that cost considerations drove the push for more-established VGI products to becoming more accepted and acceptable in scientific and commercial circles. Newton et al (2012) reported how OSM road data was used along with OS MasterMap data in crime analysis in Leeds. MasterMap provided information on buildings and house types on a commercial license while OSM provided data on roads free of charge. Cost was one of the main obstacles of using GIS to study crime therefore using OSM data saved costs while accessing up-to-date road data. Bishr and Kuhn (2007) had noted the semantic structures of VGI may restrict usability. As Gliozzo (2013) pointed out, the lack of standardised taxonomies (ie the vocabulary used in the dataset) meant that thematic accuracy suffered due to the inclusion of synonymic terms (having the same meaning but spelt differently) and homonymic terms (spelled identically but with different meanings). Although VGI projects such as OSM had some standardisation practices, other crowd-sourced products and projects may not, causing problems to be encountered during efforts to merge heterogeneous databases, with naming conflicts being especially problematic.

In looking at the quality of crowd sourced and VGI data, Goodchild (2008) suggested a more user-centred approach to metadata, rather than what he saw as the current data-centred approach. He suggested that users who struggled to find and use such data may voluntarily add metadata as an aid to its future accuracy, usability and searchability. In the same paper Goodchild also argued for a new category of metadata, relative metadata, identifying how the data can or has been used relative to other datasets. This reflected the view (in the paragraph above) taken by Fisher who encouraged both positive and negative experiential metadata. These would be relevant and useful additions to the ‘standard' metadata content, but achieving any degree of uniformity for such information would be a daunting task.

Some sites such as Flickr (2013) eschew strict standards or any uniformity for their photograph uploading and sharing service. They operate a free-ranging metadata system, with no predefined categories, in effect creating a ‘folksonomy’ (as defined below). Some suggested categories provide options for a loose structure, with very general labels such as 'who,' 'what,' 'where' and 'when' pre-supplied, to which users can attach free text information. The folksonomy model is one possible way to make geographical metadata more acceptable to the general user.

‘Folksonomy' was defined by Ince (2012) as a term used to describe the tagging of Internet content with some extra information that provides a description of the content. The term is formed by combining the words folk (the users who carry out the tagging) and taxonomy (a form of structural organization). The less-formal folksonomy contrasts with the usual types of ontology (a structural framework for organising information) used for geographical data. There are various definitions of ontology, with none dominant (Frank, 2001) but geographical definitions include: a set of knowledge about a particular domain, such as topography (Ordnance Survey, 2013); an explicit specification of a conceptualisation, and a conceptualisation is an abstract representation of the world (Comber et al, 2004).

2.4 Assessing usability of geospatial data

The discussion on data usability and quality continues, albeit slowly and with no clear conclusions. Standards are drafted, consulted upon, and left behind by technological developments. Usability factors are suggested and amended, data quality measures proposed, and no consensus is reached. There have been, however, practical examples of assessing usability and some of these will be reviewed here, starting in general terms before looking more closely at testing the usability of data, and of geographical data.

There is considerable literature on assessing the usability of entities such as products and devices, and traditional usability testing typically involved observing a user interacting with a product while undertaking specific tasks (Mayhew and Mantel, 1994). This is ideal when investigating the usability of a specific product, but less so when looking at the underlying data being used. This aspect of usability testing has yet to develop any traditions due to a number of reasons, one of which is the relative rarity of studies that evaluated the usability of geospatial data (Hunter et al 2003).

Usability evaluation of data from any subject area is relatively uncommon. Prins et al’s (2002) study of usability issues regarding medical data was mentioned at the beginning of this review. Franca et al’s (2008) study into the usability of cause-of-death statistical data in Brazil provided another rare example. Franca's study was retrospective, comparing how the subject data matched up against official, high quality government data. Their method did not examine how the structure and presentation of the data affected usability. However, it made the point that data of poor quality would fall into disrepute, and despite continuing to be collected would simply not be used by those involved in policy making or health studies. They asserted that in such cases improving data quality would improve usability.

Even less research has been carried out into the usability of spatial data (some possible reasons for this lack of interest are suggested in Chapter 7), and some examples are outlined here. Meng (2005) asserted there had been little attempt at understanding map users’ requirements, but in the same year van Elzakker (2005) looked at usability of maps and methods of measuring usability. A variety of methods were used to measure usability:

- Questionnaires - tailored for the specific study and to the maps involved;
- Focus groups - where discussions on specific topics could be examined in more detail;
- Interviews - with users, usually structured or semi-structured, going in to detail and exploring issues;
- Observation - of users actually using the system, usually conducting pre-defined tasks.

The study concluded that by incorporating user centred design (UCD) and task analysis at the design stage, the context and user goals could be identified, and the data presented in such a way as to help achieve these goals.

In another rare example of investigating the usability of map data, Hengl and Husnjak (2006) evaluated the usability of 1:50 000 soil maps in Croatia to find out possible reasons as to why the maps that were available were not used to their full potential. They suggested a methodological framework using ten aspects: lineage, consistency, completeness, effective scale, attribute accuracy, thematic contrast, accuracy of legends, integrity, popularity, and accessibility. Comparison was made with control surveys and full profile descriptions. They found various issues which all served to make the maps less usable for spatial planning, including problems with boundaries corresponding to a scale of 1:150 000 and observations corresponding to 1:250 000 scale, both translated to the 1:50 000 target map. The maps were usable for small scale applications, but not for decisions that required the greater detail of 1:50 000 maps. The root cause of such issues was deemed to be the lack of response to user needs, and concluded that the involvement of end users could improve the usability of the dataset.

Some examples of identifying levels of completeness were available: Haklay's work on OpenStreetMap in the UK (2010b), and similar research by Zielstra and Zipf (2010) in Germany, compared different map data in order to estimate accuracy and completeness against a standard (usually VGI versus a national provider, such as Ordnance Survey in the UK), and used the completeness and coverage findings as proxies for usability. These studies used relatively straightforward calculations of total road network lengths to assess completeness, and employed GIS buffering techniques to identify the comparative accuracy of road positions, with both compared to a 'gold standard' dataset. The 'total length' approach was used in one aspect of research for this study, investigating changes in OSM coverage in South Wales (see Section 4.6.3). Comparisons of VGI and FOSS map data with commercial products have been one of the few fertile sources of information on aspects of spatial data usability (see above), and several emphasise the financial savings available through the use of VGI or FOSS data. Cost is one of the few easily-identifiable and obtainable usability factors, but it is not appropriate to consider it in isolation. Again, context is important. However, comparisons between VGI, FOSS and standard commercial map products can make useful contributions to usability studies.

2.5 Previous studies on geospatial data usability

Harding and Pickering (2007) looked at spatial data usability in the context of professional users. They identified 40 different task contexts (including flood risk analysis, planning and urban design, emergency planning and response, etc), and priorities for the data differed between contexts. The three key characteristics of usability from ISO 9241-11 (1998) - effectiveness, efficiency and satisfaction - were used to address usability. Effectiveness and efficiency were used to determine user performance and satisfaction used to measure user attitude. By setting up a usability framework using performance and subjective factors the study outlined measures of all three key characteristics. This showed it was possible to gain some indication of spatial data usability, measured against a standard, but taking into account the context of the task. Further work was suggested to explore the three components with respect to data design guidelines, and examine the possibility of 'building-in' components of usability.

As late as 2011, Brown et al (2011b) noted that studies on GI data usability were still underdeveloped compared to those on mainstream usability. Most mainstream usability research was conducted on the human-computer interface (HCI), and though much was not directly relevant to geospatial data, there were some broad connections that could be made to map usability (for example Nivala et al's (2007) study into how usability engineering was included in the development of map services in Finland). As usability in software engineering was usually applied to the graphical user interface (GUI) the maps themselves were regarded as the GUI. Results supported the suitability of usability engineering for map application design, since by including the usability approach into the product design, while simultaneously taking into account the individuality and diversity of users and their tasks together with the characteristics of the maps, developers were more likely to design products that had a higher degree of usability. Mayhew and Mantel (1994) had noted a general approach to usability engineering which involved three main strategies:

1. Early focus on users and tasks - apply user profiling, task analysis, prototyping, and user walkthroughs;
2. Empirical measurement - questionnaire administration, lab and field usability studies, and (where possible) collecting objective, quantitative performance and satisfaction data;
3. Iterative design – Design/redesign taking into account user feedback, and test again.

A similar approach was taken in recent research into geographic data usability, for example Butchart et al (2013), which was described in a previous section; Tanaksaranond et al (2013) and Taigel et al (2013) will be described at a later point.

2.6 Methodologies used to assess geospatial data usability

When looking at the usability of any data, a number of different products and methodologies could be used to access and analyse it, and this is particularly true given the nature of geographic information (Brown et al 2011b). The interaction with a particular GIS can have a major effect on the usability of the data (Brown 2010), as can the widely varied range of contexts of use. One approach to conducting usability assessments of data uses a typical interface, an exemplar, but this would not identify the typical user experience where many diverse systems were actually used. Assessing multiple interfaces would enable a better understanding of the problems caused by the data across different software, but this approach would take considerable time. A usability assessment could therefore be made independently of the interface. This is difficult to achieve, and of course may not reflect the actual experience of users.

More recently, Brown et al in 2010 investigated the usability of Ordnance Survey MasterMap products, but rather than looking at the interface the study looked at the underlying map data. Using a battery of techniques, they sifted through information on map users to find issues with MasterMap using Human Factors theory: 55 users of the data were interviewed; six market research reports relating to MasterMap were reviewed; reports were reviewed from two usability workshops held with customer support staff; an examination was made of a list of Frequently Asked Questions put to customer support staff; and three databases with customer's input and comments about the products were investigated. A heuristic evaluation was then carried out on MasterMap using cognitive walkthrough techniques. This was a long-term project which aimed to identify useful features which could be built in to future products. Heuristic evaluation uses experienced-based techniques for problem solving and discovery, rather than rigidly-defined rules (as described by Stevenson, 2012). Examples of the technique include trial and error, rule of thumb, and the use of educated guesses and common sense on the part of the researchers. Heuristics derived from research or experience can be used as guidelines when designing a product.

Cognitive walkthrough is a hands-on usability evaluation technique where, usually, a beginner is given tasks to complete and is observed and (often) asked to express verbally what they are doing and why. In the MasterMap case the user was familiar with some of the map data and interfaces. In addition, a diary study was carried out with four MasterMap users asked to note their concerns with the product over a two-week period. The evaluation found 124 unique usability issues, and a grounded theory analysis was carried out on these. Grounded theory uses a reversed-engineered approach, in that rather than starting with a hypothesis and proving or disproving it with the data, the data are structured after collection and themes identified as they are grouped and categorised. From these themes it was intended to create an over-arching theory linking the issues, but the specific nature of many of them meant that it was not easy to generalise to other geographical information products. However the research identified three key themes:

1. Data was not adaptable to organisational context.
2. Lack of user control over the data.
3. Insufficient data for specific tasks.

These results showed the importance of usability in GIS and identified some important issues. The next step was to develop methods that would allow these issues to be identified and addressed during the development of GI products, rather than reflecting on usability only after it had been finalised or purchased. However, as Brown (2010) pointed out, when the most important usability issues have been identified they could be used to form a Usability Questionnaire, and this could be used to evaluate a range of GI products. This would allow direct comparison of any GI product's usability.

An heuristic approach was suggested by Brown et al (2011a), a method adopted in other fields when investigating data, for example Kleining and Witt (2000) in the social sciences; Varde et al (2008) in materials science; and Dzemyda and Sakalauskas (2011) reviewing use in medicine, biology and technology. Heuristics needed to be developed that are specific to, and appropriate for, the data being evaluated. These techniques were amalgamated into Brown et al’s 2012 proposal for PEGI: a process for the Practical Evaluation of Geographic Information. This process involved establishing the context of use of the data and creating scenarios that were relevant to the users, conducting evaluation through the use of experts using Cognitive Walkthrough and Heuristic Evaluation techniques, collating the data, prioritising the issues and reporting accordingly.

Bearman's 2010 study looked at a specific issue of usability with respect to a particular feature of a particular data set, in this case Ordnance Survey MasterMap Address Layer 2. This dataset had many attribute fields designed to be used by professional users. It was reported by OS staff that some fields were commonly ignored, with some users removing the fields during analysis, not realising they could be useful at a later stage if retained. (The field in question had a status of ‘surveyed’ or ‘not surveyed,’ intending to convey positional accuracy or uncertainty, respectively, and although the number of ‘not surveyed’ entries was low, they could affect results of subsequent analysis). Bearman suggested the usability of the field could be increased through the use of an audio alert, representing the status by different sounds.

A more detailed look at usability, again of Ordnance Survey data, was reported by Harding (2012), through task-focussed interviews. Market research had been found to be insufficient to identify the needs of users and to gain insight into the range of uses of the data, therefore semi-structured interviews with users were required to identify the context in which the information was used, while concentrating on issues not related to the system itself or the interface. Building on work by Harding and Pickering (2007), this study identified several conceptual issues that went to the heart of any data set, for example noting how far the user's conceptual view of reality must match that of the data provider in order for full understanding to be achieved. This included users having local, informal names for locations which the formal data may not reflect, so affecting usability of this data by emergency services. This ties in with the idea of 'folksonomies' (as described in Section 2.2.20), and the difficulties of incorporating them into the factual world of geographic information. The study also noted that accuracy of position and attribute were found to be key aspects of usability, and a recurring issue was the need for data pre-processing before use, which consumed valuable resources (thus lowering Efficiency, a key usability characteristic). Uncertainty in quality was found to be a significant problem, minimised by the use of full metadata communicating realistic statements of data quality enabling the user to assess fitness for purpose. Errors and uncertainty affected user confidence in data, and with trust an element of usability, has strong implications for the usability of the geospatial data in question.

Some approaches looked for proxy measures with which to assess GI data usability. Poore and Wolfe (2010) suggested a simple measure of usability measurement: how many windows did the user have to open on the computer in order to make full use of the data? These would include windows to web services or other computer software packages involved in finding, downloading, processing and using the data.

Data content was not the only important factor in data usability: the structure of the data had a considerable effect. At a simple (in GIS terms) level, users may not understand the difference and limitations offered by raster and vector data, with resultant costs of processing and data extraction. Even the file format in which the data is held may mean that, for example, neighbouring local authorities could not share information or data without further processing. Volume of data may also result in usability problems, with too much data, too much detail, or too large a geographical area resulting in slow processing, cluttered images, and time spent extracting the required information. These were common issues, as reported by Hunter et al (2007), Harding and Pickering (2007), Wilson (2010), Sopan et al (2012) and Chen et al (2013).

The changing nature of data also affected usability, with Poore and Wolf (2010) noting the shift in attitude required with Web 2.0 and Geoweb developments, with 'User Beware' being the main lesson to learn from what they termed was a metadata crisis. They also noted that metadata was no longer separate from the map, with simple metadata embedded in the actual data structure, noting VGI data following the Haiti earthquake gave location (latitude/longitude), contributor (userID), timestamp, and tags for items (buildings) and value (specifically whether collapsed), along with the source (GeoEye). Terming this information 'Metadata 2.0' they assert this can be the only metadata possible with VGI such as OSM, as the volume and frequency of change was too great for traditional metadata to keep pace with. In concluding, the authors suggested one measure of usability of such data: how many different windows on your desktop do you have to open to understand how the data set was created and how it can be used. Throughout that study most issues related to data quality, content and structure, with most usability issues reported by the more expert users. Though a qualitative, task-focussed study, the element of user satisfaction was not explored in much detail, but the element of trust was raised by users themselves, perhaps making the findings presented by Bishr and Kuhn's (2007) study on trust worth taking further. A potential next step would be to take some users and data and conduct a Cognitive Walkthrough. Although this is resource-intensive method, as Harding pointed out as recently as 2012, it is still vital to gain understanding of user needs and views on usability. The context of use was integral to the understanding of how the data was used and this represented a recurring theme in the literature on geospatial data usability.

2.7 Summary of literature on assessing usability of geospatial data

Looking more closely at research into improvement of spatial data usability, the literature mainly concentrates on interface issues, with relatively little on data usability improvement, mirroring the current emphases on quality and usability in general. Much of the work on data usability has borrowed from usability engineering research and adapted their findings as appropriate. Some broad concepts have been identified, but the paucity of studies into spatial data usability, and the resultant lack of quantitative measures of improvement, shows that further studies such as the research conducted as part of this thesis are needed to redress such gaps.

2.8 Improving usability

One approach to improving usability is to increase the integration of data. Two main approaches have been used in the literature to improve the usability of geographic or spatial data through promoting interoperability:

- Force the data and/or metadata to conform to strictly specified rules, thus making the data standardised; or
- Identify or create tools to translate any data into a form that can be compared and used for the task in question.

The Virtual NewcastleGateshead Initiative found interoperability was a major concern (Horne et al 2012) and adopted the first of these approaches. Their objective was to integrate city model data from two local authorities which used different CAD software, and this involved trying to transfer the data from a traditional CAD structure to a data rich database with geospatial objects. They found several interoperability issues, including different model geometry between the two systems, object data on one system and relation data in the other, no georeferencing of data, and a lack of connectivity with other data sources. They decided not to use software/middleware to arbitrate between the two systems, but to implement a standard for both sets of data that enabled seamless storage and data exchange. The amount of work needed to pre-process such data to convert it into a 'usable' format was seen by Wachowicz (2002) as a major block to increasing data usability amongst non-expert users.

Illustrating the second approach, Riedemann and Timm (2003) used a distributed operation service which enabled data integration on-the-fly. They saw this approach as a more efficient alternative to the craft approach, whereby a user transformed data manually, using their own experience and knowledge, into a form they could use, effectively creating a duplicate dataset that was created for one specific purpose and therefore one that would probably not be used again. Preventing duplication of effort and the creation of similar, multiple datasets of the same base data has been one of the main drivers behind these different approaches to improving integration. The service chain approach was advocated by many other authors, including Bucher and Balley (2007), Craglia (2007) and by UK Location in its guidelines (2011b). Lehto (2007) noted a further advantage in that this approach did not alter base data.

Nativi et al (2011) took the middle ground and reported on how efforts to improve data interoperability were making data more useful to a wider range of scientific disciplines, using GEOSS (Global Earth Observation System of Systems) as an example. The data generated by GEOSS would be useful to scientists in many disciplines, each with their own requirements, systems and vocabulary. The increased dialogue between science and society, as Web 2.0 emerges, also means the data should be available to those interested parties outside the scientific community. The project identified several clear challenges to integrating multi-disciplinary resources and cross-disciplinary applications, some of which have already been mentioned as key to data usability. These included: the requirement for users to learn yet more (probably immature and therefore still developing) systems and technologies; the limited functionality of the current interoperability systems; and the different semantics from the heterogeneous disciplines involved. These issues made true interoperability difficult. The GEOSS project Data Sharing Task Force used a combination of set standards along with a 'bridge-building' discovery broker service, which enabled search and discovery of data from the 400-plus datasets from all the various sources involved. A combination approach was also taken when various datasets were conflated by Wiemann and Bernard (2010), who noted that several manual or chained processing services were required to achieve this. They emphasised the importance of metadata, and specifically INSPIRE, in creating the basic conditions necessary for identifying the data and obtaining it in a format suitable for use.

The European INSPIRE directive laid down guidelines to build a national spatial infrastructure, with an over-arching, pan-European infrastructure. One of the main aims was to standardise metadata across states to enable improved searchability and data interoperability (European Commission 2007). As illustrated above, a common way of performing complex processes on spatial data was to link processes together in service chains. These relied heavily on datasets meeting the appropriate metadata standards in order to find and read relevant data though, as Bucher and Balley (2007) pointed out, the service chains should also provide metadata on themselves. As Craglia et al (2007) noted, creating and supplying metadata for web services and service chains posed an even greater challenge than those facing the supply of metadata for data sets alone.

A more user-centred approach to improving usability of map data does not refer to the data at all but instead, according to van Elzakker (2005), involved improving the use of maps in education and training (ie of all users, particularly children - the users of the future). Tanaksaranond et al (2013) reported a practical improvement in usability. They took a UCD approach by understanding the needs and requirements of users of a traffic congestion analysis and visualisation system for Transport for London (TfL) Traffic Analysis Centre (TAC). Despite being developed in-house, the system did not address some user needs. One of the most important parts of this case study was the reading of a considerable amount of background material, which supported the identification of potential users and informed the design of the interview template for structured interviews with the heads of the TAC team, consisting of set, but open-ended, questions. These interviews identified the need for specific functions that were not supported, and revealed that some data that was being gathered was not being presented. It was also noted that when the new requirements were designed into the system and tested with the TAC team, new requirements and new usability issues were quickly identified, so highlighting the iterative nature of the UCD approach. This could form the model for future usability assessments and improvements.

The UCD approach, as noted in various examples in this chapter, is increasingly being adopted in recent research and Brown et al (2011a) have suggested that part of the reason for this trend is that UCD is a tried and tested method. UCD has been used in various fields outside GI to bring about improved product quality, increased customer satisfaction and cost savings. It is a process by which usable products could be created and improved. Parker's 2012 study (as outlined in 2.2.7), indicated that including some carefully-considered VGI additions to professional datasets could improve perceptions of currency and usefulness without damaging brand identity (thus addressing several usability elements). The study stated that VGI had the potential to enhance what was already good, so making the user experience more satisfying. This was confirmed by taking the opinions of a small, specific sample group of kayakers, whose perceptions of data currency, social interaction and community membership were found to be important.

2.9 Approach taken in this thesis to assess geospatial data usability

This chapter has summarised the various elements that feed into usability characteristics, which combine to provide an indication of usability of geospatial data, noting differences between 'proprietary' GI and crowd-sourced VGI. Previous studies have been searched to identify methods of assessing data usability, and no agreed methodology or approach was identified. It is clear that any assessment of GI has to be done in context: that a stand-alone assessment of data, devoid of context, would not be valid. The challenge was to identify or develop a methodology that would place the datasets in context while giving some indication of their performance related to a task and, using the elements of usability outlined in this chapter, ascribe levels or values to each element in order to obtain an overall impression of usability. By using the same data in repeated assessments would identify whether similar patterns were exhibited in performance or results, enabling the findings obtained in one specific context to be generalise to include other contexts, the inference being that the more similar the results obtained in different contexts, then the more generalised the overall assessment of usability.

The approach taken in this thesis was to use sensitivity analysis to 'stress' the data to highlight differences and identify similarities between the datasets being assessed. The context in which the sensitivity analysis will take place is accessibility analysis, a typical GIS function in which the performance of several sets of data can be compared. Separate assessments of accessibility were made using three different methods: distance (nearest destination feature from an origin); gravity (using a two-step floating catchment area method); and destination overlap (testing for similarities of destinations identified as nearest). An introduction to each of these assessments is made in the following sub-sections, with relevant examples from the literature. However, using sensitivity analysis in the context of accessibility assessment in order to assess usability of a GI dataset is a novel approach, and the results (as reported in Chapters 4 and 5) show the potential of such an approach, with Chapters 6 and 7 noting its associated advantages and limitations.

2.9.1 A review of sensitivity analysis

Sensitivity analysis was commonly used in different industries, but very rarely in any geospatial usability context. Czitrom (1999) noted its use in the finance industry and in medicine and health spheres. In the financial sector, sensitivity analysis was commonly used in financial modelling, in such tasks as how interest rate changes would affect bond pricing, or in business planning when conducting 'what if' exercises investigating different scenarios to aid decision making. 'What if' types of analysis formed much of the sensitivity-type research in the geospatial field, in topics such as site suitability models and optimisation studies. For example Crosetto and Tarantola (2001) looked at using sensitivity analysis to examine the algorithms used in GIS modelling, and although they emphasised the need for good quality data when using a precise model, they were more concerned with assessing the sensitivity of results to the specific model used, disregarding data sensitivity due to there being far fewer alternative data sources as there were models. Oh et al (2011) used sensitivity analysis to identify significant factors relating to ground subsidence around abandoned coal mines and which factors had the least effect. By varying one factor at a time they were able to show that the influence of groundwater depth and land use had the least effects, with distance from geological lineament and distance from the mine had greatest effect on the occurrences of subsidence.

The incorporation of aspects of sensitivity analyses into accessibility studies had previously been carried out by Jones (2010) comparing walking times to medical facilities in the West Midlands, using four different network datasets, three from OS and one OSM, comparing results and identifying similarities and differences. The four different networks were all configured with the same walking speed to allow direct comparison between the networks. By taking an isochrone approach to accessibility, Jones calculated walking-time zones of 5, 10, 20 and 30 minutes from the health facilities, generated the isochrone polygons, and conducted point-in-polygon analysis to calculate the population within each category of walk-time to the health facility in question. The networks examined differed in content: OSM included roads and footpaths; OS ITN had less network lengths than OSM, a small proportion of which were classified as pedestrianised streets; OS VectorMap contained only roads; and OS Meridian2 lacked many minor roads. The different networks were found to perform differently, with 91% of population within a 30 minute walk of a GP using OSM and 93% with VectorMap. Population coverage was maximised by using a less-detailed network, but not by using the least-detailed network. This study identified usability issues with certain datasets in that particular context, for example the lack of footbridges on some networks meant that railway lines, canals, etc, were barriers to pedestrian movement, but not in datasets where footbridges were included, in this case OSM was the only dataset which included some footbridges. Jones (2010) noted the no-cost data-rich mapping sources offered by both OS OpenData and OSM but concluded that the inclusion of walkways was crucial in assessing accurate walkzone analysis. This study indicates how the overall results of a geospatial sensitivity analysis can identify differences in results, and how investigation of these differences can highlight specific usability and quality issues with the geospatial data used in the analysis.

Apparicio et al (2008), in comparing methods of measuring accessibility to health services, noted that accessibility findings were sensitive to the methodology used, when comparing Euclidean, Manhattan (the distance between two points measured along axes at right angles, such as the distance through a typical US gridded street layout) and network distance. In the research for this thesis, therefore, the same methods (that is, the same process using the same parameters in the same GIS) will be used, with only the item of interest (the map data) varying. This was a key difference to the Apparicio et al (2008) study, which did not apply different datasets to the models used, which could have revealed differences between different map datasets in the context of their particular study area, Montreal.

With very little other literature on assessing usability of geographic data using objective methods, this research took a novel approach that builds on both the Jones (2010) and Apparicio et al (2008) studies by comparing pedestrian accessibility to a variety of destinations, using various methods of locating those destinations and using different network datasets. By utilising an OFAT (one factor at a time) approach to sensitivity analysis using a typical GIS process and a variety of datasets, the variations in output would enable areas of the data which caused the most significant changes to be identified, allowing further investigation to be more easily targeted to the root cause. Patterns of these causes of variation would help inform whether such issues were specific to one particular situation or were general to the dataset, while the levels of variation would help identify which of the data, and which aspects of the data, were therefore the most, or the least, appropriate in the context of the task, thus assessing what data were most and least usable.

2.9.2 A review of accessibility analysis

As with many geographical terms, there are several definitions of accessibility. The approach taken here considered the *potential geographic* accessibility to a facility: *potential* as opposed to the actual utilisation of a facility or feature; *geographic* as opposed to the many other issues of accessibility which were not considered here, such as wealth or deprivation (which included the ability to pay to access features), transport availability and efficiency (again often related to wealth and deprivation, as those who can afford to travel by car or public transport have wider travel areas, while those with low incomes, or with disabilities, for example, may have much smaller travel areas), and other social, cultural, educational or temporal issues (such as safety fears relating to certain areas or routes, personal preferences for certain destinations or ways of getting there, or the opening or availability times of destination features).

There was a considerable literature on the many and varied approaches to measuring accessibility, especially in health studies where the accessibility of the population to various medical facilities has come under considerable scrutiny. The assessments used in this thesis were typical of those studies by, for example, Luo and Wang (2003), Higgs (2004) and Burkey (2012), or in the study of accessibility to other facilities such as public transport networks (Biba et al, 2010) or post offices (Comber et al, 2009). As the range of existing literature shows, each approach had its own advantages and disadvantages, and each tried to represent the real-life accessibility of a population to a service or feature without going through an expensive and time-consuming series of in-depth surveys and observations or long-term travel diary exercises. This section will provide an overview of methodologies relevant to this thesis, outlining some of the more common alternative methods and their respective advantages and disadvantages, to highlight the suitability of accessibility analyses in general and of the specific approaches taken in the thesis. With such considerable previous research, it was apparent that accessibility analysis would be familiar to most GIS practitioners and was a task that would also be familiar to decision makers. The application of accessibility analysis in the context of assessing the usability of GI data is much less common, though the study by Jones (2010) into health accessibility which compares the performance of OSM against OS map data provides a good example.

Container and coverage methods provide easily-understood results from simple calculations, from data that was usually easily available. Another of the relatively simple accessibility tools available was linear buffering, where a zone of a required distance was drawn around a geographical feature, or features. In this way, adjacency or inclusion can be determined. Simple, Euclidean buffering has been criticised for its lack of sophistication and ignorance of topography, barriers (such as rivers and railways) and actual access routes (Biba et al, 2010; Langford et al, 2012), but was found to be useful at regional level, where computational demands would exceed any benefit, and where general information is required (for example which cities were within 3 hours flying time of a certain location, etc). Network buffering offers a more realistic representation of actual accessibility, but requires a network dataset. Network access was used frequently in many areas of GIS research, such as access to hospitals and health care (Burkey, 2012; Luo and Wang, 2003), accessibility of post offices in the UK (Comber et al, 2009; Langford and Higgs, 2010), walking access to urban transport (Biba et al, 2010; Horner and Murray, 2004), accessibility to green space (Comber et al 2008), and other applicable examples.

More sophisticated methods of assessing accessibility include the various incarnations of the Floating Catchment Area (FCA) method. FCA is a special form of gravity model used by Ottensmann in 1995 to predict library use in Indianapolis, then progressed by Radke and Mu's (2000) spatial decomposition proposal. This method was similar to the Origin-Destination (OD) assessments available in commonly-used commercial GIS, and has considerable use for accessibility studies into subjects such as public transport (Langford et al 2012) and health care (Luo and Wang, 2003). Developments include the Two-Step Floating Catchment Area (2SFCA) method (as used by Wang and Luo, 2005, in assessing healthcare spatial access in Illinois). A further-enhanced version by Luo and Wang (2003) and others, the E2SFCA, which incorporated a distance-decay element, was used extensively in health accessibility studies, (Luo and Qi, 2009; McGrail and Humphreys, 2009; Langford et al, 2012; Wan et al 2012).

Examples of measures used to assess potential geographic accessibility, particularly in health studies, as outlined by Talen (2003), are summarised in Table 2.3. The literature continues to debate the various approaches taken and the ongoing refinements to existing models, but validation of any are rare. On shortest distance approaches Haynes et al (2006) noted that travel time estimates were a good approximation of actual patient travel time to the nearest hospital, but also that straight line distances were equally reliable. Various researchers noted similar ratios of network distance to Euclidean distance, several finding factors of around 20% in common, including Martin and Williams (1992) and Love and Lindquist (1995). Burkey (2012) found conversion factors or between 25% and 32% could be applied. These ratios and factors will be compared to the results obtained in this study.

Accessibility Measure	Details	Advantages	Disadvantages
Container	A ratio of supply points to population, for example the number of GPs in a county.	Often used due to the simplicity of calculation. Returns an easily-understood and easily-compared ratio.	Considered overly-simplistic as it ignores both cross-boundary travel and proximity (McGrail and Humphreys, 2009). Typically assumes an even distribution of demand and supply within a large area. Scale effects, as outlined by Luo & Wang (2003) who noted the higher the aggregation level then the more serious the levels of error. Ignores possibility of cross-border travel.
Coverage	For example, number of post offices within 5km of a certain point.	Often used due to simplicity of calculation. Returns an easily-understood and easily-compared figure.	Considered overly-simplistic due to its unlikelihood of giving a meaningful measure of accessibility. Ignores possibility of cross-border travel.
Minimum distance	For example, distance to the nearest A&E. Could be calculated using Euclidean (straight line) or network distances.	Relatively simple to calculate using GIS. Returns an easily-understood and easily-compared figure (Talen and Anselin, 1998). Adapted by Burkey (2012) to calculate inefficiency ratios (actual mean distances divided by optimal mean distances).	Euclidean distances ignore geographical barriers. Inefficiency ratios had high computational demand with all possible combinations calculated to find a solution, in Burkey's example in North Carolina there were 5261 possible locations in which to locate 117 hospitals, which involved 1.59×10^{242} permutations.
Travel cost	For example, average distance from population centroid to all GP surgeries.	Straightforward to calculate in GIS.	Takes no account of availability, such as capacity of supply or levels of demand.
Gravity	An index in which the sum of all facilities (weighted by size or supply-side characteristics) is divided by the 'frictional effect' of distance.	Takes overlapping service areas into account. Incorporates levels of supply and demand.	Results in highly concentric patterns of results in rural areas or where few overlaps exist (McGrail and Humphreys, 2009). Returns (effectively) a ratio, difficult to compare and interpret by general users. As a ratio, same results can arise with high supply/high demand AND low supply/low demand (Neutens, 2015)

Table 2.3: Examples of types of accessibility measure, with advantages, disadvantages, and examples of use (adapted from Talen, 2003).

2.10 Chapter summary

To set the use of the data in context, a variety of typical GIS tasks would be conducted, and the performance of the subject datasets then compared and contrasted. The tasks would be carried out at a variety of spatial scales, and use a range of GIS data types (point, line and polygon). They would be carried out as if they were genuine GIS exercises of topical interest, specifically accessibility to supply points of relevance to health, welfare or active travel agendas. One novel aspect of the research carried out for this thesis is the combination of accessibility analysis, sensitivity analysis, statistical analysis and visual analysis, all of which combined to reveal similarities and differences in the data worthy of further investigation.

As will be discussed in the forthcoming chapters, use of any single analytical method would not have identified the same number and types of issues that were found when all methods were utilised. This itself indicated that examinations of data usability were unlikely to be successful or representative if only one technique was employed; a portfolio of tools offers the best opportunity for gaining insight into the usability of geographic data.

The approach taken in this thesis builds on earlier research to look at a previously-neglected area related to spatial data usability. Several factors distinguish this study from those conducted previously:

- Few other studies have compared data that represents the same features or networks. Those that have compared data (Jones, 2010, for example) compared networks but not the representation of the destination features;
- Few previous studies have compared different types of destination feature (services) to ascertain if patterns of accessibility differ between them. Again Jones (2010) provided an example by comparing accessibility to GPs and pharmacies, and noted different results between the two;
- Although many GIS studies have used sensitivity analyses when conducting ‘what if’ or optimisation studies, no previous study has used the results of sensitivity analysis to highlight areas of concern in the underlying data, with the aim of assessing the performance of the data in terms of usability as well as quality;
- No other study has attempted to quantify the differences in usability between geospatial datasets;
- Although several studies have reported on differences in results from using network and Euclidean distances, and although some of them noted differences between their results in metropolitan and suburban areas, no comparison has been made between urban and rural contexts. This study compares the findings of these previous studies, several of

which proposed convenient conversion factors to account for the difference between Euclidean and network measures.

Although not the original aim of this thesis, the research conducted here highlighted the ability and flexibility of modern GIS to conduct hundreds of analyses that would have taken considerably more time had they been calculated manually. The undertaking of this study was possible because of the availability of modern GIS techniques. However, as stated in the literature (Crosetto and Tarantola, 2001), the choice of analytical approach, the choice of model and the choice of GIS all has an effect on results of analysis. These findings will inform the discussion and conclusion to this thesis, as reported in Chapters 6 and 7.

If data usability can be measured (as asserted in this thesis) then there is potential for also assessing levels of improvement, rather than taking a simpler binary approach to usability of classifying data simply as 'usable' or as 'not usable.' The Literature Review identified several ways in which geospatial data could potentially be made more usable, including the following factors:

- The use of standard data formats;
- Providing full, accessible metadata (which also permitted findability and translation by web services);
- Automating metadata creation (to some extent, to ease administrative burden and improve accuracy);
- Including information about uncertainty in metadata;
- Including experiential metadata, comments on use, etc;
- Dataset designed to prioritise usability, not data storage and handling;
- Utilising UCD principles wherever possible, and improving products by iteration;
- Including VGI for specific contexts, where applicable;
- Filtering data according to user context, where possible;
- Providing data of the quality required in the context of use;
- Providing users with sample data, before procurement.

Again, these factors will be used to inform the discussion of the results (Chapter 6) and the conclusions to this study (Chapter 7). Although the primary aim of this thesis is to help identify the most appropriate dataset in the context of accessibility modelling, a quantitative and objective method of assessing elements of usability could also serve to aid data producers in improving the usability of their geospatial datasets in a wide range of GIS tasks and they have wider relevance to a whole host of data users.

Chapter 3 Methodology

3.1 Introduction

The review of the literature relating to usability analysis (see Chapter 2) indicated that very little research had been conducted investigating the usability of geographic data. A selection of past studies into data usability, and into geographic data usability in particular, is summarised in Table 3.1. These studies demonstrate the point that an agreed methodology into geographic data usability has not been identified in the literature as yet. What little research has been published to date considers the effects of using the data on a variety of usability elements, as outlined in Chapters 1 and 2. These activities were carried out post-purchase or post-use, but little had been done to assess the data itself for levels of usability. Most of this research involved qualitative studies, with only the benchmarking research taking a quantitative approach. Benchmarking studies, as carried out by Haklay (2010a) and Zielstra and Zipf (2010), offered a relatively straightforward methodology for analysis by using total network lengths as an indication of usability. Their approaches, however, did not look at the effects of using the different networks in any particular context, nor did they look at quality aspects of the datasets which may have affected their usability.

This thesis intends to address this research gap through the specific lens of a combination of relatively well established GIS techniques that enable the calculation of accessibility, and a relatively new technique, that of the two-step floating catchment area (2SFCA) calculation. By taking the novel approach of using sensitivity analysis to highlight areas of difference it is intended to investigate the most significant of instances in order to identify root causes of these differences which, when investigated, will indicate issues of usability with the data sets in question. This will use commercially available as well as crowd sourced data sets to represent geographic features in accessibility models. The application of sensitivity analysis to assessments of accessibility enabled the varying outputs of a typical GIS task to be recorded as certain key variables were varied in the model. Case studies were used as the framework within which these processes were applied, and a proposal made as to how the results from the various analyses could be combined to provide an indication of overall usability.

Study	Method of assessing usability					
	Questionnaire	**Focus groups**	**Interviews**	**Observation**	**Expert evaluation**	**Benchmarking**
Mayhew and Mantel (1994)				Users conducting pre-defined tasks		
Prins et al (2002)					Medical data, issues of completeness and accuracy.	
Hunter et al (2003)				Users conducting pre-defined tasks		
van Elzakker (2005)	Specific to study and maps involved.	On specific topics	Structured or semi-structured	Users conducting pre-defined tasks		
Hengl and Husnjak (2006)					Methodological framework	
Franca et al (2008)						Retrospective comparison of cause of death data.
Haklay (2010a)						OSM v proprietary data
Zielstra and Zipf (2010)						OSM v proprietary data
Brown et al (2010)					Used a battery of techniques	
Harding (2012)			Task-focussed			
Tanaksaranond et al (2013)			Structured			

Table 3.1: Summary of studies into data usability, and geographic data usability, from section 3.3, with the techniques used to assess usability. Only one method (expert evaluation) was possible before use, and the techniques employed varied widely.

The overall approach to this research involved assessing usability of geographical data by conducting sensitivity analysis on a variety of geographical data sets, using typical GIS processes, and examining differences and variations in their outputs. This is illustrated with reference to the use of accessibility analysis. These differences and variations would be used to form a quantitative assessment of the usability of the data. The experience gained in the execution of the research was used to form a qualitative view as to the usability of the data in a specific context. In this case, the GIS processes related to the accessibility analysis of a variety of supply-side features in South Wales, with accessibility analysis representative of typical GIS functions which make use of the geographical data in question, as outlined in Section 1.1 of the Introduction chapter. The use of sensitivity analysis in this context was explained and justified in Section 2.9 of the Literature Review.

For the purposes of this research accessibility is defined as the ease of access to facilities, or availability of facilities, and will be used to measure potential geographical accessibility. Other barriers to accessibility other than geography (such as attitude, deprivation, disability etc), were not addressed here and there is no attempt to measure realised accessibility (that is, actual use). As detailed in the Chapter 2 the assessments undertaken here were typical of those that could be used in the calculation of accessibility to medical facilities, as reported by Luo and Wang (2003), Higgs (2004) and Burkey (2012), or accessibility to other facilities such as public transport networks (Biba et al, 2010) or post offices (Comber et al, 2009), with more detail provided in Section 2.9.2.

This chapter will detail the various processes used throughout the research for this thesis. The study area will be identified and described in Section 3.6 before the data used as input to those processes is outlined in Sections 3.7 to 3.10.

3.2 Accessibility measures

The many and varied approaches to measuring accessibility were outlined in the Literature Review (Section 2.9) with summaries of their respective advantages and disadvantages outlined in Table 2.3. Those used in this thesis are detailed below.

3.2.1 Container and Coverage

Being simple and straightforward to calculate, container and coverage figures were assessed for each type of feature, for comparison with the results obtained using the other approaches.

3.2.2 Minimum Distance

Several different variations of distance measure were used to assess accessibility in this study. The most simple approach used Euclidean distance (also known as straight-line distance or 'as-the-crow-flies' distance). This method took no account of intervening topography or barriers to travel and did not intuitively reflect 'real-life' travel. Actual travel distance may be better represented by network distance, and this measure was also used in this study. Different network datasets were used and compared. Some were different products from Ordnance Survey (OS): Integrated Transport Network™ Layer (ITN); ITN with Urban Paths (UP); and Open Roads (OR); with one network dataset derived from volunteered geographical information (VGI) data, OpenStreetMap (OSM). The procurement and preparation of all the network datasets are detailed fully in section 3.10.

Some researchers compared distance measures using Euclidean and various network measures, with Martin and Williams (1992) identifying a 20% conversion factor when assessing accessibility to GPs in the Bristol area. Love and Lindquist (1995) asserting that straight line distances were a reasonable estimate of network distances to health care facilities in Illinois, and also found a 20% conversion factor, while Burkey (2012) identified a range of conversion factors from 26 to 32% from straight line to network distance in a study regarding access to healthcare facilities in several US states.

One of the main advantages of using distance to measure accessibility is that the results, in absolute units, are easily understood by researchers and policy makers (Talen and Anselin, 1998), whether conversant or not in geographical terms. The attractiveness of this approach will be highlighted as the results of the more complex ways of representing accessibility are presented, which may be viewed as being more challenging to interpret. One of the main assumptions with the use of minimum distance models is that the population (or appropriate segment of that population) will always travel to the nearest available facility. This is not necessarily the case, as factors other than distance may influence choice of destination, such as facilities offered, personal preference, or if a journey is to be 'chained' in to a series of tasks (for example, if visiting the shops after a visit to the doctor an individual may use a shop on their route, rather than one geographically closer to home but in a different direction).

3.2.3 Gravity models

A form of gravity model was used in this thesis to compare and contrast the results from the distance measures. The two-step floating catchment area (2SFCA) method was used, as detailed in the Literature Review (Section 2.9.2). The enhanced version of the model (E2SFCA) was considered, which incorporated a distance decay function, but was not utilised due to difficulties in identifying what actual decay parameters to apply as there were many to choose from and little research into which was the most appropriate (Higgs et al, 2015), with the choice made by researchers often appearing arbitrary (Neutens, 2015). A simpler, binary approach was therefore taken: a facility was either within the threshold distance of a demand centre and was therefore a potential destination; or it was outside the threshold destination and therefore not a potential destination. It was acknowledged that use of a distance decay element could reflect a more realistic view of the real-life situation (if research indicated an appropriate parameter to apply), in that a closer facility would exert more of a 'pull' on a population than a more distant one.

3.2.4 Floating catchment area models

Floating catchment area models are extremely useful in accessing potential accessibility by highlighting the influence of supply capacity and demand population levels, particularly where levels of supply and demand have an effect on service accessibility. Accessibility to schools is one good example, where a facility with a finite supply level (such as a primary school with an upper limit on pupil numbers) is in an area of high demand (where the number of primary school-age population in an area is particularly high). Distance measures may assess the population here of having high level of accessibility to that feature, but when supply and demand levels were included, accessibility measured in this way may show a poorer level of accessibility.

As Neutens (2015) pointed out, there were shortcomings with all of the various FCA and FCA-type models, one being that as they measured population-to-provider ratios then similar results will arise where individuals live in areas of high demand and high supply to the results from those living in areas with low demand and low supply.

Two illustrations are provided here as to how 2SFCA results are obtained: the formulae for the calculation of 2SFCA (from Luo and Qi, 2009) are set out in Equations 3.1 and 3.2; with a visual illustration provided at Figure 3.1.

The methods used to calculate 2SFCA are as follows. Step1: For each supply location (j), search all population locations (k) that are within a threshold (d_0) from location j (this threshold is the catchment of each supply feature), and compute the supply-to-demand ratio, Rj, within the catchment area. In Equation 1 Pk is the population at location k whose centroid falls within catchment j (dkjr<=d0), Sj the supply capacity at location j, and dkj the travel distance between k and j.

$$\mathbf{Rj} = \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} \mathbf{P_k}}$$

Equation 3.1: Step 1 of the 2-step floating catchment area model of accessibility.

$$A_i^F = \sum_{j \in \{d_{ij} \leq d_0\}} \mathbf{R_j} = \sum_{j \in \{d_{ij} \leq d_0\}} \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} \mathbf{P_k}}$$

Equation 3.2: Step 2 of the 2-step floating catchment area model of accessibility.

In Step 2 (Equation 2) for each population (demand) location (i), search all supply locations (j) that are within the threshold distance (d_0) from location i (that is, within each catchment area i), and sum up the supply-to-demand ratios as derived in step 1. AFi represents the accessibility of the population at location i to the supply feature based on the two-step floating catchment area method, Rj is the supply-to-demand ratio at supply location j whose centroid falls within the catchment centred at population location i (i.e., dij<=d0), and dij the distance between i and j. A larger value of AFi indicates a better access to the supply feature at that population location. The first step assigns an initial ratio to each catchment (or service area) centred at supply locations, and the second step sums up the initial ratios in the overlapping service areas where residents have access to multiple supply locations. Each 2SFCA result is (basically) a ratio of supply to demand, with only selected features and population entered as the numerator and denominator (Luo and Qi, 2009).

A step-by-step illustration of the 2SFCA approach is shown in Figure 3.1, where in Step 1 the service catchment is set (Figure 3.1:1), in order to find all the population locations that fall within the threshold distance for each service (Figure 3.1:2), enabling the population-to-provider ratio to be calculated for each supply facility; repeat this process for every supply feature (Figure 3.1:3); then moving to Step 2, for each population location identify all services that fall within the threshold distance, and sum their population-to-provider ratios that were calculated in Step 1(Figure 3.1:4). This then provided an assessment of accessibility for each population representation, or demand point. For this study, 2SFCA network calculations were carried out using a tool developed by Langford and Fry (2010) that operated as an Arc plug-in. This tool will be referred to in this thesis as the 2SFCA plug-in. An updated version was made available by Langford et al (2015) to download, cost free, from Research Gate.

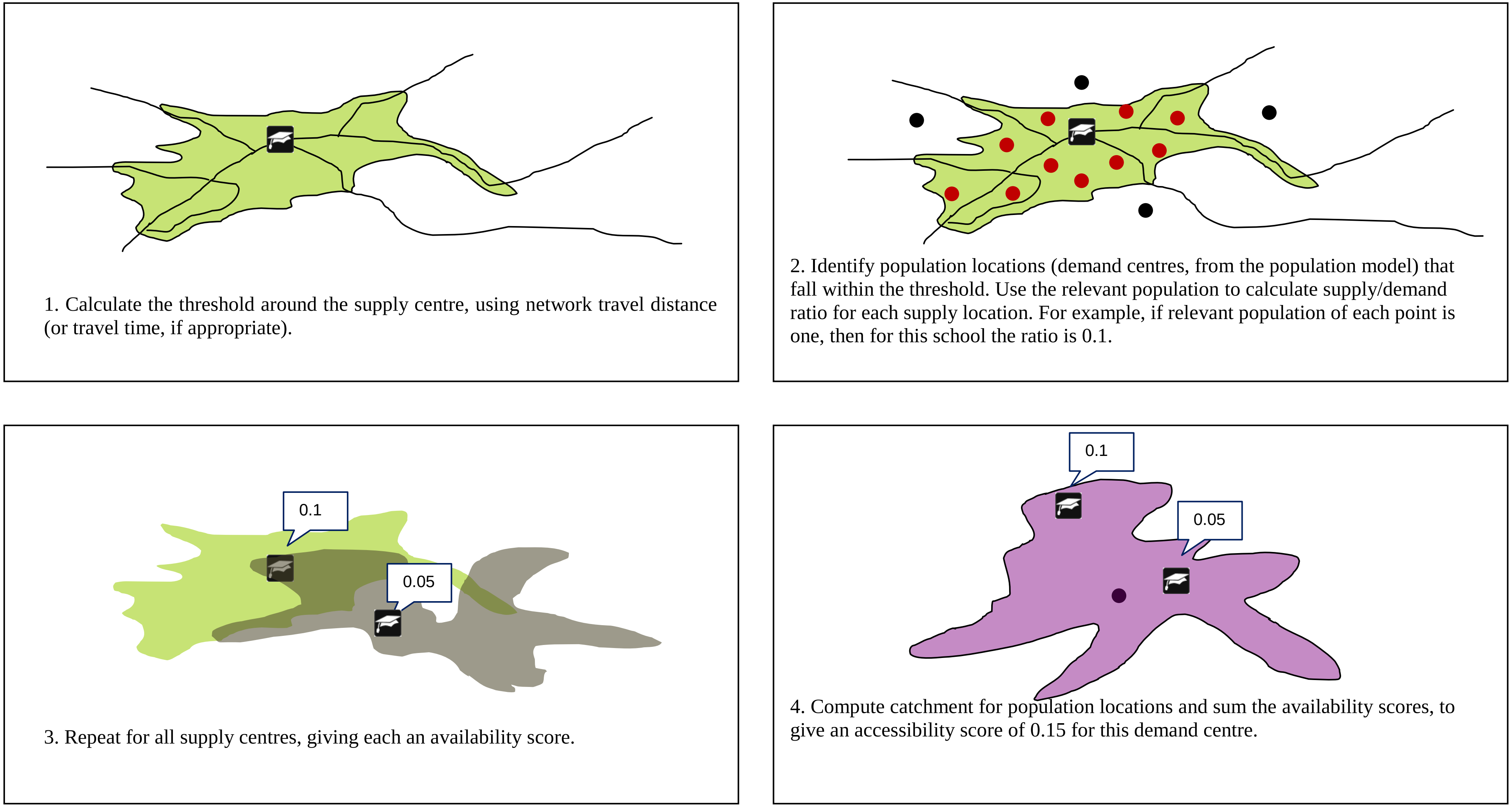


Figure 3.1: Illustration of 2SFCA calculation methodology (Langford, 2015).

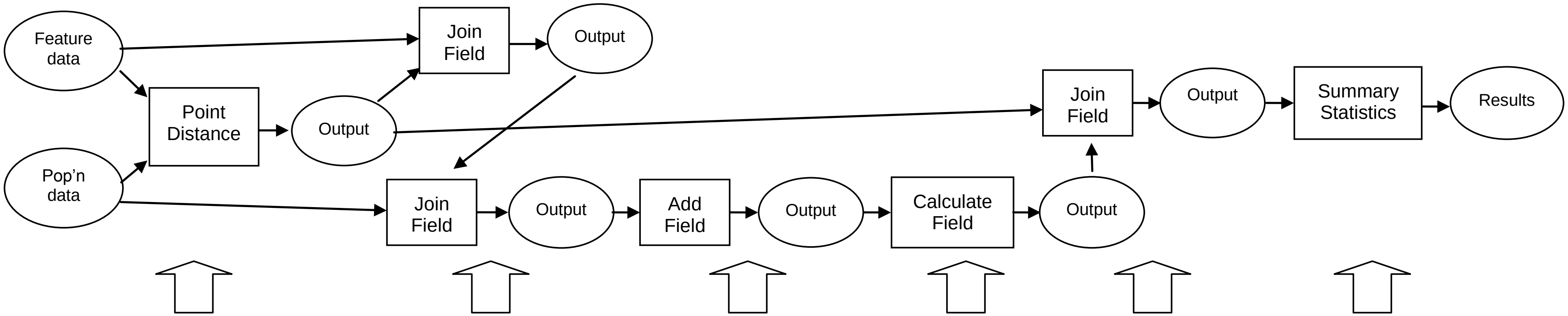
The 2SFCA plug-in could only be used with network datasets. In order to compare all available distance measurements, including Euclidean, with those of 2SFCA, a simple 2SFCA tool was created to calculate 2SFCA using Euclidean distances. The tool was built using Arc ModelBuilder, a quicker method of creating a tool than recoding the VBA of the original plug-in. The tool was simpler than the plug-in by having no capacity for the inclusion of a distance decay factor, and was created to enquire whether the conversion factors that applied to Euclidean to network distances also applied to the equivalent Euclidean and network 2SFCA results. A convenient conversion factor would reduce the need to obtain and use network datasets in assessing accessibility. The FCA plug-in and the Arc tool enabled supply and demand data to be entered through a customised interface, and allowed the many repetitive calculations that were required (involving calculating hundreds of ratios at a time) to be made quickly. A pseudocode flow diagram for this tool (pseudocode is a high-level description of the operating principles of a computer program or algorithm intended for human reading and understanding, with the flow diagram showing the steps taken in the finished ModelBuilder tool) is shown in Figure 3.2 and a simplification (to aid clarity) of a screenshot of the Arc Model itself is shown in Figure 3.3.

There were two main reasons for using an FCA model of accessibility in this thesis. Firstly, in accessibility studies, particularly those researching topics in the health sphere, FCA analysis (and its many variants) were widely used, and therefore considered one of the typical GIS calculations that would be carried out by researchers. Assessment of the various datasets in the course of these assessments would provide indications of issues affecting usability. Secondly, by incorporating variables of supply and demand an indication of their effects on outcomes can be assessed, and any significant fluctuation in output used to flag up what areas of data required further, more in-depth investigation.

The FCA plug-in requires that each feature representing a supply or demand point is represented by one point. Demand points were represented by population weighted centroids, as described in section 3.9. In the case of both primary and secondary schools polygon centroids, Point of Interest points, postcode points or address points were all suitable representations as the capacity of the school (represented by the ‘school roll’, as explained in Section 3.7) can be related to each point. Datasets which represented the schools by several points, such as access points, had an important limitation: the FCA plug-in treated every access point (each of which had been allocated the relevant attributes of the school, in this case the school roll) as a separate supply point. Multiple access points to one feature would result in each being treated as a separate school by the plug-in Any population points in the vicinity of schools with multiple access points would therefore return much higher, and spurious, ratios of supply to demand. Perimeter points, being much more numerous, returned even higher supply levels. Therefore for each school the main access point was located and the mode perimeter point assessed (as described in Section 3.4, and these points were then used to create further, separate datasets for each supply category. It was noted that in the case of perimeter points, the mode point chosen by the Arc OD Cost function could (and did) vary between networks, therefore the 'main' perimeter point was allocated separately for each network, and only used in calculations involving its corresponding network. The main access point was an inherent feature of each school and was independent of the network used.

Schools: Source of capacity data[1]	Cardiff Council, Vale of Glamorgan Council, Bridgend Council, WAG	Census OA statistics
Processing required	None	Extract and estimate those of relevant school age from URP[2]
Methodology section		
GPs surgeries: Source of capacity data	WAG	Census OA statistics
Processing required	None	Simple percentage of URP
Sports Centres: Source of capacity data	None suitable	Census OA statistics
Processing required	N/A – figure of '1' applied	None, full URP figures used
Community Hubs: Source of capacity data	None suitable	Census OA statistics
Processing required	N/A – figure of '1' applied	URP minus school-age population AND those Economically Active)
Methodology section	3.7	3.9

Figure 3.2: Pseudocode flowchart to calculate 2SFCA using Euclidean distances, with sources of capacity.
1. Section 3.7 explains how supply capacity was defined, obtained and processed for each type of feature.
2. URP is a UK census term denoting Usual Resident Population.



Supply points identified within thresholds	Supply capacities allocated	Field added, ready to accept results of ratio calculation	Supply/demand ratios calculated	Pop'n points, with ratios, allocated to the thresholds of the appropriate feature	Ratios summed for all points within the threshold around every demand point
Demand points identified within thresholds	Demand levels allocated				
Step 1				**Step 2**	

Figure 3.3: Arc ModelBuilder Model used to calculate 2SFCA using Euclidean distances.
Features within the threshold are identified using the Arc Point Distance tool, which only outputs feature identification and distance information. Supply and demand data is added to this output in the next step. The supply/demand ratios are calculated and added to a new field in the data. The ratios are summed and final results output for each demand point.

3.3 GIS processes

Esri ArcMap 10.2 and ArcGIS Network Analyst extension was used for the GIS processes in production of the final results. ArcMap is one of the more commonly-used GIS and possessed the functionality required for geographical analysis and network analysis without the need for further coding or programming that would be required with FOSS GIS alternatives such as QGIS. The University of South Wales also supported Arc products, but not other commercial GIS products such as MapInfo. Data producers are increasingly issuing products which are directly compatible with ArcGIS or already in Arc format, hence the option of Arc as the best all-round and most convenient choice. As many of the ArcGIS processes involve algorithms subject to commercial confidentiality, the exact workings of each process may not be known, hence one of the conclusions of this study (see Chapter 7) suggests repeating all or some of the work here using an alternative GIS, such as QGIS.

ArcMap terminology will be used when referring to the processes undertaken for this thesis. Langford and Higgs (2010) noted an issue with Network Analyst, where it snapped population centroids to the nearest road when calculating network distances. This snapping characteristic of Network Analyst, which is required in order for the FCA plug-in to run and Arc OD calculations to be made (see section 3.4.6), also applied to supply points, and this issue had a noticeable effect on some outputs as will be detailed in the Results chapter, from section 4.2. Snapping refers to the method by which the GIS locates points, which may not be on a network 'edge', onto the nearest available edge. The results of this study presents distances to the nearest metre (implying a high level of accuracy), but these distances may not necessarily be from the exact location of an origin point to the precise location of the destination point: instead, the distance will be calculated from the point on the network nearest to the origin, to the point on the network nearest to the destination. Snapping is therefore a source of potential inaccuracy inherent in all network analysis as the process of snapping is required in order for network analysis to function. The location of the point representing the position of a feature may therefore snap to different roads depending on how that feature is represented. The OS Sites dataset, particularly with its access points, offers the opportunity to conduct network analysis to a feature which is represented by points which are actually located on the network. Even with this dataset the points of origin will still be subject to snapping. Researchers should be aware of the potential effects of snapping upon their results, and Chapter 4 will mention some, for example when origin points are located within feature polygons, and when network lengths are mapped within destination polygons, but journey distances are still recorded.

Usability issues relating to ArcMap will not be addressed as part of this study, unless they relate specifically to the use, manipulation or analysis of the data.

3.4 Sensitivity Analysis

As outlined in Chapter 1, the use of sensitivity analysis in the context of assessing usability was intended to highlight differences and identify similarities in the performance of datasets which represented the same features. Through multiple iterations of similar processes, these differences would be made more pronounced and the similarities more identifiable. As was detailed in the Literature Review (Section 2.5), sensitivity analysis was a tool commonly used in the financial industry and in business planning as well as in the fields of medicine and health (Czitrom, 1999). Its use in geographical applications is, however, much rarer, though Section 2.5 provided some examples.

The flow chart in Fig 3.4 illustrates the sensitivity analysis process used in this study, with a brief explanation of the approach taken. It is acknowledged that the OFAT approach (changing one factor at a time, an accepted sensitivity technique) cannot estimate or quantify the levels of any potential interaction between the input variables: each variable is treated as independent of the others. The potential of changing multiple variables at a time and using multiple regression or spatial regression techniques is acknowledged and discussed in Section 7.6, however at this time it was not yet known which (if any) of the input variables (such as the method for locating a feature, or the network used to assess travel distances) were a significant factor in the outputs of accessibility analysis. This thesis addresses this gap in knowledge, but the results from this study would inform future decisions as to whether it would be worthwhile to conduct a properly-designed experiment incorporating several changes at a time and applying a form of regression analysis in order to investigate potential interactions between the variables. As Czitrom (1999) also noted, OFAT was a popular technique as the outputs were easy to understand.

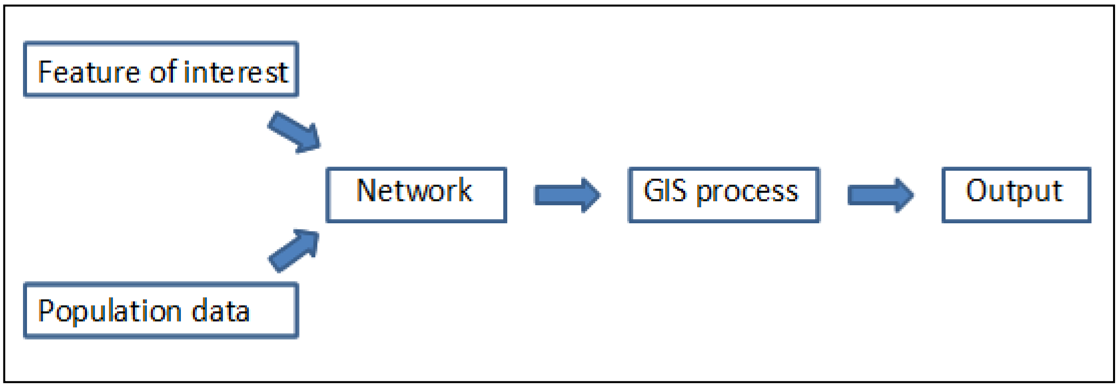


Figure 3.4: Flow chart showing the process route for sensitivity analysis carried out for this study. An OFAT (one factor at a time) approach was taken, whereby one factor was altered (for example, the representation of one type of feature) while the others remained constant (ie the population representation, the network used and the GIS process) resulting in differing outputs.

For the first part of the study, the representation of population was kept constant and the way the feature of interest was represented was varied, and the results examined when the data was used to assess geographic accessibility. The task itself was as follows, using the example of primary schools:

- Identify a suitable destination/supply feature (in this case primary schools);
    - Identify the nearest facility (school) for each OA in Cardiff;
    - Measure the distance to each different representation:
        - site polygon centroid
        - nearest access point
        - nearest point on boundary
        - OS Point of Interest centroid
    - Repeat for all network and Euclidean distances;
    - Repeat for schools in Vale of Glamorgan;
    - Repeat the accessibility study using the FCA plug-in, to calculate 2SFCA accessibility score rather than distances;
- Repeat for all five features (primary schools, secondary schools, GP surgeries, sports centres and community hubs, as described in Section 3.7);
- Collate and compare results.

There were several options available as to the GIS tools and processes that were used in the analysis, and the intention was to make the processes as straightforward as possible. The Arc OD Cost Matrix tool (part of the Network Analysis Toolset) was chosen as it was fast to compute and complete and could handle datasets as large as those in this study. It also provided a visual output of the origin-destination calculation, which provided a quick and convenient method of checking results. This tool was used to calculate the nearest feature for site centroids, school access points, school perimeter points and PoI points. However, the OD Cost Matrix tool could only be used in network analysis. For Euclidean distances the 'Generate Near Table' tool was used, which resulted in a simple table of results and did not add to the Attribute Table of the original data (as did some other Euclidean measurement tools), as by the time all calculations were completed the Attribute Table would have grown needlessly larger and more complex. It was decided, for the sake of consistency, to use the OD Cost Matrix tool results to find the nearest point on a perimeter of each school site, rather than any of the other tools that could potentially be used in Arc. This meant some manipulation of the perimeter data, in order for the tool to work correctly and in order for the FCA plug-in to return meaningful results.

The FCA plug-in required a dataset of one point per feature in order to calculate its accessibility score. The polygon of each school perimeter therefore posed a problem. A solution was identified which required each polygon to be converted to a series of points, and this was done using a combination of two tools. The first was a ‘Point Conversion’ tool created by Jason Parent (http://www.arcgis.com/home/item.html?id=e19b53170e004e46827b8129d6ef9bfe, accessed 4 July 2014), and the second the ‘Feature Vertices to Points’ tool in Arc. Used individually, each conversion process left gaps that may have proved significant. When the results from each tool were combined, each school had its perimeter converted to a line of densely-spaced points. A representative point on each school perimeter was identified from the results of each network’s OD Cost Matrix output, with the mode point being chosen as the ‘main’ perimeter point. This was a much greater generalisation when compared to access points, as many different points around the perimeter may have been ‘hit’ by the OD Cost calculation outputs, and in some cases the mode point was only one or two ‘hits’ different from other points on the polygon. Allocating one representational point on a polygon therefore carried a risk associated with over-generalisation and the concerns over such representational problems are discussed in Section 6.2.2.

3.5 Analysis methods

This section describes the tabular, statistical and mapping approaches completed in order to undertake the sensitivity analysis. The findings from the tabular and statistical analysis are reported in Chapter 4; those from the visualisation analysis are reported in Chapter 5.

Destination overlap was an addition to the use of Shortest Distance and 2SFCA as measures of accessibility. It was recognised that quantifying the changes in distance to nearest destination would be of interest, but that would not indicate whether those changes would affect the outcomes of a typical study. The use of a Destination Overlap metric was therefore intended to illustrate the practical effects of the extent that any change in network, location method or population representation had on distance calculation. For each network or location method, the closest destination feature to each OA centroid was identified. Comparisons with other results would indicate how many of the destinations remained unchanged and how many were different, expressed as a percentage. Part of this study was therefore to assess whether different patterns of feature distribution (ie comparing different features), and whether different methods of feature representation (some involving small differences in distance, some larger) had an effect on the choice of nearest destination.

Statistical analysis was conducted on the results from all distance and 2SFCA calculations using the analysis that was most appropriate to the data. The results from the accessibility analysis were highly skewed and did not conform to normal distribution despite a variety of transformations being applied. As the results arose from the repeated retesting of the same datasets (for example different networks and different representations of features, but using the same OAs as origins), the sets of results could not be considered as independent. Being non-independent and not conforming to normal distribution severely restricted the choices of statistical tests available. The lack of parametric conformance and of independent samples meant that the more robust t-test and ANOVA tests were not appropriate: both the One-Way ANOVA and the Repeated Measures ANOVA required normally-distributed data; the One-Way ANOVA required independent groups; both the t-test and the Repeated Measures (paired samples) t-test required normally-distributed data; and the t-test required independent groups. Both the Kruskal-Wallis and Mann-Whitney tests required independent groups, and Pearson required normally distributed data, leaving one commonly-used test available for correlation and one to test for differences, both less sensitive statistical tools than their counterparts used for independent groups or normal distribution. Spearman's rank correlation coefficient was used for comparisons of similarity due to the nonparametric and non-independent characteristics of the distance and 2SFCA results data. There are several recent examples of the use of Spearman's test in previous studies involving accessibility and proximity included those of Burgoine et al (2013) investigating proximity to food outlets as part of a study into obesity, using access metrics which were skewed and not normally distributed, and of Ngui and Apparicio (2011) in comparing and analysing 2SFCA scores and distances to medical clinics in Montreal. The results of statistical analysis in this thesis indicates that a further statistical test of difference could have been taken in these studies to confirm (or show otherwise) that their high correlations also equated to results with no or little statistical difference. Friedman tests (the non-parametric alternative to one-way ANOVA) were used on the entire set of results from each particular feature to assess whether there were any differences within them. A non-significant result would indicate there were no differences between the sets of data. If the results from the Friedman tests were significant, indicating the existence of differences somewhere within the dataset, then Wilcoxon signed-rank tests (the non-parametric alternative to one-way ANOVA with repeated measures) were used on a pair-by-pair basis to identify the specific differences between each and every paired set of results. All statistical analysis was carried out using IBM SPSS statistics software, version 22.

Choropleth maps were produced to illustrate visually the geographical distribution of areas with differing levels of assessed accessibility. For 'nearest distance' measures, the same absolute values were used as break-points across both study areas and all networks, features and locations. For 2SFCA calculations, it was noted that the results would all be (effectively) ratios, though expressed within a wide range, due to the FCA plug-in having a feature built in to 'factor up' the results in order to preserve accuracy. The use of absolute measures (as with distance results) enabled results to be compared between different areas and different studies, and was the preferred approach in this thesis. The 2SFCA results, being ratios, meant that direct comparisons of results between areas and between studies was not an option. On the other hand, the adoption of an entirely relativistic approach (ie using quantiles across all results) may have meant that all the maps looked virtually identical. Different approaches were therefore trialled with 2SFCA maps, and a compromise approach taken. This involved mapping the results from the ‘centroid’ location for each feature using the ITN network, and taking the rounded quintiles (that is, five quantiles) as the splits for all the other feature locations. The maps so produced would enable realistic comparisons of changes due to the different location features, but would be incorrectly utilised if used to make comparisons across networks, for example. The implications of such choices are outlined in Chapter 5.

In addition to the observations of McGrail and Humphreys (2009) (as summarised in Table 2.1 in the Literature Review), Luo and Wang (2003) also noted that the use of a larger threshold in Step 1of the 2SFCA method (the same size of threshold which is then used in Step 2, see Figures 3.1 and 3.3) generated strong spatial smoothing and reduced variability of accessibility across space, and also resulted in concentric patterns of accessibility around destination features, particularly when supply features were clustered together. The maps produced from the results of the 2FCA analysis will be examined for such characteristics. In addition, sensitivity analysis has been conducted on the size of the thresholds used, in order to compare the effects found. The advantages and potential limitations of this approach are discussed in Chapter 6.

3.6 Study areas

Two neighbouring South Wales unitary authority areas were chosen for this study: the City and County of Cardiff; and Vale of Glamorgan County, as shown in Figure 3.5. A brief summary of their respective sizes and populations is given in Table 3.2. Cardiff is the capital and largest city in Wales. The Vale, with considerably lower population, has one main urban area, the port town of Barry. The Vale of Glamorgan (‘The Vale’) is over twice the size of Cardiff in terms of area, but has just over 30% of Cardiff’s population.

	Vale	**Cardiff**
Area (km^2)	340	150
Population	126 336	346 090

Table 3.2: Study area characteristics (as of census day, 27 March 2011).

There were several reasons behind the choice of study area. As an urban centre, Cardiff is an area rich in geographic features typical of a small city. It has a central shopping and business area, now being repopulated with new, residential developments, surrounded by areas of densely populated urban villages as well as suburbs with lower housing densities, with areas of deprivation in large, peripheral housing estates. Within the county boundary it has a wide variety of potential destination features, again typical of an urban settlement of its size. The Vale is a more rural area, and perceived as one of the more affluent areas of Wales, and provided the opportunity to study urban-rural differences in any results. This, it was hoped, would provide contrasting contexts with which to compare the usability of a range of spatial data sets.

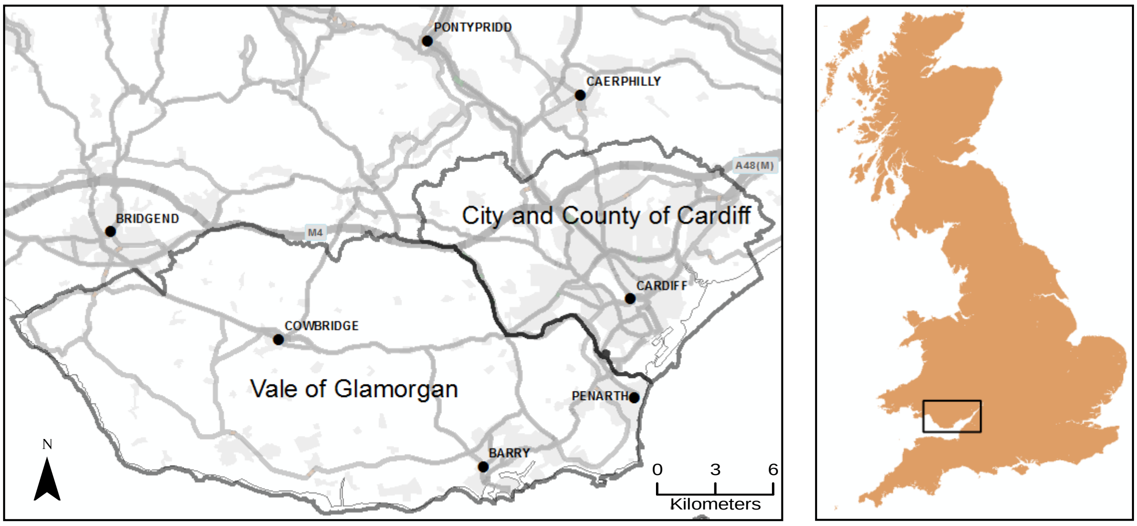


Figure 3.5: The location of the two study areas in South Wales

The choice of the two areas also enabled other potential comparisons to be made, particularly whether there was any usability divide between the two areas, despite their adjacent geographical position. With an urban and rural study area, differences in the supply and demand patterns could be explored, and these differences in inputs may help illuminate different aspect of the datasets under examination. By using more than one area the opportunity is increased of using data supplied by more than one surveyor (or team), helping to highlight potential issues of consistency of both the spatial and non-spatial information that makes up the datasets. The findings of Haklay (2010b) and Zielstra and Zipf (2010) relating to the completeness and coverage of VGI in urban and less densely populated areas suggest the usability of VGI may differ between the two study areas, and the usability of OS data in such circumstances will also be compared.

3.7 Supply-side characteristics

3.7.1 Overview of supply-side features

As outlined in the introduction to this chapter, sensitivity analyses were carried out on a series of accessibility assessments relating to various destinations in order to highlight issues with the datasets used in each case study. Each of the destinations was considered to play a role in the health, welfare or community of the neighbourhoods and areas in which they were located. Five different classes of destination were assessed:

- Primary schools - concerned with active travel and the school commute;
- Secondary schools - concerned with active travel and the school commute;
- GP surgeries - important in health planning and health justice studies;
- Sports centres - of interest in health and activity studies;
- Community hubs - facilities which act as a focus and a resource for communities are important for social health and welfare reasons.

Libraries and community centres (combined in the 'community hub' category) and schools were identified by Horner et al (2007) as some of the key destinations in their study of transportation accessibility in Seattle, an example which provided additional justification for the types of feature chosen for this study.

The main overall aim of the research was to assess usability through a comparison of the results of GIS analysis using datasets from different sources but representing the same features in the study areas. A variety of datasets were sourced to represent different supply feature locations and differing travel networks, as summarised in Table 3.2 and detailed in this chapter with justifications for their use and caveats identified. Alternative methods of representing population (demand) will also be compared, as will the selection of different network datasets obtained and used, along with the GIS processes involved. The inputs from the GIS processes will be varied, one factor at a time, using multiple combinations of supply, demand and network, and the differences in output used as an initial investigation point in order to identify broad characteristics, or issues specific to a particular dataset, that indicate good or poor usability in the context applied. Important stages in the preparation and use of each of these data sources were also documented to address wider aspects of actual usability. The supply-side datasets used are summarised in Table 3.3, with further details in Table 3.4.

By using the five different features as detailed at the beginning of this section, there was a deliberate intention to use both closely-defined features and also those more loosely classified. For example, primary schools were relatively closely defined, with little room for subjective judgement by the researcher. Community hubs, on the other hand, were much more loosely defined, meaning some judgement was required in the extraction of features from the larger datasets when using the classification system provided with the data. All datasets used did, however, require some judgement to be applied to the selection of features even where, as with primary schools, classifications appeared clear, at first sight. Section 3.8 describes various alternative data sources which were considered for this study, examined but then not used. For supply-side data many of the datasets considered had loose or informal classification systems, particularly the datasets from VGI sources, where contributors were to classify PoI features as they saw fit. Couclelis (2010) took issue with this approach as being 'ridiculously imprecise' and this, and lack of attribute completion in VGI sources, effectively restricted their use in studies such as these. Even with the stricter ontologies and classification systems used by OS some issues became apparent, as will be discussed in more detail in Chapter 6, where some of the most precise level of classifications were not completed, leaving some features to have errors of commission, resulting in the inclusion of some features in a broader classification which should have been in another sub-category. The specific example given was the inclusion of private secondary schools in the broader 'secondary school' classification despite there being a sub-category specifically for non-state secondary schools, a sub-category which was not used in some geographical areas.

There were two principal sources of data for the location of destination features: OS Points of Interest; and OS Sites. The Points of Interest (PoI) dataset is a location-based directory of all business, transport, health, education and leisure services in Britain (Ordnance Survey, 2015b), with a substantial collection of regularly-updated features. The dataset is licensed to OS by PointX, a joint venture between OS and Landmark Information Group (PointX, 2016). The locations for this study were extracted from data provided by Ordnance Survey, as the PoI dataset was not available from any non-commercial source at the time of use (though subsequently it was made available for free-of-cost academic use via Digimap, at http://digimap.edina.ac.uk/). OS supplied a copy of the entire PoI dataset for the South Wales area for the purposes of this research (dataset Version 3.1 dated March 2012). The features required for each case study were selected into separate feature-specific datasets using ArcGIS, firstly using Selection by Location (to obtain all PoI features for the study areas, plus those within a buffer distance of 5km for primary schools and 8km for the other four features) then Selection by Attribute, using the OS classifications supplied for each particular type of feature, with the classification scheme obtained from the relevant User Guide, provided with the data from OS and available from the OS website (Ordnance Survey 2015d). All schools were categorised as having their locational accuracy classed as category 1: located to the location or address, this location having been identified using OS internal resources or OS specialised geocoding software (Ordnance Survey 2015d, p. 33). Categorisation of the PoI dataset was achieved by using internal OS data and information from around 150 external suppliers, some with national coverage (such as 118 Information, Department of Transport, Local Data Company), and some more local sources (such as the Welsh Assembly Government). Some of the potential implications for data quality from the use of different sources are considered in Section 3.8.

Features located outside the study areas were included for buffer zones around each of the local authority areas, to allow for cross-border travel and to minimise edge effects (as suggested when conducting accessibility studies by, among others, Ngui and Apparicio, 2011). The 5km buffer for primary schools reflected the maximum reasonable distance for active school travel, as detailed by Statistics for Wales (2012), which stated that 5km was the 'reasonable maximum' distance a primary school pupil would be expected to cycle to school, while for walking the 'reasonable maximum' was considered to be 45 minutes travel time, the equivalent to 3.6km at an average walking speed of 4.8km per hour (3mph). The setting of a 5km Euclidean buffer ensured that any demand point which did not have a primary school within 5km (using either Euclidean or network distance) would definitely not have a school within a reasonable distance for any mode of active travel. This also ensured that any demand point would have a supply point within a 'reasonable' distance, even if the OA centroid was located close to the study area boundary (which was unlikely, given the population distributions on the boundaries, and the population-weighted methods of locating the centroids). An 8km buffer reflected the increased distance reasonably expected for a secondary school pupil to travel to school (Statistics for Wales, 2012). In the absence of any other official guidelines or information as to the reasonable or maximum travel times or distances to the other features, the 8km buffer was retained for GP surgeries, sports centres and community hubs.

The numbers of each of the supply-side features both within the unitary authority boundaries and within the buffered study areas are provided in Table 3.5. The numbers of features differs considerably, offering the opportunity to identify any trends relating to either the most or least numerous features. Numerical indications of the distribution of the different features are expressed in Table 3.6; geographical distribution is illustrated in maps in Figures 3.6 to 3.10.

The chosen features were identified by ArcGIS Average Nearest Neighbour as having varying patterns of dispersal throughout the study areas, offering the opportunity to compare the differing distributions. The figures in Table 3.6 indicate that secondary schools in both Cardiff and the Vale are the most widely dispersed features. Community hubs in both areas were clustered, as were GP surgeries, but less so than community hubs. Sports centres in Cardiff were distributed randomly, with the distribution of primary schools in the Vale close to random, with very low levels of clustering. The Average Nearest Neighbour tool works by measuring the distance between each feature and its nearest neighbour, and averaging all the distances so calculated. If the average distance is less than that of a hypothetical random distribution then the distribution in question is considered ‘clustered.’ If the average distance is greater, then the distribution is considered ‘dispersed.’ The NN Ratio is the calculated average distance divided by the expected average distance (from the hypothetical random distribution). The accompanying z scores in Table 3.6 are standard deviations that equate to probability values, so that z scores below -1.96 and above 1.96 relate to the 5% significance level. Scores falling between +/-1.96 are considered likely to reflect a random spatial pattern (ArcGIS Support, 2016).

The maps at Figures 3.6 to 3.10 provide visual confirmation with, for example, community hubs, assessed as clustered, particularly concentrated around population centres. Primary schools appear the most scattered feature of the rural Vale and were classified as random. GP surgeries were located in a relatively small area along the Vale coast with very few located inland, and were assessed as clustered. Using different features, with varied patterns of dispersal, was intended to address potential geographical bias that may have been an issue had only one feature been used, or a selection of features with similar distribution patterns.

A further OS dataset was used to locate supply-side features: Sites. At the time this study commenced (2013) OS Sites was a newly-launched commercial dataset. Now part of the OS MasterMap Topography Layer, Sites is provided as a free add-on to customers obtaining or using the Topo Layer. It contains 'footprint' polygons of main features in the categories of medical (ie hospitals), education (schools, colleges and universities) and transport (airport, water transport and rail stations) with the location of access points to each of these facilities. These points were located on the polygon edges and were stated by the accompanying user guide (Ordnance Survey, 2015e) to be of all the points of access to each particular feature, categorised appropriately into pedestrian only, vehicle only, and pedestrian/vehicle access. These polygon and point datasets were identified as offering an addition to the existing locational methods outlined in this chapter. The Sites dataset was provided by OS in May 2014, in .gz format, which was translated and converted into Arc-usable shapefile format. An example of how this database represents a typical school site is given in Figure 3.11.

Name of dataset	**Provider**	**Description**	**Derivation**	**Location method**	**Advantages**	**Disadvantages**
Points of Interest (PoI)	Ordnance Survey	National location-based directory of services.	Classifications supported by a number of commercial partners or government sources (eg all schools provenance classified as 'Welsh Assembly Government').	Four categories of positional accuracy. All schools classed as the highest level '1,' ie positioned to the location or address.	Complete. Detailed classification scheme. Available cost-free via Digimap. Trusted brand.	Commercial rates of purchase for non-academic use. Multiple sources.
Sites	Ordnance Survey	National view of detailed extents of important locations, including access and routing points.	Functional sites extracted from OS Topography Layer. Access points captured visually from Topo Layer and Imagery Layer.	Positional accuracy to match that of Topo Layer, ie RMSE of +/- of: 0.5m urban; 1.1m rural. On boundary of site, OR true position OR within 1m of site boundary.	Derived from authoritative map data. Intended to enable underlying data to be used in more analytical contexts. Position stated of actual access point, removing estimation or guesswork.	Supplied as free add-on for existing data users, not provided as stand-alone product. Field surveys of access points "to be carried out" (Ordnance Survey, 2015e).

Table 3.3: Supply-side datasets and their characteristics.
Details of the provenance of each chosen type of feature are provided in Table 3.4 (below).

Feature	Positional accuracy*	Derivation
Primary schools	1	Welsh Assembly Government
Secondary schools	1	Welsh Assembly Government
GP surgeries	1	Beechwood House Publishing Ltd
Sports Centres	1, 2	118 Information, OS, PointX, Sports Council for Wales.
Community Hubs	1,2	118 Information, Local Data Company, OS, The Education Company.

Table 3.4: Positional accuracy and derivation of OS Points of Interest supply-side features.
* 1: positioned to the location or address;
2: positioned to an adjacent location or address;
3: positioned to the road within the address or location;
4: positioned within the geographic locality.

	Cardiff		Vale	
Feature	In UA area	Incl buffer	In UA area	Incl buffer
Primary schools	93	167	49	123
Secondary schools	21	33	9	24
GP surgeries	63	114	21	103
Sports centres	31	55	10	53
Community hubs	76	169	39	164

Table 3.5: Number of features within the boundaries of each study area and within the relevant buffer (5km for primary schools, 8km for the other features).

		Feature				
		Prim schools	Sec schools	GP surgeries	Sports centres	Comm hubs
Cardiff	NN Ratio	0.86	1.32	0.87	1.00	0.72
	z score	-2.50	2.76	-1.95	-0.05	-4.60
	Conclusion	Clustered	Dispersed	Clustered	Random	Clustered
Vale	NN Ratio	0.98	1.43	0.69	1.12	0.61
	z score	-0.21	2.49	2.65	0.70	-4.60
	Conclusion	Random	Dispersed	Clustered	Random	Clustered

Table 3.6: Overall distribution of features, calculated using ArcMap Average Nearest Neighbour tool. NN Ratio > 1 and high, positive z score indicates dispersed pattern. NN Ratio < 1 and low, negative z score indicates clustered pattern. NN Ratio = 1 indicates random pattern of distribution.
(The above figures were calculated using only the features within the boundary of each study area).

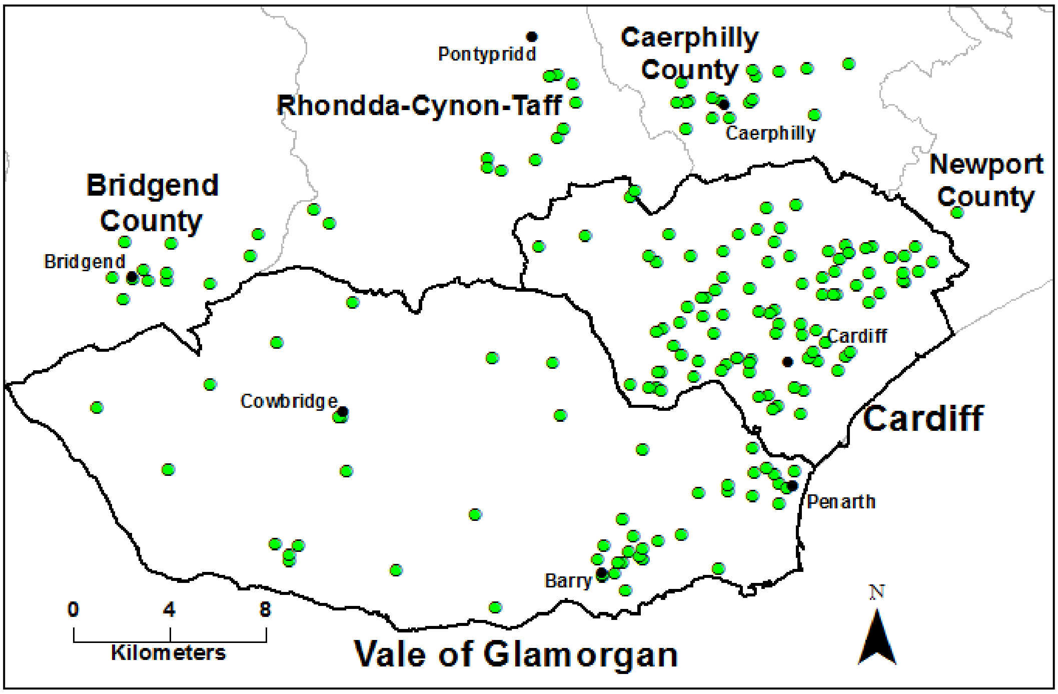


Figure 3.6: Distribution of primary schools in the study areas, plus those from neighbouring areas within a 5km buffer.

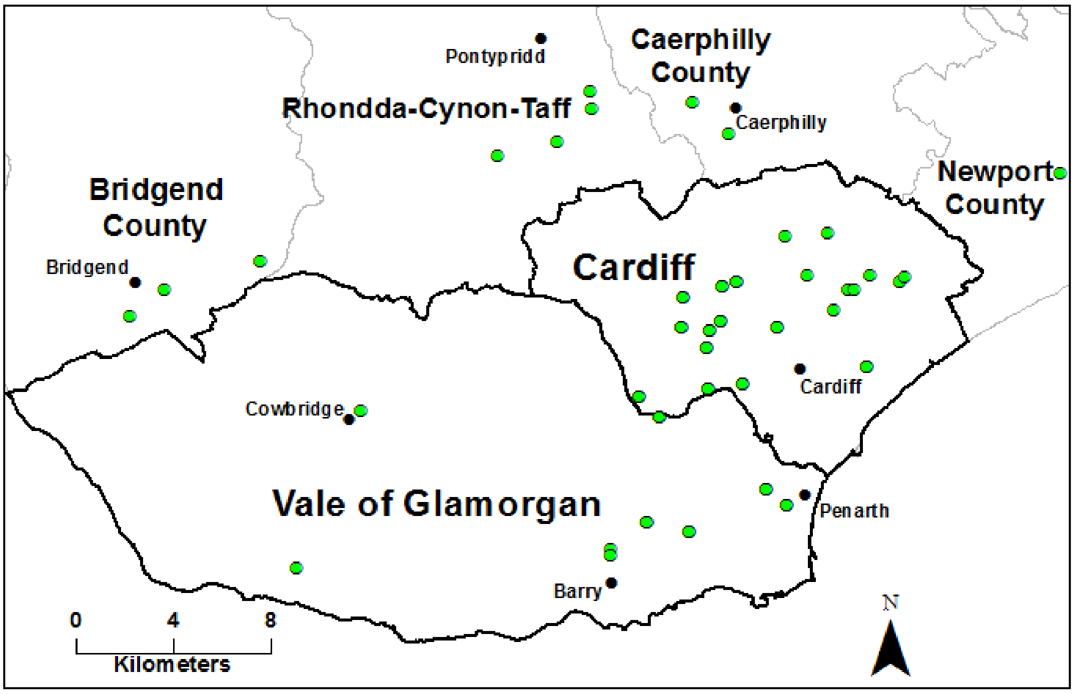


Figure 3.7: Distribution of secondary schools in the study areas, plus those from neighbouring areas within an 8km buffer.

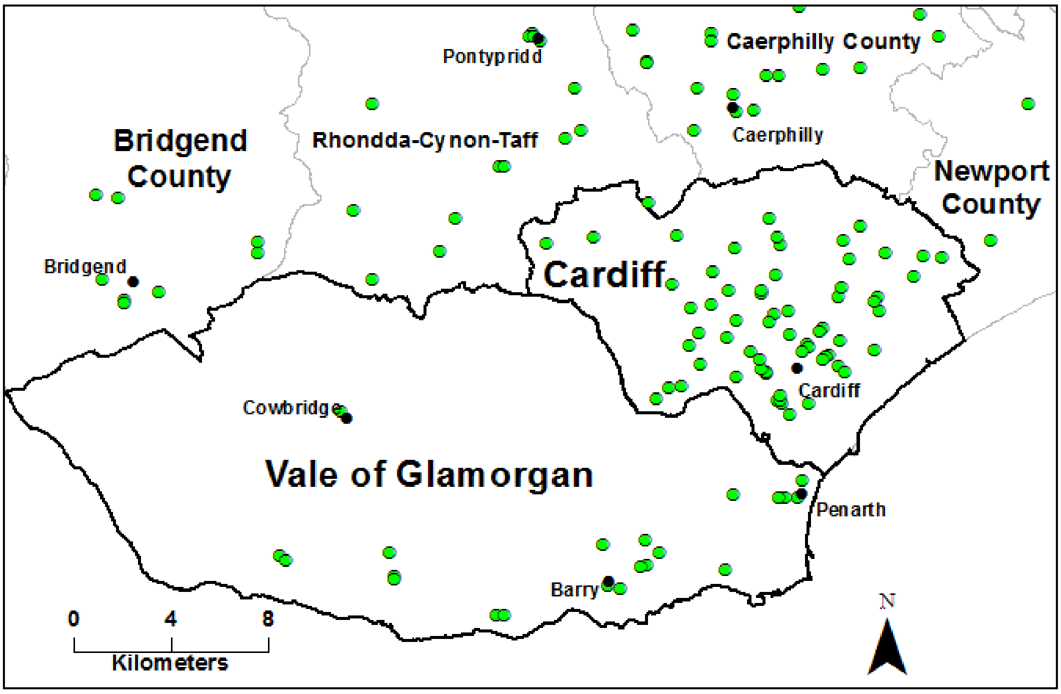


Figure 3.8: Distribution of GP surgeries in the study areas, plus those from neighbouring areas within an 8km buffer.

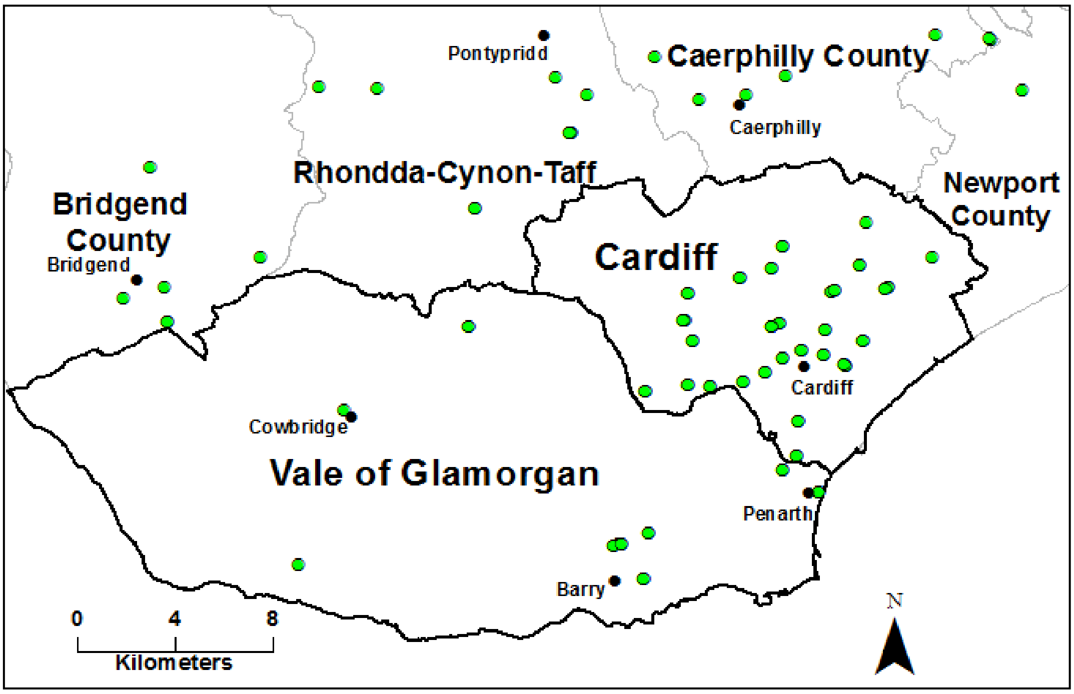


Figure 3.9: Distribution of sports centres in the study areas, plus those from neighbouring areas within an 8km buffer.

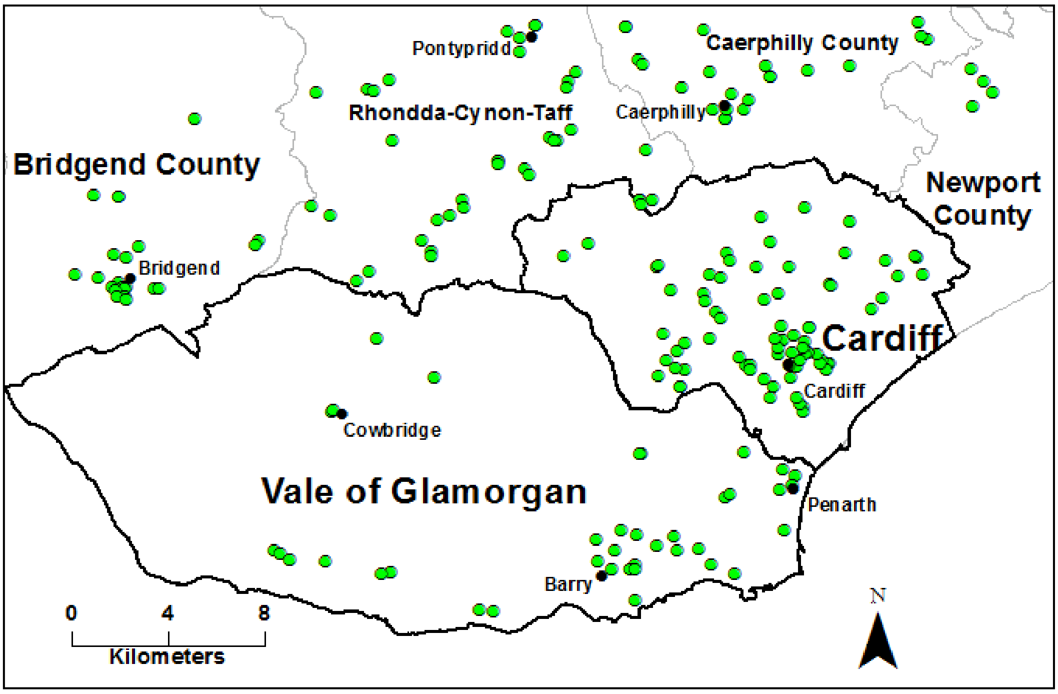


Figure 3.10: Distribution of community hubs in the study areas, plus those from neighbouring areas within an 8km buffer.

3.7.2 Supply-side features: schools

OS Sites dataset was used for both secondary schools and primary schools. Access points for pedestrians were taken directly from OS Sites data. Polygon centroids were calculated using the Arc 'Feature to Point' tool in the Data Management toolbox.

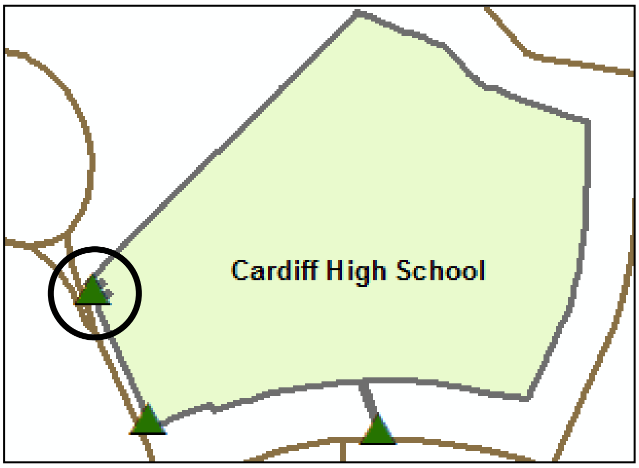


Figure 3.11: Example of Sites feature, with surrounding roads for context. Pedestrian access points are shown as triangles, with the access point circled classified as 'Motor Vehicles, Pedestrian.'

A regional geographical extract was provided by OS, and ArcGIS used to extract features for the study areas plus those within buffers of 5km for primary schools and 8km for secondary schools, using both Select by Location and Select by Attribute. The number of records provided via the initial OS delivery of Sites was considerably less than that of PoI, due to the relatively few categories included (as stated previously) and the relatively low numbers of such features in South Wales when compared to other areas. Data-handling issues were therefore reduced, and selection of the required features relatively straightforward. As the process utilised in the sensitivity analysis used to identify usability issues involved as assessment of accessibility to primary and secondary schools, the access points included as part of the Sites dataset were Selected by Attribute in ArcGIS to include only those available to pedestrians. Given the three attributes allocated to access points (pedestrian only, vehicle only, pedestrian and vehicle) and the full completion of the relevant fields in the dataset, selection was unambiguous.

The Sites dataset did not identify features such as GP surgeries, sports centres or community hubs, therefore no attempt was made to utilise Sites for these features. The alternative datasets so obtained enabled comparison of location methods to be used in the sensitivity analysis and to enable an indication if the use of this new dataset would have an influence of the results of an accessibility assessment. However, the two datasets were not directly comparable. For example, two schools were included in the Sites dataset for Cardiff, but not the PoI dataset: Cardiff Steiner School and Cardiff Muslim School. Neither were found in any category of the PoI classification scheme.

A further issue which was apparent with the Sites dataset was that two primary schools in Cardiff (Melin Gruffydd and Whitchurch) had no associated access points. This error of omission would affect the assessed accessibility of population centres around the locations of these schools. Enquiries made to OS indicated that Sites access points had not been completely field surveyed by the time the data was provided, but that access points had been identified from aerial imagery and existing map data. Some patterns of school boundary fencing and road/pavement characteristics had made identification of access points difficult in some cases (see Figure 3.12 for an example using Melin Gruffydd Primary School). With these schools having no access points it was clear that an error of omission had been made, however it could not be ascertained whether other access points were omitted from schools which had one or more included in the dataset (as some schools, particularly secondary schools, had multiple points of entry). The doubt caused by the identification of an obvious error did, however, affect user confidence in the accuracy, quality and authority of the dataset. The Sites dataset was used as supplied, without making any attempt to add the missing access points to the schools in question. This was due to two reasons: firstly as the main issue of this exercise was the usability of the datasets, not obtaining a fully accurate accessibility assessment of schools in

Cardiff and the Vale; secondly, the identification of the functional access points would require a level of subjective judgement incompatible with the other work in this thesis. On this second issue, the most accurate way of identifying the access points would be to conduct a ground survey (that is, go and look at the features in question), and if this option was not available, to use Google Street View or similar to view the school boundaries, and judge whether gates and entrances were in use. These judgements require more of a subjective view than if, for example, a school had closed on one site and reopened on another (as was the case with Cowbridge High, see Section 6.2.3 for details). However, in assessing the performance of this particular dataset the data was used as supplied with respect to Melin Gruffydd and Whitchurch primary schools.

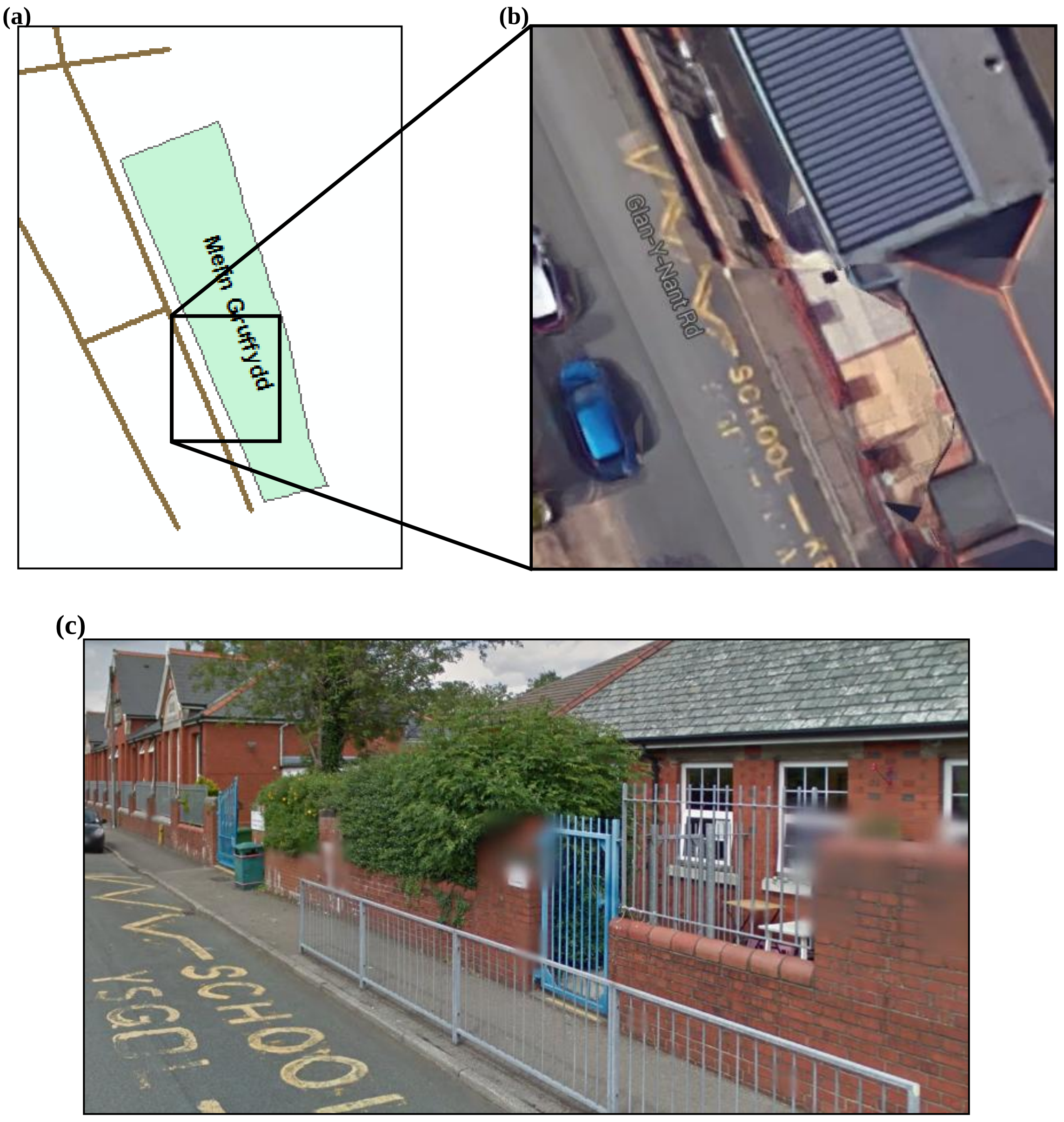


Figure 3.12: (a) Extract from Sites dataset showing Melin Gruffydd Primary School, with no access points mapped.
(b) Google Earth image showing the school perimeter, with the pattern of fencing and walls making identification by aerial imagery of access points difficult.
(c) Google Street View image showing the location of two of the school's gates, for comparison with the aerial imagery.

The opportunities afforded by Sites in representing facilities such as schools, with their substantial footprints (due to playgrounds, playing fields, etc) was clear, in that Points of Interest represented such areas with one point, generally located at the address of the facility. Sites could therefore be viewed as a less generalised map representation of a geographical feature. Other supply-side datasets which were considered but rejected are described in Section 3.8.

To illustrate the typical differences encountered when using the different location datasets, Figure 3.13 shows a secondary school with the locations from various datasets superimposed on to the OS Topographic (Topo) layer. The WAG location is used to illustrate a postcode location georeferenced by a third party compared to the same postcode location provided by OS Code-Point data.

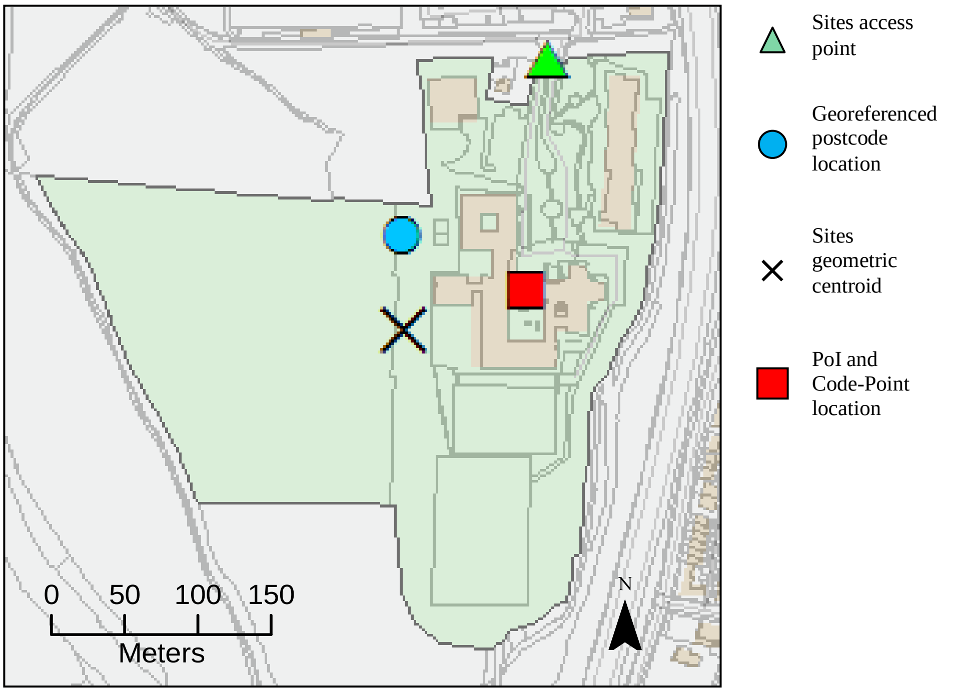


Figure 3.13: Different representations of the same supply feature (a secondary school). MasterMap Topo defines the buildings and boundaries. OS Sites Functional Site Polygon is shown by the green shading, covering school buildings, car parks and sports areas; 'X' marks the geometric centre of the Sites Polygon; OS Sites Access Point is shown as a green triangle; OS Points of Interest is shown as a red square, the OS Code-Point relating to the school is in the same location (within 1m); the WAG data location point (using the postcode provided on the WAG website, http://gov.wales/statistics-and-research/address-list-of-schools/?lang=en) but georeferenced by the website authored by Bell (2013), is shown by the blue circle.

In assessing accessibility to both primary and schools the distinction between types of school were ignored. The school nearest each population centre was considered as a potential destination, regardless of whether it was Welsh medium, Roman Catholic, church school, or a state secondary. There were two reasons behind this decision: firstly the potential geographic accessibility for each population centre was assessed as if in an ideal world, where pupils walked to their nearest school, and where oversubscribed schools and parental choice did not exist. Given the availability of research into the actual school commute, it was thought to be of interest to compare the real-world situation to the ideal-world possibility of shorter commutes and increased potential for active school travel. With respect to the data for the schools in PoI and Sites, although the type of school (eg Welsh medium, RC, etc) could be inferred from the name in some cases, there was no classification at this level. The Sites dataset had a series of fields ('stakeholde' _1, _2, _3) which had the potential to be utilised in this way, as indicated by the very small number of records which had been completed. In the case of Cardiff primary schools for example, five records were completed in the 'stakeholde' field: two as Roman Catholic Faith; three as Church in Wales. In the 'stakehol_2' field all five had the entry "Religious Interest In" and all the fields under 'stakehol_1' and 'stakehol_2' were blank. The data for secondary schools had two entries under these fields. It is emphasised that potential measures of accessibility are being assessed in these case studies, as we do not have data on the actual school accessed from the demand points.

The 2SFCA analyses considered levels of supply and demand, therefore supply capacity data was required for each feature. In the case of primary schools supply was considered to equate to the school capacity, which was represented by the number of pupils at each school ('school roll'). When obtained, this data was added to the attributes of each individual feature in ArcGIS. Information on pupil numbers for Cardiff schools (both primary and secondary) was obtained from the Cardiff Council website (Cardiff Council, 2014), for the school roll as at September 2012. Equivalent information for the Vale council area was obtained from their website (Vale of Glamorgan, 2014), and again gave details as at September 2012. The websites of neighbouring local authorities were accessed to obtain pupil numbers of schools within a 5km buffer of the study area boundaries. Bridgend Council provided school roll details for their county (Bridgend Council, 2014), and the remaining data was obtained from the Welsh government sources (Welsh Assembly Government, 2014). Of the two schools included in Sites that were not included in PoI data (Cardiff Steiner and Muslim schools), neither were listed on the WAG website and no school roll was identified. As a blank, null or zero entry would imply no capacity in calculating 2SFCA, neither featured in Sites calculations, though the discrepancy between the two OS datasets was noted.

3.7.3 Supply-side features: GP surgeries

Another feature with which to compare results from the accessibility study and therefore help understand the impact of geographic representation when undertaking usability analyses was that of GP surgeries. The distribution of surgeries (see Figure 3.8) varied both across and within the study areas when compared to that of both primary and secondary schools, particularly in the more rural Vale. No Sites data for GP surgeries were available therefore only point locations were utilised from the OS PoI dataset. With clear and unambiguous classification categories in PoI the surgeries were easily extracted from the dataset using Select by Attribute in ArcGIS. Potential alternative sources of GP locations were considered and will be discussed later in this section.

Supply-level figures were represented by the number of GPs located in each practice, with the figures obtained from WAG sources on 8 December 2014 (http://wales.gov.uk/statistics-and-research/general-medical-practitioners/?lang=en). The GP numbers were added to the attributes of the map layers. One issue that could be anticipated stemmed from the total numbers of GPs in this layer exceeding the total number of GPs officially working in each area. This was due to some GPs working in more than one surgery, with many surgeries having several branches. This potential problem was considered, but the number of GPs in each branch was still taken as the supply capacity, though it was acknowledged that if considered with a temporal element these branch surgeries may offer a lesser level of accessibility than indicated with the use of these GP numbers. The lack of such a temporal element in the GP data served to artificially increase the accessibility of the population to a GP surgery (as in this study even a branch surgery would be treated as open and working, even if in real life it was only open one or two days a week), a factor which needs to be accounted for through the use of appropriate metadata. This instance illustrated the importance of metadata in increasing the usability of data, in that a statement or caveat should clearly warn users of the potential for exaggerating GP provision in areas of branch surgeries only periodically staffed.

The GP data obtained from WAG (as detailed above) could have been used as an alternative locational method for GP surgeries by extracting the postcode provided for each surgery and mapping locations using OS or third-party georeferencing software. However, the small size of some GP practices (sometimes located in a house) meant the postcode may not be allocated solely to that practice (as larger practices may be allocated a postcode in their own right due to the volume of mail received). The PoI dataset offered a higher level of precision, therefore was the option used. An alternative option to set capacity levels was to use the number of patients registered at each surgery, figures for which were available in from the same WAG sources as GP numbers. This may have proved an interesting comparison due to wide differences in average numbers of patients per GP, as shown in the screenshot of the data in Figure 3.14, varying from over 3700 down to under 950 people per GP. A comparison between results using GP numbers compared to the number of registered patients may be worth future consideration.

Practice Code	Number of Registered patients at pract	Number of GP Practitioners working at the pract
W00141	4,215	2
W98017	2,866	2
W98019	3,354	2
W98031	9,993	5
W98032	9,418	6
W98035	8,610	6
W98041	6,209	4
W98051	2,419	1
W98619	1,358	1
W98627	2,207	1
W98016	8,804	8
W98021	21,311	15
W98023	7,494	2
W98033	7,697	5
W98045	6,424	4
W98049	9,305	5
W98053	8,963	3
W98055	3,741	4
W95010	17,746	12
W95017	7,161	4

Figure 3.14: Screenshot of WAG GP data, showing wide range in average numbers of patients per GP. (Source http://wales.gov.uk/statistics-and-research/general-medical-practitioners/?lang=en)

3.7.4 Supply-side features: sports centres

A fourth feature identified as potential destination was that of sports centres. Again not included in the Sites dataset, PoI location data was used and the accessibility analysis results used to compare directly with those of GP surgeries, which had a different pattern of distribution. Comparison with the other features were carried out using destination overlap results (see section 3.5) to ascertain what effects different distribution had on identification of nearest destinations.

A strict inclusion criteria was applied to the selection of sports centres, therefore only those features which were classified as 04 24 0293 were included (04 being classified as 'Sport and entertainment,' 24 as 'Sports complex,' and 0293 as 'Gymnasiums, sports halls and leisure centres'). Several commercial gym and fitness companies had facilities in this list, and a decision was made to remove those in order for the accessibility study to reflect those facilities which were run or managed by the local authority or which were available to the public on a 'turn up and use' basis.

It became apparent when cross-referencing against other sources of information that some errors of omission and commission had occurred, with (for example) Cardiff International swimming pool included in the classification (due, presumably, to having gym facilities in the building) while Maindy Pool in Cardiff did not have the same classification, despite also having a gym on the premises. One recreation ground was included in the Cardiff area, despite 'Sport grounds, stadia and pitches' having a separate classification. The selection of facilities in the Vale was much tighter, with the same classifications resulting in only sports and leisure centres being selected. It was also noted that in Cardiff Penylan Library and Community Centre was included, presumably due to the community centre having a hall used for sporting activities, therefore being included under the ‘sports hall’ category. As will be seen in the next section (community hubs), this highlighted the multi-purpose nature of the library system, as libraries become community hubs rather than simply a lender of books.

Identifying a suitable supply level feature for the sports centres proved problematic. The metric chosen would be required to be simple to define and readily available, therefore factors such as total floor area, the number of sports courts, and so on, were considered. However these figures were not readily available, and there was little indication from a literature search that such figures would actually provide a reasonable representation of supply. It was therefore decided to default the supply level of each facility to ‘1’ when undertaking the calculations of 2SFCA, which meant that each sports centre included in this part of the study would exert an identical ‘gravitational pull.’

3.7.5 Supply-side features: community hubs

The fifth and final features of interest were community hubs. There were very few instances of research that used the term ‘community hub’ that referred to locations and organisations that provided facilities for a wider, representative population, rather than for a particular or specific interest group. This lack of research, and even of a definition, occurs despite the recurring use of the term in politics and media (BBC, 2015a; BBC, 2015b). One definition was provided by Octopus Communities in Islington, London:

> “Hubs are large multi-purpose community centres that provide the focus for local community activity by bringing together local people, organisations, and businesses to improve the quality of life in their area.” (Octopus Communities, 2014).

Octopus included community centres and activity centres in their definition, but not libraries or sports centres, although the definitions used by other organisations included or even emphasised those other particular aspects. For example, Sports Scotland (2014) emphasised their particular area of interest as they considered sports community hubs as separate entities from other types of community facility. A further example was that of The Media Trust and their Community News Hubs (Leverhulme Trust, 2010), again emphasising one particular agenda. For this exercise, therefore, a mixed approach was taken, utilising the classification scheme available through the OS Points of Interest dataset. Classification ‘06 34 0456 Halls and community centres’ were included from the ‘Public Infrastructure > Infrastructure and facilities’ category, as those were the types of facility in mind when choosing the Community Hub category initially. Classification '0458 Libraries' was included, as the role of libraries had become more than just the lender of books, with educational activities for children, pensioners, and other groups within the community. This choice was supported by the work of Houghton et al (2014) who stated the case for further promoting libraries in New Zealand as community hubs and places of lifelong learning.

Only point locations were available for community hubs, and once the categories were finalised extraction from OS PoI was simple and straightforward, again using the 'Select by Attribute' functions available in Arc. Alternative sources (such as Yell) were overly inclusive, with searches on 'community facilities' producing results including language schools, household waste recycling centres, company social clubs, housing associations, and so on. OS PoI was therefore the only source used for locating these facilities.

Ascertaining a supply level for the community hub classification again proved difficult, both in theory and practical terms. Identifying a suitable metric was problematic, with size of facility, opening hours, usage level, etc all being considered and discarded as either not reflecting the true 'gravity' level of the facility or due to the difficulty foreseen in obtaining reasonably accurate and meaningful data, if any such data existed in an obtainable and usable form. For 2SFCA purposes, therefore, a default of '1' was used for the supply side figure.

3.8 Alternative supply-side data sources

Before choosing PoI and Sites as the main sources of locational data, several other, alternative datasets were sourced, examined and considered. With an increasing culture of open data, it was thought initially that many different datasets would exist from which information for this exercise could be extracted. However, when assessed in terms of data quality, coverage, accuracy and currency, none of the alternatives appeared usable, which emphasised the many factors, more than simply data quality, which made some data more usable than others.

Other alternative datasets were considered, such as:

Yell	Results of a search on 'Primary Schools' were highly inclusive, and included some obviously incorrect entries (and included, for example schools of music and dancing and driving schools). However a more recent search (conducted in November 2015) noted a new user interface on the webpage, and a much stricter selection result, and all 150 responses appeared relevant. Obtaining

location data from Yell was difficult, and either involved the manual recording of postcodes for geocoding, or the 'scraping' (that is web harvesting or website data extraction) of each map-result page in order to obtain lat-lon location data for each school, a time-intensive process. Making use of data obtained this way may also violate the intellectual property rights of Yell, and would almost certainly breach the terms of use of their website.

OSM PoI — Coverage and completeness outside Cardiff city centre was not sufficient for OSM PoI to be considered as an alternative source of destination data. Mapped features were sporadically mapped in suburban and urban fringe areas.

Google — Search results were also overly-inclusive, with some private tuition organisations appearing on the maps resulting from a primary school search. Some mislocated schools in Cardiff were immediately obvious, as were several mislabelled schools. For example, Coryton Primary was located correctly, but a second point 5km south was also labelled Coryton Primary. Obtaining their lat-lon data would be subject to the same caveats as mentioned with the Yell alternative, as mentioned above.

ABP — OS Address Base Premium (ABP) was considered as an alternative data source of supply-side location data. ABP (which is made up of several separate files) has the file 'Org_Records' with a field 'Organisation' which identified 13 secondary schools (compared to 31 in Sites). Using the ABP classification scheme (from the file Class_Records) to Select by Attribute in ArcGIS to the finest level (ie classification 'C E 04 SS' representing Commercial > Education > Secondary/High School > State Secondary) resulted in 36 schools being identified, but using 'C E 04' resulted in 49. When compared on a map, after performing a Join function in ArcGIS on the file containing the location data (file XYID21_BLPU) several schools from Sites and PoI were not present in either ABP selection, examples of which included Michaelstone (which was classified as a college in ABP), and the eastern site of Whitchurch High (a split-site school which, when investigated, did not have any main administrative functions at the omitted site). In view of the inconsistencies in content, it was decided not to use ABP as one of the main sources of location data for schools.

Address Layer 2 — This OS dataset provided points of every address in the country. There was no clear classification scheme associated with it, and the classifications supplied are not provided or linked from the AL2 guidance notes that were provided with the data. Several of these classifications originated from other sources with, for example 'Scat' which originated from Valuation Office Agency (VOA) non-domestic rates special category codes, and 'PDescCode' which are 108 other VOA codes for non-domestic rates values and billing. Another category, 'LandUseGp' refers to National Land Use Database (NLUD) Group, a 41-group scheme which was found on the Department for Communities and Local Government) DCLG website (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/11493/144275.pdf. Accessed 12 Feb 2016). Despite searches of gov.uk website and into the online VOA rating manuals (https://www.gov.uk/government/publications/valuation-office-agency-rating-manual, accessed 12 Feb 2016), no details were found of the VOA codes, and none of the information that was available gave a sufficiently-clear indication of the nature of the feature in terms of supply or destination type. As a specific example, a building identified as a judo kwai was investigated using AL2 and found to have the BaseFunction category of 'CLUB.' There was no indication whether this was a social club, a sporting club, or a hobbyists club, and would cause problems if such locations were the subject of accessibility or availability assessments. Being too imprecise to determine the nature of facilities, AL2 was not used to identify and locate supply-side destinations.

A number of other alternative data sources were also considered, but were immediately assessed as unsuitable for further investigation. Potential sources included freely-available data from vehicle satellite navigation data supply organisations, such as that notified on the GPS Data Team website (https://poi.gps-data-team.com/united_kingdom/) which provided 'free and almost free GPS POI files.' These files only contained locations of features that were directly car-related, such as petrol stations. No data for schools, surgeries or sports centres, etc were available without purchase or subscription. The categories for point of interest data that was available free-to-use changed frequently over the course of this research. From the GPS Data Team website, for example, two categories appeared in late 2015: 'library' and 'university.' Though available for browsing, neither could be successfully downloaded. The university category was also over-inclusive, with student unions, private colleges and commercial organisations listed. It was noted that the University of South Wales was listed under its old name (University of Glamorgan), indicating the data's lack of currency (the university changed its name in 2013) or temporal inconsistency, with other entries having been recently updated.

A further alternative source of GP surgery data included NHS Wales, whose website (http://www.wales.nhs.uk/ourservices/directory/) listed all NHS GP surgeries in the Cardiff and

Vale NHS area. However, each location identified through NHS Wales would have to be georeferenced using the postcodes provided on the website, introducing a source of potential inaccuracy that would require highlighting to users (as outlined in Section 3.7.3, with postcode locations less accurate than PoI's location to the actual facility).

No alternative sources of sports centre data were considered for this part of the research. Alternative sources of data did exist (through peripheral work carried out during the course of study), held by various second and third-sector organisations, but issues of confidentiality (commercial confidentiality and concerns over disclosure of personal information) prohibited these organisations from sharing**.** No credible alternative sources of data were identified for community hubs. As its definition was open to so many different interpretations it was entirely probable that an alternative definition could be used to obtain useful information from another source. For example, the ABP dataset had classifications that resulted in nearly four times the number of features than identified with PoI. Initial investigation indicated that many locations were residential addresses, and it was assumed these were the administrative contacts relating to clubs, societies and facilities, not necessarily the location of the facilities themselves. The classification for church hall, as another example, included those that were not open outside times of worship and used purely for religious purposes, thus not meeting the definition of a community hub. The definitions were therefore too broad to be useful in this case and illustrates the importance of ontologies when classifying geographical features, and the difficulties caused to research through the use of differing classification systems or less-formal ontologies, as discussed in Chapter 2.

The datasets which were considered as sources for all the supply-side features are listed in Table 3.7 with summaries of reasons why they were unusable, with associated shortfalls in usability illustrated through the listing of usability elements not satisfied by data. A data usability checklist, such as that provided in Appendix A, as discussed in Section 7.2, would have aided the decision-making process in these considerations. In brief, the alternative sources varied widely in terms of all of which were usability characteristics. It was not possible to obtain free-to-use high quality, accurate, current data for the relevant features in the area of interest, with the data from alternative sources falling short of the standards set by the OS databases.

3.9 Demand-side characteristics

UK 2011 Census Output Areas (OAs) were chosen as the main unit of population representation. OA polygons were the smallest unit of census aggregation, forming the building blocks which covered the entire surface of Great Britain, matching local, regional and national government administrative areas. OAs were constructed using clusters of adjacent unit postcodes and were intended to have as similar population sizes and to be as socially homogenous as possible, according to tenure of household and dwelling type (ONS, 2011a). Although Lloyd (2012) recommended OA-level analysis for study involving population sub-groups, their limitations were also noted, especially when the OAs were very large, and their representation may be a poor approximation of what should be a continuous population surface. The usual night-time residential population (URP) of each polygon as of 27 March 2011 was represented by a population-weighted centroid. GIS-compatible OA polygons and centroids were readily-available for download to registered students and academics, free of charge, from the UK Data Service Census Support webpages of the Edina website (http://census.edina.ac.uk/). The distribution of OA polygons and centroids within the study areas is shown in Figure 3.15, with (a) showing Cardiff and (b) the Vale of Glamorgan.

As outlined in section 3.2, one of the questions raised in this research was to ascertain if (or how) distance models of accessibility related to gravity models, such as those in the Floating Catchment Area family of models. Gravity models can incorporate levels of supply and demand, and an approach was taken to ensure that the levels of demand presented as realistic a figure as possible, with reasonable and justifiable assumptions made for each feature.

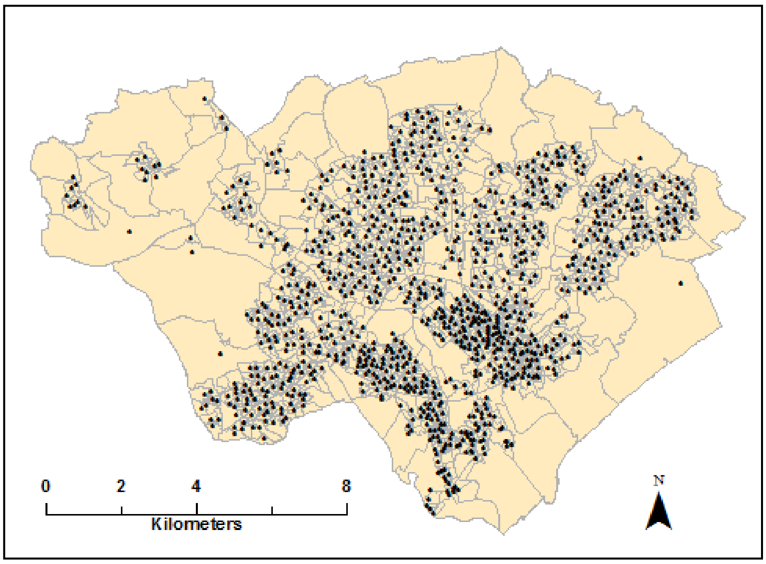
Having different features under examination offered an opportunity for each OA centroid to offer a different relevant sub-population depending on the feature under consideration. Age categories were most frequently used to identify the relevant demand for each type of facility, and datasets of 2011 OAs with the relevant age splits was taken from the NOMIS website (https://www.nomisweb.co.uk/census/2011/ks102ew). Figures for the economically active population were also used in calculating demand figures and were also obtained from NOMIS.

The age-split data from NOMIS was used to estimate the primary and secondary school-age population of each OA. Unfortunately, the age splits used in the census were not directly comparable with school ages, with the available data having splits for 10 – 14 years old, and 18 – 19 years old. A simple approach was taken, whereby the assumption was made that the maximum age of primary school pupils was 12, and that secondary school pupils were 12 to 18 years old, therefore the population in each relevant age split was halved to obtain a figure for 10-12 and 12 - 14 years old, and for 18 year olds. The full population of 15 - 17 year olds was included, though it was noted and acknowledged that some of the older group may not actually be school pupils.

Data set	Usability elements	Specifics
Yell	Content	Overly inclusive (eg schools, community hubs)
	Utility	Web scraping required – time consuming, repetitive
	Quality - completeness	Missing features compared to other data sets
	Quality – logical consistency	Wrongly classified features (eg schools)
	Quality - accuracy	Lat/lon data provided locates to postcode, not exact position of feature.
	Legal	Non-commercial use permitted. Query over bulk scraping.
OSM PoI	Quality - completeness	Low numbers of features outside major urban centres
	Utility	Web scraping required – time consuming, repetitive
Google	Content	Overly inclusive (all features)
	Quality - accuracy	Mislocated schools
	Quality – logical consistency	Wrongly named or labelled schools
	Utility	Web scraping required – time consuming, repetitive
	Legal	Long and complex terms of use. Would Google own any ‘derived’ information?
ABP	Purpose	Intended for postal use, not necessarily compatible with features under study
	Quality – logical consistency	Schools classified differently (eg sixth form college classified as ‘College’)
	Quality - completeness	Multi-site features reduced to one point: the postal delivery point
Address Layer 2	Purpose	Intended for postal use, not necessarily compatible with features under study
	Integration and convenience	Classification categories not readily available.
	Quality – completeness/Content	Features without postal delivery not included (eg back-alley gyms and halls)
GPS Data Team	Content	Restricted to selective types of feature (eg ‘library’ only became available late 2015)
	Content	Overly inclusive (anything remotely related to feature or feature name was included)
	Quality - accuracy	Some entries considerably out of date

Table 3.7: Summary of datasets investigated as potential sources of all required supply-side feature locations, and reasons why they were not usable, with reference to a selection of usability criteria.

(a)



(b)

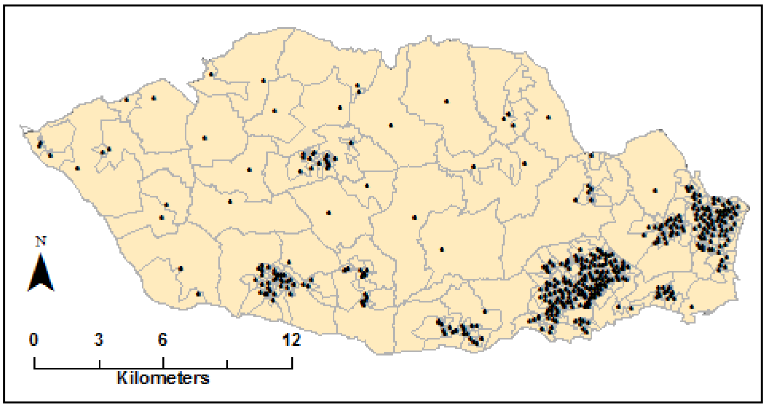


Figure 3.15: Distribution of OA polygons and centroids in (a) Cardiff and (b) Vale of Glamorgan.

The relevant demand figure for GP surgery usage was obtained from Welsh Assembly Government statistics (WAG, 2013), which indicated that 17% of the population of Cardiff had made recent use of GP services, and 19% of the population of the Vale of Glamorgan. The appropriate proportion of the Usual Resident Population (URP) was therefore calculated for each area and GP users added as an attribute to the OA centroid data.

The demand level for sports centres was considered to consist of the entire Usual Resident Population of each OA. From a brief appraisal of sports centre websites it was found that local authority-run sports centres generally made an effort to attract as wide a range of the population as possible. Most were open from early morning until late at night, thus permitting those employed to use the facilities outside their working hours, while the non-economically active portion of the population (and those on shift work) used the facilities during the day. Most (if not all) sports centres offered activities aimed at all ages and made provision for those with disabilities to make use of the facilities. With all sectors of the population catered for, the use of URP as the demand level was justified.

The relevant population of users of community hubs was assumed to consist of those individuals who were able to make use the facilities during 'normal' working hours. This was calculated using published census data by taking the Usual Resident Population (URP) for each OA and deducting from this the number of schoolchildren (as calculated for the primary and secondary school exercises) and the numbers of those Economically Active (working people). This provided an approximate number of people available in each OA who would be available to make use of community facilities during the day, and averaged over both Cardiff and the Vale consisted of approximately 28.5% of the URP (though the actual numbers differed for each OA).

3.10 Alternative demand-side representations

3.10.1 Code-Point and Code-Point with polygons

In comparison to the use of OAs, an alternative, finer representation of population was used in one part of the research (GP accessibility): OS Code-Point. The Code-Point dataset (and its associated dataset Code-Point with Polygons) has the location of every postcode in Great Britain, represented by polygons (which hold the relevant buildings relating to each postcode) and points (each of which is located in the building closest to the centroid of the postcode polygon). The number of postcodes greatly exceeded that of OAs, as shown in Table 3.8.

	Vale	**Cardiff**
No. of OAs	412	1077
No. of PCs	2696	6336

Table 3.8: Number of census output areas and postcodes in each of the study areas.

The Code-Point dataset was provided by OS with a release date of August 2013. The data was supplied in csv format (comma separated values), a standard method for delivering data, and simple to load into ArcGIS for visualisation via the 'Add XY Data' option. There were a large number of fields for each record (19 numbered fields in total) relating to the mail delivery business, one of the main purposes for which the dataset was created, most of which were extraneous. One field, however, differentiated domestic and non-domestic postcodes. The non-domestic postcodes were assumed to be commercial and industrial addresses, and could be discounted when populations were allocated to each of the postcodes (as the postcode data itself held no population data). This contrasted with census OAs which covered the entire surface of the country and included non-residential areas within their polygons. The domestic postcodes only were considered to be those with a night-time residential population (ie the URP for census purposes). This dataset therefore possessed characteristics that offered the opportunity for a more accurate way of locating population, though challenges were posed relating to the visualisation of results at the county scale, as can be seen in Section 5.2.4.

A further issue with regard to Code-Points was one of awareness, whereby multiple postcodes shared the same point in space rendering the assumption of a two-dimensional surface of population as erroneous. For non-domestic postcodes this occurred in office blocks with several delivery points (to different companies, for example), and for domestic postcodes this applied to blocks of flats or apartments. Population would require to be allocated to each of these points, and certainly not to assume they were duplicated and removed. Blocks of flats contain the highest densities of population, and the representation chosen should reflect that density. This issue also meant that the number of code points did not necessarily match the number of code point polygons, a situation not found with OA centroids and their associated polygons. In the research for this thesis care was therefore taken to ensure that all domestic postcodes were included, and that all points were allocated the correct population. This point may seem obvious, however other datasets (such as OS Sites) had instances of duplication and triplication of secondary schools, with identical polygons stacked one on top of the other. These duplicates had to be removed in order to obtain an accurate representation of school coverage. The stacked postcode points could be removed as duplicates by a researcher assuming they were duplicates, illustrating the importance of metadata where, in this case, the issue of vertical addresses and stacked postcodes was explained.

Census data was used to allocate population to each of the domestic postcodes. To do this, the population for each OA centroid was allocated to the OA polygon (using a spatial join in ArcGIS). Each postcode point was then identified as to the OA polygon within which it was located, by means of a further join. This join also provided a count of the number of postcodes in each OA, and the population of that OA was then divided evenly across each of the postcode points within its area. The assumption of evenly spread population was acknowledged as not ideal, but it represented a reasonable way of defining the populations over a relatively small area, at low levels of aggregation, without the need for time consuming and expensive door-to-door surveys of residential numbers, or other more computationally-demanding techniques while still maintaining the levels of confidentiality required in studies such as this. As a check, all the populations per postcode were summed for each study area and found to be within 1.0 of the census total population, validating the process and indicating that the various allocations and roundings had little overall effect across a county-level area. This approach is therefore similar to Goodchild and Lam's (1980) area-weighting method, but moves towards Fisher and

Langford's (1995) binary dasymetric method whereby all non-residential (and therefore unpopulated) postcodes were removed and only those postcodes classified as residential actually receive a population allocation. The assumption that uniform distribution of population within the source (ie pre-disaggregated) polygon was deemed reasonable in more recent work, with Biba et al (2010) making the same assumption in developing a method for determining the population within walking distance to transit locations.

There was a significant caveat with the use of Code-Point data. Postcodes were designed to be used as a postal delivery tool, not as an aid to research. They are updated frequently, as required by the business needs of the mail delivery service, and temporal mismatches with other datasets will occur. Postcodes change as housing developments are completed, properties are demolished, and when the postal service reorganises its business for whatever reason. However, it was felt that the opportunity should be taken to take a look at the advantages and disadvantages offered by this data from a usability perspective, and to examine whether Code-Point level data would be a useful research tool. This in turn resulted in recommendations as to the usability of the dataset in accessibility research, see Section 6.3.2.

It was noted that the link used to obtain metadata provided in the Code-Point User Guide led to the home page of data.gov, where it then had to be searched for by name, with no obvious guidance or direction provided. This inconvenience was mentioned by Forrest (2014) as "an irritating usability issue," and could be addressed through adding an appropriate comment to the Metadata page in the User Guide.

3.10.2 AddressBase Premium

An OS dataset which offered the opportunity for an even finer representation of population was AddressBase Premium (ABP), which provided (amongst a wide range of data) the location of every postal address in the country. An extract covering South Wales was provided on CD by OS with data to May 2014, in .csv format. An online User Guide noted that the layers provided had 3 themes: Address theme, with postal delivery points; multi-occupancies without postal addresses; and objects without postal addresses (ie significant structures without an address, such as car parks). Only the records with the address theme were used in this study. Conversion to an Arc-compatible format required an online tool. Once added to ArcGIS the features could be filtered using Select by Attribute to include only domestic addresses. The attributes in this field were many and varied, and illustrated the difficulties encountered when non-standardised formats were used, with similar records in upper or lower case, and various interpretations of function (for example vicarage, manse, dwelling, DWELLING, etc). However, ABP had a further classification scheme, with category 'R' for Residential and many sub-categories, all referring to the type of building the address related to (for example R D 02 represented Residential > Dwelling > Detached; R D 03 representing Residential > Dwelling > Semi-detached; and so on). For the purpose of schools analysis, for example, all housing types would be included apart from sheltered housing (which was considered unlikely to have school-age children living there). All Residential Institutions were excluded (as there were no sub-categories separating, for example, commercial lodgings, convents, hostels, retirement homes and orphanages), therefore a very small number of those which may have housed children may have been missed. These categories could be included or excluded as required, depending on the type of study being conducted.

It was intended to take a similar approach to Code-Point to allocate population to each address point, though the number of records in the study areas caused problems with Arc, causing processing to run slowly, with saving each map taking approximately 50 seconds to refresh. Generating a Near Table (the simplest distance-related task) took 1min 45secs. A trial attempt using the FCA plug-in (as detailed in section 3.2), using figures of '1' for both supply and demand levels (for simplicity and ease of calculation) resulted in Arc crashing after 15 minutes of processing. It was therefore impractical to make direct comparisons between distance and 2SFCA with address-level data and to compare the performance and usability of ABP and OA-level population data using similar methodologies. The use of ABP as a supply feature location method was considered (see Table 3.7), but it was recognised that other, less complex, datasets could effectively perform a similar task with greater efficiency (in terms of time and effort) and with greater user satisfaction (through the use of a more accessible dataset), in this particular context.

One issue of concern was that in using ABP some addresses had populations of less than 1 allocated to them. This occurred in OAs where the number of addresses was at the higher end of the range usually encountered in OAs (ONS, 2011b). However, there may be other causes, such as under-reporting or recording of the census population, properties unoccupied at the census date, or new housing developments built after the census data was gathered but included in a later ABP update. It was noted that many of the < 1.0 populations per address were located in the city centre of Cardiff and in Cardiff Bay, both areas which experienced large-scale residential building projects in areas with virtually no previous residential population. It was decided to use these population figures, rounded up to 1.0 as necessary rather than attempt to investigate the true numbers, which would take a considerable amount of time and effort. As attempts were also made to use populations relevant to the feature under consideration, it was held entirely possible that some of the areas could, theoretically, hold zero numbers of such populations, for example primary school age children. This could be true particularly in these new developments of apartments that were built in the centre of Cardiff in the heart of the shopping districts (and some developments were built ‘above the shops’ as part of new shopping centres). As a consequence, address level population representation was not used for either primary school or secondary school accessibility, but for GP accessibility, which assumed a user group that was a percentage of the entire population. This would provide an assessment of accessibility sufficiently realistic for the purposes of comparison with the other datasets to enable a reasonable indication of usability to be identified.

There were many other methods of representing population which could have been used in this study, all with associated advantages and disadvantages. Population surfaces, Super Output Area aggregation, network populations and various dasymetric methods were all considered and trialled, but with a finite time available some choices had to be made, and the decision was made to restrict the research in this thesis to those methods mentioned in the previous sections.

3.11 Network datasets

3.11.1 Overview of network datasets used

Three OS network datasets were used in the accessibility analyses:

- Integrated Transport Network™ layer (ITN);
- ITN with Urban Paths (UP);
- Open Roads (OR).

ITN offered a comprehensive dataset of the UK road network, with Urban Paths adding man-made paths in urban areas. OS Open Roads, derived from similar base data as is ITN, is a recently launched (March 2015) free-to-use high-level view of the British road network, downloadable free-to-use (from https://www.ordnancesurvey.co.uk/business-and-government/products/os-open-roads.html). All three OS products were derived from the same, base MasterMap data, which has a locational accuracy of between 1 and 9m depending on the scale at survey. OR data is generalised from this data.

An OpenStreetMap (OSM) network dataset was used to compare to the three OS network datasets. OpenStreetMap is an open initiative to create and provide FOSS geographic data such as street maps (or similar) to anyone who wants them. It is a massive online VGI collaboration, with hundreds of thousands of registered users worldwide who map features and upload data straight on to the map servers. It is unusual to have crowd-sourced international map product, and OSM has received a lot of attention and publicity, particularly in academic circles, where its quality and coverage in frequently compared and contrasted with national mapping products, for example by Haklay (2010b) comparing OSM to OS products in the UK, and Zielstra and Zipf

(2010) comparing coverage to that of proprietary sources in Germany. Although OSM's coverage is reported as increasing (Haklay, 2010b), its quality has been questioned (Goodchild and Li, 2012). Aspects of both the coverage and quality of OSM data will be assessed as part of this thesis (see below, and Section 6.4.4). Haklay (2010b) assessed OSM positional accuracy at approximately 20m, with differences between areas depending on the mapping regime.

Due to the constantly-changing VGI nature of OSM, and in order to assess its development over several years, updated versions of the OSM network dataset were obtained at regular intervals, and a specific assessment made of the changes to this network over a two year period. With few obvious sources of information on how to complete such a task, several unsuccessful attempts were made at creating a usable network from data downloaded directly from the OSM website (http://www.openstreetmap.org). On-line investigation revealed server-session download limits on the OSM server which restricted the amount of OSM data that could be downloaded at one time, limits which were exceeded by the requirements of this study.

3.11.2 OSM network data

In investigating alternative approaches, an Esri wikipage (found at http://esriosmeditor.codeplex.com/wikipage?title=Create%20a%20Network%20Dataset%20from%20OSM%20Data (Accessed 7 Jan 2014)) suggested a solution: obtain a network-ready .osm file from a third party supplier and use the tools provided in ArcGIS to create the network. This was stated as the only practical way for general users to derive their own network dataset using OSM as a source. The Mapzen website (metro.teczno.com) was initially used to obtain a .osm file in February 2014, with the accompanying metadata giving a currency date of 21 Dec 2013. The network-ready OSM data was available in "city-sized portions," which in this case included the data for Swansea, Cardiff, Newport and Bristol in one download.

ArcGIS had a suite of OSM-handling tools, and the 'Load OSM' tool was used to convert the downloaded data into Arc-usable format. The tool took over 40 minutes to create the required feature dataset for the whole of Wales. The OSM data was then reprojected in Arc to match the OS datasets (and to produce distance values in metres to compare directly with the other datasets, rather than the digital degrees as used in 'raw' OSM datasets) before being converted to a network dataset (using the 'Create OSM Network Dataset' tool) which was then Clipped to the study areas. This process resulted in multiple process errors due to issues specific to the tool, with solutions obtained from other Esri online forum discussion threads. The OSM dataset required a Network Configuration File to be created, which enabled the file to be adjusted according to the needs of the analyst. For example, rivers in the data would be a barrier to travel by road or for pedestrians, but would form part of the network for ships, and the network needs to be set accordingly. This file was an essential requirement, as without it any linear feature downloaded was being treated as a network edge, including (for example) county or administrative boundaries. Sample Network Configuration Files were provided in the Arc OSM toolbox and provided a fast and convenient method of setting up the data ready for analysis.

On subsequent return visits the Mapzen site was found to be no longer maintained, and no updated OSM data was available from that source. Subsequent downloads (used for ongoing comparison of OSM network coverage with ITN) were therefore taken from the Geofabrik website (http://download.geofabrik.de/europe/great-britain/wales.html). These later downloads had data clearly available with national boundary options, which permitted data for the whole of Wales to be selected and downloaded in one transaction.

These subsequent OSM downloads were not successfully converted in the first instance and a further tool was required, which was obtained from:
http://www.codeplex.com/Download?ProjectName=esriosmeditor&DownloadId=462970. This tool was successful in providing configuration files and converting the second OSM download, though was required to run overnight in order to complete its work. A third set of data was downloaded on 14 January 2015, with the Geofabrik website offered the option of downloading a pre-packaged dataset for Wales in ESRI-compatible shapefile format, with associated reduced conversion and loading times. In comparing overall acquisition times (which is a cost in terms of time, money and resources, and has a considerable effect on the Efficiency element of usability), obtaining the OSM network took over a day in the first instance, slightly less than a day in the second, with the third and fourth downloads taking 45 minutes from the time of entering the website to having a usable network dataset converted, loaded and ready to be used in Arc. Such usability issues relating to data preparation were comparable to those encountered in the conversion of OS ITN and UP data to a usable Arc network.

Once the OSM network had been created, the entire suite of ArcGIS Network Analysis extension tools could be used, enabling their full functionality to be applied to the network. The other OSM-specific tools in the ArcMap OpenStreetMap Toolbox could be used on the source data, but not on the resulting network dataset. Several issues were immediately evident with the OSM network datasets when examined in Arc, the most obvious being a multiplicity of edges (lines), many doubled or quadrupled in parallel. It became apparent that these indicated (for example) roadways (one edge for each direction), cycle lanes (running alongside each road at the kerbside) and pavements (at the side of each road). This resulted in, for example, some dual carriageways in the north of Cardiff being represented by eight parallel edges. Other issues included broken connections and incorrect classifications affecting results. More detail on OSM issues are included in Section 4.5 of the Results chapter and the potential implications of using OSM in these types of studies will be discussed in Section 6.4.4.

It was confirmed, using aerial imagery, that footpaths were included in the original OSM network dataset downloaded, the dataset which would be used in assessing pedestrian accessibility. The subsequent OSM download datasets (used for the coverage comparison with ITN) were also checked as to whether any of the lengths (termed 'edges' in OS/Arc networks, or 'ways' in OSM) had any obvious non-roadway categories, and many were identified. OSM therefore had the following selected out for the purposes of the network comparison (noting that pedestrian pathways, etc were still required for the main accessibility assessments carried out as the main research project): bridleway; bus stop; construction; cycleway; footway; path; pedestrian; proposed; raceway; services; steps; track. This left only the following categories: living_street; motorway; motorway link; primary; primary_link; residential; road; secondary; service; tertiary; tertiary_link; trunk; trunk_link; unclassified. The number of unclassified ways was high, and included many main roads (recognised through local knowledge and of the patterns of the roads themselves) such that the decision was taken to include them, accepting that the risk of errors of commission were outweighed by the obvious errors of omission that would occur if the category was not included.

3.11.3 OS ITN and UP data

OS ITN data was supplied on disc by OS. Extracting the data to work with it in ArcMap involved a multi-step process, using standard guidance provided by OS. The guidance that was made available was not comprehensive, and the loading and conversion process not intuitive. The conversion of files took considerable computing time, being left to run overnight, and found to have completed successfully the following morning. In considering the usability elements of such a process, although effective, it was felt that the conversion process was far from efficient, in terms of time and resources used. Subsequent similar tasks (for example, to obtain the data to compare with OSM network coverage for the same time period) took considerably less time, due to increased familiarity with the system.

The data for Urban Paths was supplied on disc directly from Ordnance Survey. This was supplied in .gz format, which added another step in the conversion for use by GIS, in that the file had to be unzipped, translated from gml, and then converted to a network in Arc. For the study of accessibility of the population who walk to their chosen service, the optional attribute of 'length' was checked as required, with the other options for 'one-way',' turns' and 'vehicle restrictions' not required. If accessibility by motor vehicle was being examined then these attributes would be required, along with those for travel time. Road hierarchy was adjusted to prevent pedestrian journeys on motorways and on expressways which prohibit pedestrian use. The vast majority of such roads were in Cardiff, and included the A4232 Cardiff Bay Link Road and stretches of Eastern Avenue which connected to the A48(M). Without local knowledge it would have been unlikely that the non-motorway roads would have been identified as prohibited for pedestrian use. The attribute ‘Speed’ was set at 4.8kph for all road types to reflect a typical walking speed (Scottish Government, 2006), though this was found to be unnecessary, as the assumption of a constant walking speed was analogous to distance measured (in that at a 4.8kph walking speed a distance of 400m would always equate to 5 minutes walking time, 800m would equate to 10 minutes, 1200m would be 15 minutes, and so on). The option of connecting the network at ‘Any Vertex’ was chosen, over-riding the default ‘End Point’ option, enabling pedestrian routes to change road or path at any crossing, with no restrictions, unlike car travel, for instance, which would be subject to turn restrictions.

Updated versions of the ITN dataset were required for periodic comparison with OSM network data. These were downloaded from Digimap® (http://digimap.edina.ac.uk/), provider of maps and geospatial data to UK Higher and Further Education establishments. The data was received in gml format, which took considerable time to convert to an Arc-compatible format (using the relevant Arc Productivity Suite tools) before a working dataset could be built. Growing familiarity with the Productivity Suite tools reduced the conversion times considerably for subsequent requirements.

3.11.4 Alternative network data

Other network datasets were available for use or purchase, but were not considered appropriate for this study. The Highways Agency road network was available free for download but only contained data on roads which were the responsibility of the Agency, that is trunk roads, motorways, etc. Such a network is more suitable for use in regional or country-wide accessibility studies rather than local research, as LA-maintained roads (the ‘smaller’ roads) are not included. Navteq and TeleAtlas maintain non-generalised, national street-level data for use by satnav systems. Their data is expensive to purchase with no research access permitted (Haklay, 2010a) and is rarely used in academic studies. OS Meridian 2 data can be used to create a road network dataset, as can OS VectorMap District. Both are available to download free of charge and their road layers converted to a network in, for example, ArcGIS. As neither are designed specifically as networks their performance is limited by, for instance, overpasses and bridges ‘breaking’ the road network that passes beneath. As network datasets, both were, in any event, superseded by OS Open Roads.

Figure 3.16: Comparison of all four networks in the same area of Vale. Note: UP was always used as an addition to ITN, but only the UP lengths are shown here.

ITN

RoadLinkTOID *	RoadLabel	DescTerm	Nature	Node1 *	Node2 *	Orienta	FromGradeSeparation	ToGradeSeparation	OneWay	Edge_Length	OBJECTID *	SHAPE *	SHAPE_Length
4000000021624637	CARDIFF ROAD	A Road	Single Carriageway	4000000021481067	4000000021481402	+	0	0	N	721.70928	18003	Polyline	721.70928
4000000021637893	A4231	A Road	Dual Carriageway	4000000021481047	4000000022101314	+	0	0	N	72.046134	18067	Polyline	72.046134
4000000021637894	SULLY MOORS ROAD	B Road	Single Carriageway	4000000021481053	4000000022101316	+	0	0	N	114.900167	18068	Polyline	114.900167
4000000021663411	A4231	A Road	Dual Carriageway	4000000021481065	4000000021481066	+	0	0	N	96.322886	18263	Polyline	96.322886
4000000021705722	CARDIFF ROAD	A Road	Traffic Island Link At Junctio	4000000021481050	4000000021481067	+	0	0	N	27.338653	18691	Polyline	27.338653
4000000021747309	CARDIFF ROAD	A Road	Traffic Island Link At Junctio	4000000021481049	4000000021481067	+	0	0	N	26.148922	19095	Polyline	26.148922

Open Road

FID	Shape *	fictitious	identifier	class	roadNumber	name1	name1_lang	name2	name2_lan	formOfWay	strategic	length	structure	loop	startNode	endNode	formsPart
2809	Polyline	false	54677c2a-c83d-4ac9-992c-3d92608cc401	Unclassified		Conybeare Road	eng			Single Carriageway		2.83		false	L06691982	L06055160	
2809	Polyline	false	52ba50ee-fd34-4262-9ffb-dfd87bc7e743	Unclassified		Bridgewater Road	eng			Single Carriageway		6.132		false	L06691983	L06691955	
2809	Polyline	false	92aa5bc8-3526-46f9-985f-f2108d9c7339	Unclassified		Conybeare Road	eng			Single Carriageway		4.729		false	L06691985	L06691983	
2809	Polyline	false	4d66cc92-ee3e-42da-a054-11c9af44ce22	Not Classified		North Road	eng			Single Carriageway		6.24		false	L05731377	L05731375	
2810	Polyline	false	77498aee-4d83-456c-a127-427ed30b2389	B Road	B4267	Sully Moors Road	eng			Single Carriageway		4.805		false	L06691987	L05731375	
2810	Polyline	false	c63dbc80-b991-4bc9-865c-261502cbcc24	A Road	A4231					Collapsed Dual Carri		7.025		false	L06691990	L08048279	

OSM (a)

OBJECTID *	SHAPE *	highway	building	natural	waterway	amenity	landuse	place	railway	boundary	power	leisure	man_made	shop	tourism	route	historic	aeroway	aerialway	barrier	military	geological	OSMID
16067	Polyline	residential																					26495686
22404	Polyline	unclassified																					32681441
24328	Polyline	secondary																					34320480
24329	Polyline	secondary																					34320481
34092	Polyline	secondary																					44372122
42251	Polyline	residential																					58741972

OSM (b)

osmuid	osmvisi	osmversi	osmchange	osmtimestamp	osmSupportingElement	acces	avspeed	construct	proposed	maxheigh	maxspeed	maxweight	oneway	slowdown	name(tag value)	SHAPE_Length	Length1
82241	true	3	21664876	13/04/2014 14:19:04	no	<Null>	<Null>	<Null>	<Null>	<Null>	30 mph	<Null>	no	<Null>	Elm Close	0.000407	43.878994
11169	true	15	16591718	17/06/2013 16:50:54	no	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	no	<Null>	Fort Road	0.016411	1335.252823
11169	true	4	17840855	14/09/2013 22:45:32	no	<Null>	<Null>	<Null>	<Null>	<Null>	40 mph	<Null>	<Null>	<Null>	Sully Moors Road	0.008278	823.790386
11169	true	2	17840855	14/09/2013 22:45:29	no	<Null>	<Null>	<Null>	<Null>	<Null>	40 mph	<Null>	yes	<Null>	<Null>	0.000388	35.023546
82241	true	18	20894292	03/03/2014 18:40:20	no	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	no	<Null>	Lavernock Road	0.039214	3336.057406
82241	true	3	21664876	13/04/2014 14:12:39	no	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	no	<Null>	Ashby Road	0.007376	648.787718

UP

PathLinkTOID	DescTerm	PathName	HasDateTimeRest	Node1	Node2	Orientation	FromGradeSeparation	ToGradeSeparation	Edge_Length	OBJECTID *	SHAPE *	SHAPE_Length
4000000065837017	<Null>		<Null>	4000000063487927	4000000063480145	-	0	0	7.837546	8429	Polyline	7.837546
4000000065836438	<Null>		<Null>	4000000063480145	4000000063486950	-	0	0	38.150247	8430	Polyline	38.150247
4000000065836062	<Null>		<Null>	4000000063484504	4000000063484702	-	0	0	50.76364	8431	Polyline	50.76364
4000000065835928	<Null>		<Null>	4000000063487023	4000000063488705	-	0	0	161.74963	8432	Polyline	161.74963
4000000065835797	<Null>		<Null>	4000000063487157	4000000063486950	-	0	0	32.577405	8433	Polyline	32.577405
4000000065837165	<Null>		<Null>	4000000063487735	4000000063486950	-	0	0	50.155125	8434	Polyline	50.155125

Figure 3.17: Examples of attributes of all four networks. Note that OSM is split due to number of columns. Empty OSM attributes are representative of the area.

3.12 Visualisation of results

3.12.1 Visualisation of results using OA-level data

As highlighted in Section 3.9, OA population-weighted centroids were used as the main representation of population throughout this thesis. The Output Area polygons themselves were downloaded as GIS-compatible polygons from the UK Data Service Census Support webpages of the Edina website (http://census.edina.ac.uk/). These polygons were used as the main method of presenting and visualising results. The relatively low levels of aggregation reduced the potential error from the modifiable areal unit problem (MAUP), where aggregated data is subject to scale effects (when different results occur when data are aggregated to different spatial resolutions) and zoning effects (when data are aggregated to different boundary configurations) (Openshaw and Taylor, 1981; Carrington et al, undated). Although OAs were the lowest unit of census reporting, the census results were still aggregated from individual and household units. The OA units also offered a presentational unit that enabled visual interpretation of the resulting choropleth maps. The small geographical size of some of the OAs, particularly in the higher and more densely-populated areas of Cardiff and Barry, made visual differentiation difficult, and some experiments were carried out into alternative methods of visualising the mapped results, using cartograms for example, results of which are reported in Section 5.2.5.

3.12.2 Visualisation of results using postcode-level data

The Code-Point with polygons dataset does not cover the entire country seamlessly. As the Code-Point with polygons User Guide says

> "There may be some rare occurrences of polygons or areas enclosed by polygons without a postcode allocation." (Ordnance Survey, 2014).

For example, at the time of analysis the postcodes of CF3 6XL and 6LP on the outskirts of Cardiff were large, convoluted polygons which formed a loop, leaving an island in the middle not covered by any postcode. The use of Code-Point polygons offered an opportunity for greater accuracy in representing population, in that areas without any postcode should not have any population allocated to it. The classification system of Code-Point, combined with the polygons, offered the opportunity to identify non-domestic post code areas, again enabling population to be allocated only to areas with domestic postcodes. This indicated that the dataset could be highly effective in research contexts relating to smaller geographic areas, such as at a town or city level. However, some issues with the visualisation of results are relevant to the aim of this thesis and are discussed in Chapter 5. These have implications to several of the usability factors associated with the Satisfaction usability element, such as visual appearance and trust (particularly with respect to how apparently ‘missing’ data is approached). This is due to the choropleth maps using Code-Point polygons exhibiting zones of no data in polygons with no residential postcodes. The visualisation of such results is challenging. As well as presenting aesthetic issues, the comprehension and interpretation of such a visualisation may be hindered without the awareness as to the underlying reasons for the unusual appearance of the map. Such issues are discussed more fully in Chapter 5.

Code-Point polygons were designed to be used as a unit of analysis and visualisation at the postcode level (Ordnance Survey, 2014), but to date have not been extensively used, one exception being Burden et al (2014) comparing the error in accessibility results from different levels of data (and finding that postcode and OA-level data have the more accurate representations of distance than those of LSOAs and MSOAs). However, local authorities or commercial organisations may use them for their own purposes, for information at or visualisation of smaller areas. Such work (such as market research, for example), may appear in the grey literature, but some have been promulgated as case studies which utilised the finer detail outlined in the previous paragraph. For example, Hull City Council mapped teenage pregnancies by postcode, revealing previously unknown hotspots, enabling targeting of sex education services to specific schools in those areas (Ordnance Survey, 2012a).

3.12.3 Visualisation of results using address-level data

Ordnance Survey provided a geographic sub-set of AddressBase Premium (ABP) data to be used in this study as an alternative method of identifying and locating facilities. As discussed in Section 3.8 and summarised in Table 3.7, ABP is a complex compound of several datasets, designed to work together to provide comprehensive data on every address in the country. Setting up the data initially was problematic, and full operability was not achieved due to the complex nature of the various tabular Joins and/or Relates required when using in ArcGIS. Despite the full potential of all aspects of the dataset not being realised it was considered as an alternative data source for several features. It was also considered as a finer-resolution method of locating population, through the allocation of census OA population figures to the address points within each polygon, using point-in-polygon processes. For a county-wide analysis, however, this scale was considered to be inappropriate for many reasons, particularly the number of data points to be processed in both network and 2SFCA calculations and the associated computer load. There were also further issues with visualisation, there being no polygons supplied with ABP. OS MasterMap Topography Layer, showing individual building outlines, contains links to associated ABP data and could form a base layer of property polygons on which to superimpose the points. These small polygons would introduce challenges with presentation and interpretation of results due to the amount of ‘white space’ that would be present, due to areas without buildings. Unlike Code-Point polygons or OAs, the surface of the study area would not be covered by the ABP/Topo polygons, thus making choropleth-type presentation unfeasible. The construction of Thiessen polygons (or similar) would cover the surface of the study area, but then would lose the address-level accuracy at the smaller area scales. The problems both encountered and foreseen resulted in the under-utilisation of ABP, which was restricted to being considered for facility location purposes. However, the potential of such sources for population representation will be discussed in Section 6.3.4 in relation to other usability considerations.

3.13 Compiling and presenting usability information

Bringing together the results from the various analyses in an informative manner for prospective users of data would be a useful addition in the assessment of usability. Existing techniques, such as compiling errors and issues with the data in a typology of errors and conducting SWOT analysis, are outlined in sections 6.6.1 and 6.6.2, respectively. A novel approach is described here: the provision of a Utility Factor (one of the specific outcomes outlined in Chapter 1). This approach was taken following discussions with other academics and GI data users from industry on the merits of the various approaches taken in this particular study (with destination overlaps and statistical measures of similarity and of difference), and the potential benefits to users of combining several results into one, more easily-comprehended value. All agreed that an attempt should be made to identify an approach, and that the results of other studies be fed into it, when they become available, in order to validate the approach, or to identify potential improvements.

The Utility Factor described here distils the results of the various accessibility analyses into one figure. The factor is derived from the tabular results reported in Chapter 4 and indicates the potential interchangeability of each pair of datasets in a given context, reflecting the relative usability of each dataset. The factor is calculated as follows:

$$UF = \frac{P(abs\ (C\ x\ 100) - \ abs\ (D))}{100}$$

Where: *UF* is the Utility Factor;
C is the Spearman’s rank correlation coefficient between two comparators;
D is the Wilcoxon’s Z-score between the same two comparators;
P is the Destination Overlap (%), also between the same two comparators.

Equation 3.3: Utility Factor.

Note that correlation coefficients (C) and Wilcoxon Z-scores may be negative, hence the absolute value is used to ensure only positive values are used in the formula. In the cases examined in this study, correlation coefficients had a minimum absolute value of 0.030 and a maximum of 1.000. Wilcoxon scores ranged from 0.002 to 28.428, and Destination Overlaps from 60.2% to 100%. These figures would create a theoretical maximum UF of 99.997 and a minimum of -15.308, or if rounded: 100 and -15, respectively. Using figures obtained in the study for accessibility be distance to Cardiff GP surgeries as an example (see Table 4.75), comparing ITN and OSM, the calculation would be as shown in Equation 3.4.

C = 0.966; D = -2.168; P = 91.5.

$$\text{UF} = \frac{91.5(96.6 - 2.168)}{100} = 86 \text{ (rounded)}$$

Equation 3.4: Utility Factor worked example 1.

In the case of the example in Equation 3.4 the UF was relatively high. The comparison between ITN and Open Roads returned the highest UF of 89, compared to ITN and OSM at 86 as shown in the example. This indicates that in this situation the OSM data was not as similar to that of ITN as was OR. As an example of a lower UF, figures for Cardiff sports centres and distance were used, as shown in Equation 3.5, comparing ITN to UP. The resulting UF of 60 was one of the lowest obtained in comparing networks using the nearest-distance measure of accessibility (see Table 4.79). This measure also removes an opportunity for confusion where a high absolute figure can mean similarity in one measure (correlation coefficients) but greater differences with another (when using Spearman’s test, for example).

C = 0.930; D = -20.546; P = 82.5.

$$\text{UF} = \frac{82.5(93.0 - 20.546)}{100} = 60 \text{ (rounded)}$$

Equation 3.5: Utility Factor worked example 2.

It must be emphasised that the Utility Factor applies to the datasets used in the context of the research for this thesis and for the particular GIS tasks conducted. For use with other tasks it would have to be adapted. However, in any comparison of results it would be expected that indications of correlation would be obtained (Spearman, in this case), and it is suggested here that a statistical indication of difference should also be obtained (Wilcoxon was used here), along with some measurement of the practical effect of the use of the different datasets (in this case destination overlap was used). The application of this formula in other contexts would be required for verification, and is suggested as a future direction for potential research.

3.14 Chapter summary

This chapter has provided details of the approach taken in this study, along with background to the choices of data and justification for other data sources not being used. Different methods of assessing accessibility were outlined with their associated advantages and disadvantages, and the approach taken for this thesis explained and justified, with specific emphasis on the use of sensitivity analysis in the context assessing data usability. The characteristics of the datasets chosen for the study representing both supply- and demand-side features as well as networks, were examined in detail. Issues with particular datasets were noted, including the level of processing required prior to the commencement of the analysis. Alternative sources of geospatial information were explored and assessed, highlighting the variations in usability of such data and that data characteristics such as quality are but one aspect of usability. The pros and cons of using different datasets in the visualisation of results were outlined and explained.

Throughout this exploration of the methodology used in this thesis, justification in the literature has been sought for each approach used. However, the use of sensitivity analysis in accessibility studies in the context of assessing usability is a novel approach. This approach resulted in the datasets in question being stress tested with anomalies being highlighted. The individual and specific issues identified were taken as indicative of the dataset in question, enabling more generalised observations to be made as to the characteristics and issues inherent in each dataset. These characteristics and issues will be investigated throughout the forthcoming chapters.

Chapter 4 Results: tabular and statistical analysis

4.1 Introduction

Chapter 1 outlined the background to this research and Chapter 3 the methodology which was applied. The results from the various case studies will be reported in this chapter, by considering different representations of supply, demand and network in both distance and FCA accessibility analyses. After reporting the results of the more basic approaches (container and coverage, supply-demand ratios) the results of the main accessibility measures (shortest distance and two-step floating catchment area) will be outlined, along with assessment of the differences found in nearest destination (destination overlap), followed by results obtained from the statistical analysis into the similarities and differences between the alternative data sources. These similarities and variations will be analysed and discussed in Chapter 6 in order to address the overall usefulness and usability of the data used while informing the discussion as to the performance of the data in the context of the accessibility studies themselves. Specific issues which were encountered during the various steps involved in the analysis will also be included in Chapter 6.

As outlined in previous chapters, the intention was to conduct sensitivity analyses in the context of case studies involving assessing accessibility to five different destination features in order to compare the outcomes of several different GIS analytical processes, thus ‘stressing’ the datasets in different ways and assessing the differences (and similarities) in results. The differences in outcome were used as initial points of investigation into reasons for the differing comparative performances of the datasets. Numerical and statistical similarities and differences in nearest distance and 2SFCA results will be identified, with destination overlaps to assess whether the changes in nearest distance figures result in the identification of different supply features as nearest to any given origin. The question as to whether the differences in distance and 2SFCA results are reflected in typical map-based visualisations is addressed in Chapter 5.

This chapter is structured as follows: a summary of study area statistics is given, providing a reminder as to the numbers of supply and demand points within each county; a brief summary of ‘traditional’ measures of accessibility (container and coverage) provides an initial indication of how well each area, and the population of each area, is served by each supply-side feature; comparisons are made between the outcomes relating to the supply side, then between demand side representation, then networks are compared and subsequent issues encountered are discussed. A series of further comparisons are made, including a comparison of distance and

2SFCA outcomes, and an assessment of consistency made using the results of destination overlaps. Issues specific to the OSM network dataset, and OSM map data in general, are then discussed in a separate section, with the following chapter considering whether the results reported here result in different choropleth map presentations.

	Cardiff	Vale
Area (km^2)	150	340
Population	346 090	126 336
No. of OAs	1077	412
No. of PCs	6336	2696
No. of addresses	151 979	55 492
No. of primary schools	93	49
No. of secondary schools	21	9
No. of GP surgeries	63	21
No. of sports centres	31	10
No. of community hubs	76	39

Table 4.1: Summary of county data.

Key geographical characteristics of the study areas (area, population, etc), demand data, and a summary of the supply figures relating to each of the features examined are provided in Table 4.1 as background to this chapter. Tables 4.2 shows the figures relating to the more basic measures of accessibility for each supply feature: coverage and container methods; again provided as background to illustrate how impressions of accessibility can change, not just according to the sophistication of the method employed, but also depending on the data used. These ratios were relatively simple to calculate but did not necessarily provide sufficient detail to reflect any differences in accessibility, particularly within the relatively large area of a county. They will be compared to the types of result obtained through other methods, including network analysis and 2SFCA. Other results are presented to illustrate the similarities or differences between the datasets used, so providing as assessment of which datasets may be as effective at representing supply, demand or the travel network in the context of the accessibility studies conducted here. Effectiveness, as detailed in Section 1.3 of the opening chapter of this thesis, was one of the three key usability characteristics (as ‘effectiveness’ asks the question, “Can the data be used to complete the task required?”), and in this case will provide users with an assessment of their appropriateness in these different scenarios.

By using five different types of destination feature (as outlined in Tables 4.1 and 4.2) with differing location and distribution characteristics (for example, located in the heart of communities versus located on the periphery) any difference in the results of the analysis could be highlighted. This will allow results to be generalised with more validity than through the use of only one type of feature and also to undertake the analysis in different geographical settings in order to examine the consistency, or otherwise, of the findings. The range of datasets utilised enabled suitability to be assessed in different situations.

Supply feature	Cardiff			Vale		
	Coverage by area (average area served by each feature in km^2)	Pop'n per feature	Relevant pop per feature	Coverage by area (average area served by each feature in km^2)	Pop'n per feature	Relevant pop per feature
Primary school	1.6	3721	294	6.9	2578	222
Secondary school	7.12	16480	1339	37.75	14037	1179
GP surgery	2.4	5493	934	16.2	6016	1143
Sports centre	4.8	11164	11164	34.0	12634	12634
Community hub	2.0	4554	1200	8.7	3239	1007

Table 4.2: Container and coverage measures of accessibility.

As several of the datasets had functionality which overlapped with others, the opportunity existed for comparisons to be made. Direct comparisons, where possible, were carried out between the datasets in order to highlight major issues.

4.2 Review of datasets

Section 3.7 detailed all the various datasets used to represent the various inputs used in the GIS processes used in the production of this thesis: supply-side (to represent destination features); demand-side (to represent journey origins and population); and network (to represent travel distances). The information contained in that section is summarised in Table 4.3. The intention was to identify the key differences and similarities between the datasets in their application in accessibility studies, drawing on the relevant case studies where appropriate, in order for these similarities and differences to be highlighted and described in relation to the usability criteria outlined previously in the opening chapter.

Also listed in Table 4.3 is Euclidean (or straight line) distance. The traditional approach in accessibility studies was to use Euclidean distances, therefore comparisons with these approached is important. Although not, by definition, a transport network, Euclidean distances were calculated and referred to alongside the other networks. The use of Euclidean distances in accessibility studies was documented in section 2.8 of the Literature Review where it was noted that various conversion factors had been proposed in order to provide a network equivalent distance. The opportunity was therefore taken to ascertain if such straightforward conversion factors applied to the data used in this thesis, or whether there were any consistent patterns between Euclidean and network distances to destinations, or if comparative measures differed from feature to feature, or from urban to rural contexts.

4.3 Supply-side comparisons

Section 4.1 detailed the features under examination and two of the more basic measures of accessibility (container and coverage), the results of which were purely dependent upon the number of relevant features within the study area and each county's population. In order to illustrate the differences that could be found by using different features, representations of five services were compared, with the reasons and justifications for the five features detailed in Section 3.7 of the Methodology chapter. Primary schools were the most numerous of the five features in both Cardiff and the Vale, and were spread widely throughout both areas, reflecting the sizes of the facilities and their role in the community, in that primary schools were usually small, local facilities. The nature of this feature reflected in the coverage figures, with Cardiff's average of one school per 1.6km^2 the 'best' coverage of any feature in Cardiff, and the equivalent figure for primary schools in the Vale (6.9km^2) also the smallest coverage area. The raw figures hint that the total population of the Vale was better served by their schools and community hubs, a pattern which is reflected by the relevant population per facility, indications which will be compared to the results of more sophisticated accessibility analysis.

The basic coverage figures for Cardiff and Vale secondary schools as shown in Table 4.2 reflect the pattern of secondary education, with primary schools acting as 'feeders' to fewer, larger secondary schools, with lower numbers of secondary school which served a larger average catchment area, and also much higher coverage per capita figures when compared to primary schools. The different quantity and patterns of distribution of secondary schools compared to primary schools offers an opportunity to assess accessibility in another context. Similar numbers and distribution would be assumed to produce similar results; this approach exposes the networks and supply-side data to a different stress, and was intended to provide further opportunities for differences, or similarities with primary schools, to be identified.

Datasets used				
Feature	**Ordnance Survey**	**Non OS**	**Strengths (in relation to accessibility studies)**	**Limitations (in relation to accessibility studies)**
Supply-side	Points of Interest		Detailed, comprehensive.	Heavily generalised. Very large facilities represented by point.
	Sites		Detailed, comprehensive, highly accurate representation of functional polygons. Access points give actual points of entry, with clear classifications.	Access points not fully surveyed. Some errors of omission and commission.
	AddressBase Premium		Fine scale, to address level.	Complex, inconsistencies in classification.
Demand-side		Census OA centroids	Free. Seamless coverage of UK. Stable content (very similar in 2011 to 2001). Population-weighted.	Population 'adjusted' in some cases, to ensure confidentiality. Long updated cycle (10 years).
	Code-Point		Larger scale. Content changes and updated regularly. Distinguishes domestic/non-domestic postcodes.	Boundaries change through time, impractical for studies of long-term change.
	Address Layer 2		Fine scale, to address level. Content changes and updated regularly.	Difficult to distinguish domestic addresses.
	AddressBase Premium		Fine scale, to address level. Content changes and updated regularly. Distinguishes domestic/non-domestic addresses.	Complex. Requires disaggregation. Addresses updated much more frequently than supporting population figures.
Network	ITN		Comprehensive. The 'gold standard' of UK network data. Excellent for travel by motor vehicle.	Not comprehensive for journeys by cycle and on foot.
	ITN with Urban Paths		UP not national. Comprehensive where applied.	Some inconsistency in application.
	Open Roads		Open data. Simplified ITN. Good for travel by motor vehicle.	Limited for journeys by cycle and on foot.
		OSM	VGI. Open data. Updated in real time. Cycle map layer.	VGI. Uncertainty over content quality. Unclear classifications, lack of definitions. Data drop-off with distance from large urban areas.
		Euclidean	Easy to calculate. Simple to understand.	Overestimates accessibility. Not a true reflection of real-world travel. Ignores barriers.

Table 4.3: Summary of datasets compared in this thesis. A full SWOT analysis of each dataset is provided in Table 7.2.

In terms of GP surgeries, Cardiff appeared considerably better covered than the Vale. As with GP surgeries, Cardiff had approximately three times as many sports centres as the Vale. Community hubs were the second most numerous type of facility examined in this thesis and as with primary schools, the Vale had just over half the number of facilities compared to Cardiff. Again, the differing patterns stress the data in a slightly different way, enabling the highlighting of potential issues with each dataset.

Table 4.33 in Section 4.5 (Network comparisons) provided a simple comparison of network performance, but also can also be looked at as another indication of distribution of the five types of feature by showing the distances separating each feature through the study areas. Table 4.4 (taken from the Methodology chapter) reports Nearest Neighbour results using ArcGIS, and provided a different measure of distribution. The Nearest Neighbour tool (from the ArcGIS Spatial Statistics toolbox and Analyzing Patterns toolset) is a quick and easy method of assessing distribution of features, particularly when comparing different fixed-point features in a common study area (ArcGIS Tool Reference, available at http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/average-nearest-neighbor.htm, accessed 15 January 2016). The NN index is the ratio of the Observed Mean Distance to the Expected Mean Distance, where the expected distance is the average distance between points in a hypothetical random distribution. Other tests of distribution available in Arc, particularly Global Moran's I spatial autocorrelation tool, requires features to have both location and value. Nearest Neighbour was therefore considered most appropriate for the simpler assessment of purely locational distribution.

It may have been expected that destination features would be distributed in a manner that matched the patterns of settlement in an area, and that rural features would therefore be more highly clustered (matching the few small towns and villages as opposed to the densely-populated urban surface), but in the Vale only community hubs returned an undeniably clustered result. Cardiff had community hubs, GP surgeries and primary schools as clustered, with sports centres randomly distributed and secondary schools dispersed. In the Vale, both sports centres and secondary schools were assessed as dispersed features on this measure of distribution.

These figures help to justify the chosen destination features as differing in number and distribution, and therefore differences in accessibility would be expected between the features. If the case study features had very similar (or identical) numbers and patterns of distribution they may have returned very similar results. The intention at the outset of this study was to consider a diverse range of features, and the summary of feature characteristic supports this aim.

		Feature				
		Prim schools	Sec schools	GP surgeries	Sports centres	Comm hubs
Cardiff	NN Ratio	0.86	1.32	0.87	1.00	0.72
	z score	-2.50	2.76	-1.95	-0.05	-4.60
	Conclusion	Clustered	Dispersed	Clustered	Random	Clustered
Vale	NN Ratio	0.98	1.43	0.69	1.12	0.61
	z score	-0.21	2.49	2.65	0.70	-4.60
	Conclusion	Random	Dispersed	Clust/Disp	Dispersed	Clustered

Table 4.4: Overall distribution of features, calculated using ArcMap Average Nearest Neighbour tool. NN Ratio > 1 and high, positive z score indicates dispersed pattern. NN Ratio < 1 and low, negative z score indicates clustered pattern. NN Ratio = 1 indicates random pattern of distribution. (Calculated using the features within the boundary of each study area).

Tables 4.7 and 4.8 show a summary of the mean distance from each demand point or origin (in this case census OA population-weighted centroids) to the nearest supply point or destination facility. Although travel time may be a more realistic real-world representation of an individual’s accessibility to a destination than Euclidean distance, for pedestrians travel distance is directly proportional to travel time, assuming (according to Scottish Government, 2006) an average walking speed of 4.8kph (3mph).

Using OAs, the mean distances from each demand point to the nearest supply-side representation did not reflect the same patterns as distances between the supply points themselves, as per Table 4.33. However, in both measures the OSM figures were lower than their ITN equivalents in both Cardiff and the Vale, though greater than UP and very close to the distances measured for Open Roads. This indicated that OSM may return lower figures than ITN due to the inclusion of footpaths and cycleways within its network, but also that the ranking of the networks changes depending upon the destination feature.

GP surgeries, sports centres and community hubs were not features which were included in the Sites dataset and were located using only the Points of Interest dataset. The tables relating to the results for these three types of feature were therefore considerably simpler than those for primary and secondary schools, due to the fewer number of pairs involved in comparing all permutations of feature location method.

The results shown in Table 4.7 and 4.8 overlap into several areas of interest: comparisons between networks and comparisons between representations of supply. The former will be discussed in section 4.2.3; the latter will be discussed in this section. It is apparent from the schools results that the method of representing the position of these features has an effect on accessibility, as measured by shortest distance to a feature. The differences can be small: using primary schools as an example, with the difference between Vale Sites centroids and PoI points, which had the same mean distance when rounded as measured on the ITN network; or relatively large (the maximum difference of 185m between Cardiff Sites centroids and Site perimeters, on the ITN network).

Secondary schools, with their much larger perimeters (secondary schools generally have a larger footprint than primary schools, reflecting higher pupil numbers, more and/or larger buildings, larger car parks, more sports fields, etc) have a much larger range of differences, particularly when perimeters are used as the locational feature, with differences of over 500m in the Vale, and over 300m in Cardiff. The perimeter point, of both primary and secondary schools, was the lowest-scoring feature in both Cardiff and the Vale, which was as logically expected, as every other representation would either be on or inside the boundary of the feature, and therefore further away from any journey origin. Though perhaps not as realistic a destination feature for schools (which generally have secure perimeters), open spaces such as parks or recreation areas could use perimeters as valid points of arrival or entry if such detailed data on such features was available.

It may be useful to quantify some of the differences in the representations of features. Taking secondary schools as the most extreme case (with their larger sites), there would obviously be differences in the locations of the different ways to represent these features, and these physical differences are given in Table 4.5. For comparison, the same table is presented at Table 4.6 reflecting the implications of the adjustments made when calculating 2SFCA scores, as the 2SFCA plug-in required the use of one representational point per feature in order for meaningful results to be obtained.

There are variations reported in the results in these tables, some small, some great. The results show that differences exist in the measurement of distance to the nearest supply-side feature according to method used and to the feature under consideration. The significance or relevance (or otherwise) of these differences were considered, and two principle approaches were taken: firstly by the application of suitable statistical tests; secondly by examining whether or not these (sometimes small) differences had an effect on which particular feature was identified as the nearest destination.

As outlined in Chapter 3 (Methodology), ArcGIS OD-matrix tools were used to obtain the network distances from each OA to its nearest destination feature, with ArcGIS Near Tables generated for Euclidean distances, for comparison. These GIS processes produced a set of figures which could be compared to others generated for destinations located using a different method. Statistical tests were used to compare the sets of results. Correlations provided an indication of the similarities between results. For example, in Cardiff case studies 1077 distances were generated, each representing the distance from an OA centroid to a destination point. The correlations indicate the level of similarity in rank between each set of results. The choice of Spearman's Rank Correlation test was described in Chapter 3, and was the most appropriate option for the nature of the data here. In particular, the sets of results were not independent and the distance results were not normally skewed.

	Representation		
	Site centroid	**Access Point**	**Perimeter**
Site centroid			
Ped access pt	137		
Perimeter	78	0	
PoI point	80	108	64

Table 4.5: Average difference (m) in position of representational methods for Cardiff secondary schools, used in assessing accessibility by nearest destination.

	Representation		
	Site centroid	**Main Access Point**	**Main Perimeter Point**
Site centroid			
Main access pt	161		
Main Perimeter pt	168	197	
PoI point	80	156	195

Table 4.6: Average difference (m) in position of representational methods for Cardiff secondary schools, used in assessing accessibility by 2SFCA.

To summarise the Methodology used, nearest distance results were calculated using all five networks for all four location methods, and the results compared for consistency and difference. The combined results for all tests will be treated as an accessibility case study to each type of destination feature. The first feature to be examined was primary schools, followed by secondary schools, GP surgeries, sports centres and community hubs. This order will be reflected in the following presentations of results.

Network	Euclidean				ITN				UP				OSM				Open Roads			
Location	**Cen**	**Acc**	**Per**	**PoI**	**Cen**	**Acc**	**Per**	**PoI**	**Cen**	**Acc**	**Per**	**PoI**	**Cen**	**Acc**	**Per**	**PoI**	**Cen**	**Acc**	**Per**	**PoI**
Prim schl	411	402	338	411	726	680	541	719	636	597	485	627	716	674	537	713	711	670	534	717
Sec schl	1169	1148	1007	1187	1710	1610	1408	1776	1568	1451	1338	1627	1760	1705	1685	1733	1733	1577	1401	1752
GP surg'y	500				813				713				817				807			
Sports	840				1311				1156				1281				1296			
CommHub	520				877				764				868				873			

Table 4.7: Mean distance from each demand point (census OA centroid) in Cardiff to nearest facility for each supply-side feature.
GP, sports centres and community hubs were represented only by PoI.

Network	Euclidean				ITN				UP				OSM				Open Roads			
Location	**Cen**	**Acc**	**Per**	**PoI**	**Cen**	**Acc**	**Per**	**PoI**	**Cen**	**Acc**	**Per**	**PoI**	**Cen**	**Acc**	**Per**	**PoI**	**Cen**	**Acc**	**Per**	**PoI**
Prim schl	556	532	488	559	942	886	791	942	860	794	712	838	923	875	784	945	931	877	781	952
Sec schl	1618	1590	1422	1642	2481	2293	1955	2415	2320	2129	1896	2247	2467	2353	2263	2430	2460	2275	2010	2395
GP surg'y	908				1366				1275				1342				1356			
Sports	1621				2337				2223				2351				2326			
CommHub	746				1145				1047				1127				1133			

Table 4.8: Mean distance from each demand point (census OA centroid) in the Vale to nearest facility for each supply-side feature.
GP, sports centres and community hubs were represented only by PoI.

NB. The abbreviations used for the alternative location methods in these tables (and in those to follow), as described in detail in Chapter 3, are as follows:
Cen - Sites centroids; Acc/AccPts - Sites access points (usable by pedestrians); Per/Perim - Sites polygon perimeter (the closest point on the boundary of the school site);
PoI - Point location taken from OS Points of Interest dataset.

4.3.1 Primary schools

Table 4.9 therefore shows the 190 cross-tabulated correlations of nearest distance calculations for Cardiff primary schools, all of which were significant at the 1% level. Not only were all results significant, the overall levels of correlation were high, with the highest recorded as .995 between results from ITN and Open Roads to perimeters. The lowest correlation was .688, for Euclidean distance to access point versus OSM centroid. The lowest found in comparing network datasets was .747 between UP access point and Open Road PoI point.

In looking solely at location methods, the comparisons between Sites centroids and PoI points were consistently the highest correlated when looking at each network separately (apart from Euclidean distances). This indicated the level of similarity in the overall sets of results between using these two methods of representing a feature's location. The results of comparing the travel distances to the four different locations measured using the same network showed a narrow range of high correlations, with those of UP achieving the maximum correlation of .889, with the lowest (Open Road) at .849.

In order to ascertain whether results for Cardiff were representative of rural as well as urban areas, the correlation tests were repeated on the outputs from Vale of Glamorgan primary schools, and the resulting correlation levels are shown in Table 4.10, all of which were significant at the 1% level. The Vale correlations showed a high of 1.000, indicating perfect correlation between the results of using Sites centroids and PoI points as a destination with the ITN network. It must be emphasised, however, that this did not necessarily mean that the results were identical in every respect: the Spearman correlation test involves the rankings of the values of the results and not the absolute values of the results themselves.

The lowest correlation for the Vale results was .829, for Euclidean distance to PoI point versus OSM centroid. The lowest found in comparing only network datasets was .864 between UP perimeter and OSM PoI point. These lowest values from Cardiff were considerably below those of the Vale, and involved different combinations of data.

Comparisons between the results of the four different locations using the same network again showed a narrow range of strong correlations, with UP again returning the highest average of .952 (with a range of .041 between highest and lowest correlations) and Open Road the lowest with .927 (with a range of .042), both higher than Cardiff, both indicating very high levels of correlation, and all exhibiting a consistent range. The patterns of results between Cardiff and the Vale did not justify assuming that results from one area would be similar to those in the other, therefore separate analysis would be carried out for both areas, though awareness would be maintained for common patterns.

As was detailed in Chapter 3, Spearman's statistical test of correlation was the best test available due to the nature of the data involved. As all the distance comparisons were significantly correlated, separate tests of difference were also carried out on the distance results for both counties. Friedman tests indicated that some differences existed between the datasets and that appropriate post-hoc multiple comparison tests (in this case paired tests) be performed in order to identify where these differences occurred. Wilcoxon Z scores identified which paired comparisons had significant differences and which did not. For primary schools in Cardiff, the Friedman test found that there was a statistically significant difference in the overall distance results (chi-sq = 12828.093, p = < .001). Table 4.11 shows the results of applying multiple Wilcoxon tests to the same data. To aid visual interpretation, results which were not significant at the < .001 level are highlighted, and their associated significance levels indicated. Similar tests were applied to the distance results for the Vale of Glamorgan. The Friedman test found statistically significant differences (chi-sq = 3668.860, p = < .001) therefore multiple Wilcoxon paired comparison tests were conducted, with the results shown in Table 4.12, again highlighted to aid interpretation.

The vast majority of the Wilcoxon paired comparison results from both Cardiff and the Vale (coincidentally 89% for both areas) were significant. Although the number of significant results was the same neither the results themselves, nor the pattern, was identical. There was a degree of overlap between the results, with 17 out of the 21 comparisons which were outside the < .001 level common to both Cardiff and Vale results. These results indicated that although there was a high correlation between distance results, most combinations of supply-side features and networks produced statistically significant differences in distances to the nearest destination feature, in the context of primary schools. The results also indicated a degree of similarity between the results from the urban and rural areas.

Some Wilcoxon results indicated an absence of significant difference. For example, the comparison between OSM and the Open Roads datasets had 6 out of 16 cross-comparisons with a statistical significance outside the < .001 level (5 of which were outside the 5% level) which suggests, considering the high correlations levels, a level of similarity between the results. More detail on the similarities is given in section 4.5 in discussing network comparisons.

In order to ascertain whether more detailed attributes of supply-side features can affect accessibility scores, primary schools in Cardiff and the Vale were subjected to 2SFCA analysis, and the results compared to those obtained from the distance calculations.

As with correlations of distance results, Spearman rank correlations were applied to the 2SFCA results. The patterns regarding correlations of 2SFCA results had some differences from those calculated using shortest distance, but also some similarities. The correlations of 2SFCA results for Cardiff primary schools are provided in Table 4.13. As with distances, the correlations for were generally strong, with the highest figure recorded as .998 between results from Euclidean access point and Euclidean perimeter. The highest network correlation was .993 between ITN centroids and Open Roads centroids. The lowest correlation was .366 for Euclidean distance to PoI point versus UP PoI point. The lowest found in comparing network datasets was .520 between UP access point and Open Road PoI point (the same combination of network data that had the weakest correlation for distance measures). Even those poorer correlations were statistically significant at the 1% level. Potential reasons for these trends are discussed in Section 6.2.2 with regard to the appropriateness of these data sources to represent different types of supply-side features.

Equivalent correlations for Vale of Glamorgan primary schools exhibited a pattern that was considerably different compared to those of Cardiff, as can be seen in Table 4.14. Possible explanations for these different patterns are also discussed in Section 6.2.2. The highest correlation was .998, indicating near-perfect correlation between two Euclidean distances measures using centroids and access points. The highest network correlation was .993, between two locations measured using OSM: again between centroids and access points. The highest correlation between two different networks was .990 involving ITN centroids and Open Roads access points.

There are contrasting findings with regard to the strength of correlations. There were many (65 out of 190) non-significant correlations, the majority of which (47 out of the 65) were weak and negative, indicating that many of the results, when ranked, are reversed compared to the others. The variation between networks was high, as was the variation between location methods when using the same networks. Many of the lowest correlations (mostly not significant at the 5% level) were those involving PoI point locations, accounting for 43 out of the 65 combinations that were not significant at the < .001 level. Potential reasons for this are illustrated with reference to case studies in Section 6.2.2. The levels of correlation for 2SFCA in the Vale were weaker than those for Cardiff, the reverse of the situation with regard to correlations of nearest distance measures. This indicated a possible geographical influence upon accessibility results as well as the possible influences of supply and demand levels, issues which will again be investigated and discussed in Section 6.2.2.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	.916	Acc																	
Per	.983	.917	Per																
PoI	.973	.925	.963	PoI															
ITN					**ITN**														
Cent	.748	.710	.730	.744	Cen														
Acc	.745	.825	.742	.757	.846	Acc													
Per	.843	.810	.856	.838	.850	.872	Per												
PoI	.723	.704	.712	.757	.903	.856	.842	PoI											
UP									**UP**										
Cent	.839	.804	.823	.832	.915	.806	.841	.825	Cen										
Acc	.820	.912	.823	.832	.781	.914	.842	.773	.874	Acc									
Per	.906	.862	.924	.898	.795	.814	.928	.784	.887	.891	Per								
PoI	.828	.815	.821	.862	.834	.822	.846	.899	.911	.881	.890	PoI							
OSM													**OSM**						
Cent	.725	.688	.708	.723	.887	.818	.834	.858	.827	.757	.781	.805	Cen						
Acc	.737	.817	.733	.751	.838	.970	.859	.848	.801	.900	.805	.816	.829	Acc					
Per	.831	.798	.842	.825	.841	.851	.976	.831	.832	.826	.910	.835	.846	.873	Per				
PoI	.729	.716	.717	.759	.870	.845	.835	.938	.811	.775	.783	.869	.905	.862	.847	PoI			
OR																	**OR**		
Cent	.754	.714	.736	.750	.982	.849	.855	.902	.903	.783	.798	.835	.877	.837	.849	.857	Cen		
Acc	.744	.826	.740	.758	.841	.987	.868	.851	.803	.910	.810	.820	.816	.976	.850	.844	.845	Acc	
Per	.843	.810	.857	.838	.844	.867	.995	.835	.836	.838	.925	.841	.829	.857	.974	.829	.854	.869	Per
PoI	.724	.700	.713	.758	.861	.821	.831	.959	.795	.747	.776	.872	.824	.810	.824	.905	.874	.818	.832

Table 4.9: Correlations of distance results for Cardiff primary schools.
(Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

Key: Overall high ; Overall low ; Network high (if reqd) ; Network low (if reqd) .

NB. If overall high or low involves network comparisons, then separate network high or low will not be required.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	.983	Acc																	
Per	.992	.979	Per																
PoI	.982	.977	.979	PoI															
ITN					**ITN**														
Cent	.849	.848	.841	.839	Cen														
Acc	.869	.883	.865	.866	.944	Acc													
Per	.899	.892	.911	.890	.926	.946	Per												
PoI	.849	.848	.841	.839	1.000	.944	.926	PoI											
UP									**UP**										
Cent	.905	.903	.895	.896	.928	.913	.906	.928	Cen										
Acc	.914	.930	.910	.913	.900	.936	.914	.900	.962	Acc									
Per	.944	.933	.954	.938	.882	.900	.954	.882	.932	.946	Per								
PoI	.905	.913	.901	.921	.899	.914	.897	.899	.958	.973	.938	PoI							
OSM													**OSM**						
Cent	.839	.842	.835	.829	.965	.934	.914	.965	.892	.887	.868	.884	Cen						
Acc	.873	.888	.869	.868	.932	.976	.941	.932	.912	.927	.899	.909	.948	Acc					
Per	.898	.891	.910	.887	.915	.934	.984	.915	.899	.904	.942	.890	.929	.954	Per				
PoI	.837	.849	.834	.852	.910	.935	.897	.910	.886	.900	.864	.919	.920	.939	.906	PoI			
OR																	**OR**		
Cent	.853	.852	.843	.841	.989	.936	.918	.989	.924	.899	.879	.896	.960	.929	.912	.908	Cen		
Acc	.871	.888	.868	.869	.934	.989	.936	.934	.906	.939	.899	.913	.927	.967	.926	.928	.938	Acc	
Per	.905	.899	.916	.895	.910	.936	.989	.910	.898	.916	.952	.894	.901	.933	.976	.889	.919	.943	Per
PoI	.841	.854	.838	.857	.909	.932	.893	.909	.886	.909	.868	.927	.897	.916	.885	.978	.918	.943	.901

Table 4.10: Correlations of distance results for Vale primary schools.
(Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

Key: Overall high ; Overall low ; Network high (if reqd) ; Network low (if reqd) .

NB. If overall high or low involves network comparisons, then separate network high or low will not be required.

The wide differences within groups of results affected the general trends, with the highest correlation found, when all methods of location were included, between ITN with Urban Paths and OSM with an average of only .475, with the highest 'internal' comparison (using the four location methods measured with the same network) being found using the OSM dataset, with 0.556 (though the equivalent Euclidean comparison had a correlation of .952).

Separate tests of difference were also carried out on the 2SFCA results. A Friedman test on the entire set of Cardiff results indicated there was a statistically significant difference between the datasets (chi-sq = 18041.533, p = < .001), and Wilcoxon Z scores were used to identify which paired comparisons had the significant differences. The results of the paired comparisons are shown in Table 4.15. Following a significant Friedman score (4951.325, p = < .001), Wilcoxon paired comparison tests were also carried out on the Vale 2SFCA results, with the outcomes shown in Table 4.16. A possible geographical component may be involved, giving the different patterns exhibited in the tables of results for Cardiff and the Vale. Cardiff results show far fewer non-significant outcomes, suggesting (in combination with strong correlations) fewer cases of similarity between results. Vale results (again in combination with relatively strong correlations) have many more non-significant differences, implying a higher degree of similarity between their 2SFCA results. Case studies will be used to suggest possible explanations, as well as presenting interpretations in order to ascertain if such numerical and statistical variations translate into visible differences using typical methods of statistical map visualisation.

The pattern of results from the Wilcoxon tests for Cardiff differed widely from those of the Vale. Where Cardiff had six combinations which were outside the < .001 significance level, the Vale had 32. All but one of Cardiff's six combinations related to PoI points, whereas only 7 out of the Vale's 32 related to PoI. This pattern was in contrast with the low correlation figures involving PoI in the Vale, which indicated less similarity and could have been expected to result in a higher level of difference being assessed.

Other aspects of the patterns of non-significant 2SFCA results differed between those of the Vale and those of Cardiff. Only one comparison was common to both: that of UP perimeter and OSM perimeter. This indicated there was no significant difference in the overall results achieved using that particular combination of network data both in urban and rural contexts. The results from distance and 2SFCA measures of accessibility indicate that the use of different data sources which represent the same supply-side features have a statistically significant effect on outcomes, potential reasons for which are put forward in Section 6.2.2. These results suggest that the way in which a feature is represented using these key data sources can influence access scores.

	Euclidean				**ITN**				**UP**				**OSM**				**OR**			
	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI
Eucl																				
Cen		*< .001*	*< .001*	*.085*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Acc	-12.196		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Per	-28.428	-28.411		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
PoI	-1.722	-12.917	-27.827		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
ITN																				
Cen	-28.064	-27.031	-28.425	-27.746		*< .001*	*< .001*	*.003*	*< .001*	*< .001*	*< .001*	*< .001*	*185*	*< .001*	*< .001*	*.010*	*< .001*	*< .001*	*< .001*	*< .001*
Acc	-26.622	-28.292	-28.394	-26.767	-12.732		*< .001*	*< .001*	*.005*	*< .001*	*< .001*	*< .001*	*< .001*	*.030*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Per	-16.989	-19.005	-27.120	-17.226	-28.407	-28.327		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*059*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
PoI	-27.750	-27.054	-28.374	-28.195	-2.921	-11.831	-28.289		*< .001*	*< .001*	*< .001*	*< .001*	*.999*	*< .001*	*< .001*	*.487*	*.848*	*< .001*	*< .001*	*< .001*
UP																				
Cen	-27.971	-26.562	-28.425	-27.531	-18.247	-2.789	-19.399	-11.183		*< .001*	*< .001*	*.016*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*.225*	*< .001*	*< .001*
Acc	-25.928	-28.306	-28.400	-26.230	-18.501	-16.901	-15.370	-17.748	-13.365		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Per	-13.588	-16.894	-27.393	-13.947	-28.282	-27.647	-12.922	-28.134	-28.391	-28.134		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
PoI	-27.545	-26.614	-28.359	-28.151	-13.667	-4.029	-19.021	-16.984	-2.416	-11.834	-28.280		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*.013*	*< .001*	*< .001*
OSM																				
Cen	-27.688	-26.679	-28.268	-27.366	-1.326	-8.722	-27.039	-.002	-11.331	-16.068	-27.505	-11.098		*< .001*	*< .001*	*.121*	*.132*	*< .001*	*< .001*	*.297*
Acc	-26.112	-27.966	-28.194	-26.278	-11.767	-2.164	-25.052	-10.682	-2.363	-12.435	-25.841	-3.835	-11.127		*< .001*	*< .001*	*< .001*	*.011*	*< .001*	*< .001*
Per	-15.671	-17.974	-26.263	-15.922	-27.399	-25.503	-1.889	-26.887	-18.451	-13.948	-8.753	-17.874	-28.408	-28.184		*< .001*	*< .001*	*< .001*	*.359*	*< .001*
PoI	-27.372	-26.871	-28.186	-27.846	-2.568	-9.086	-26.283	-.695	-9.999	-16.054	-26.846	-12.666	-1.551	-11.877	-27.856		*.796*	*< .001*	*< .001*	*.607*
OR																				
Cen	-27.972	-26.926	-28.424	-27.632	-9.790	-9.994	-27.577	-.192	-12.523	-17.037	-27.729	-11.865	-1.507	-9.684	-26.808	-.259		*< .001*	*< .001*	*.060*
Acc	-26.456	-28.278	-28.391	-26.628	-13.463	-13.843	-26.961	-12.777	-1.215	-9.080	-26.761	-2.495	-10.742	-2.545	-24.703	-10.939	-12.156		*< .001*	*< .001*
Per	-16.231	-18.402	-26.970	-16.526	-28.337	-28.217	-10.261	-28.235	-19.690	-15.727	-6.170	-19.269	-27.270	-25.530	-.916	-26.573	-28.397	-28.308		*< .001*
PoI	-27.719	-27.027	-28.374	-28.180	-4.698	-9.964	-27.264	-9.814	-9.601	-16.376	-27.481	-11.215	-1.043	-9.367	-26.263	-.515	-1.884	-11.777	-28.310	

Table 4.11: Differences between distance results for Cardiff primary schools. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001 level; green = significant at 1% level; amber = significant at 5% level; red = not significant at 5% level).

	Euclidean				ITN				UP				OSM				OR			
	Cent	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI
Eucl																				
Cent		*< .001*	*< .001*	*.605*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Acc	-9.347		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Per	-17.588	-17.248		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
PoI	- .518	-10.238	-17.588		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
ITN																				
Cent	-17.449	-17.540	-17.584	-17.279		*< .001*	*< .001*	*.225*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*.011*	*< .001*	*< .001*	*< .001*	*.069*
Acc	-16.748	-17.505	-17.515	-16.712	-10.983		*< .001*	*< .001*	*.664*	*< .001*	*< .001*	*.064*	*< .001*	*.033*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Per	-12.621	-14.138	-16.950	-16.376	-17.589	-17.151		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*.006*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
PoI	-17.449	-17.540	-17.584	-17.279	-1.214	-10.860	-17.589		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*.011*	*< .001*	*< .001*	*< .001*	*< .001*
UP																				
Cent	-17.464	-17.557	-17.586	-17.244	-8.613	.435	-9.918	-7.861		*< .001*	*< .001*	*< .001*	*< .001*	*.659*	*< .001*	*< .001*	*< .001*	*.851*	*< .001*	*< .001*
Acc	-16.600	-17.549	-17.513	-16.521	-13.824	-10.592	-4.879	-13.768	-12.341		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Per	-11.043	-13.236	-17.050	-10.937	-17.541	-16.884	-9.509	-17.541	-17.589	-17.230		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
PoI	-17.317	-17.546	-17.587	-17.520	-9.655	-1.850	-8.406	-9.523	-4.525	-11.837	-17.568		*< .001*	*.258*	*< .001*	*< .001*	*< .001*	*.291*	*< .001*	*< .001*
OSM																				
Cent	-17.179	-17.409	-17.569	-16.997	-3.688	-5.900	-15.223	-3.688	-4.158	-10.881	-16.111	-6.302		*< .001*	*< .001*	*.001*	*.036*	*< .001*	*< .001*	*.022*
Acc	-16.338	-17.314	-17.403	-16.282	-9.537	-2.127	-4.676	-9.537	-.441	-6.931	-14.910	-1.131	-9.471		*< .001*	*< .001*	*< .001*	*.316*	*< .001*	*< .001*
Per	-11.976	-13.509	-16.584	-11.840	-15.999	-13.890	-2.726	-15.999	-9.031	-4.008	-5.493	-7.686	-17.541	-17.123		*< .001*	*< .001*	*< .001*	*.264*	*< .001*
PoI	-17.152	-17.466	-17.579	-17.327	-2.553	-7.582	-15.453	-2.553	-5.405	-12.658	-16.441	-8.965	-3.286	-10.594	-17.568		*.096*	*< .001*	*< .001*	*.002*
OR																				
Cent	-17.412	-17.489	-17.581	-17.209	-7.981	-8.971	-16.893	-7.981	-4.911	-12.633	-17.248	-8.450	-2.092	-8.301	-15.534	-1.663		*< .001*	*< .001*	*.958*
Acc	-16.710	-17.504	-17.518	-16.674	-11.032	-7.587	-16.420	-11.032	- .188	-7.444	-16.496	-1.056	-6.199	-1.003	-13.473	-7.850	-9.862		*< .001*	*< .001*
Per	-12.385	-13.952	-16.876	-12.217	-17.326	-16.782	-6.609	-17.326	-10.240	-5.211	-5.654	-8.701	-15.202	-12.843	-1.117	-15.372	-17.547	-17.151		*< .001*
PoI	-17.347	-17.550	-17.586	-17.492	-1.820	-11.365	-17.091	-1.820	-6.763	-14.890	-17.360	-10.321	-2.286	-9.786	-15.830	-3.074	- .052	-12.725	-17.568	

Table 4.12: Differences between distance results for Vale primary schools. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001 level; green = significant at 1% level; amber = significant at 5% level; red = not significant at 5% level).

Eucl	**Eucl**																		
Cent	Cen																		
Acc	.996	Acc																	
Per	.997	.998	Per																
PoI	.963	.953	.956	PoI															
ITN					**ITN**														
Cent	.462	.440	.440	.399	Cen														
Acc	.607	.613	.616	.473	.682	Acc													
Per	.611	.621	.621	.472	.678	.984	Per												
PoI	.429	.402	.403	.374	.977	.610	.612	PoI											
UP									**UP**										
Cent	.462	.440	.442	.395	.971	.664	.663	.953	Cen										
Acc	.600	.606	.611	.460	.600	.947	.939	.522	.638	Acc									
Per	.610	.617	.621	.462	.622	.949	.966	.552	.653	.978	Per								
PoI	.422	.393	.394	.366	.949	.575	.581	.970	.976	.542	.567	PoI							
OSM													**OSM**						
Cent	.461	.438	.438	.394	.973	.651	.645	.956	.954	.569	.593	.934	Cen						
Acc	.596	.604	.606	.461	.671	.984	.971	.598	.655	.935	.939	.565	.661	Acc					
Per	.609	.615	.618	.471	.671	.973	.988	.607	.659	.932	.960	.578	.660	.981	Per				
PoI	.467	.442	.442	.400	.960	.618	.614	.954	.940	.539	.565	.931	.988	.629	.632	PoI			
OR																	**OR**		
Cent	.464	.443	.444	.400	.993	.682	.678	.973	.976	.608	.630	.956	.972	.670	.672	.956	Cen		
Acc	.607	.614	.617	.471	.669	.990	.978	.597	.662	.959	.958	.573	.638	.976	.969	.605	.676	Acc	
Per	.611	.618	.621	.470	.669	.978	.992	.602	.663	.949	.974	.580	.637	.965	.983	.606	.675	.984	Per
PoI	.426	.399	.399	.373	.973	.600	.603	.992	.958	.520	.550	.976	.955	.588	.598	.951	.979	.595	.599

Table 4.13: Correlations of 2SFCA results for Cardiff primary schools.
(Using Spearman’s Rank Correlation Coefficients; all correlations significant at the 0.01 level).

Key: Overall high ; Overall low ; Network high (if reqd) ; Network low (if reqd) .

NB. If overall high or low involves network comparisons, then separate network high or low will not be required.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	.998	Acc																	
Per	.909	.902	Per																
PoI	.965	.963	.974	PoI															
ITN					**ITN**														
Cent	.428	.440	.173	.307	Cen														
Acc	.348	.358	.184	.267	.729	Acc													
Per	.124	.108	.201	.166	.388	.298	Per												
PoI	-.087	-.084	-.100	-.098	-.055	-.032	-.050	PoI											
UP									**UP**										
Cent	.425	.438	.170	.304	.988	.715	.376	-.054	Cen										
Acc	.399	.412	.143	.278	.983	.713	.387	-.057	.991	Acc									
Per	.059	.043	.184	.122	.286	.219	.955	-.038	.290	.305	Per								
PoI	-.087	-.086	-.100	-.096	-.043	-.035	-.032	.954	-.045	-.046	-.025	PoI							
OSM													**OSM**						
Cent	.411	.423	.157	.290	.980	.706	.412	-.061	.976	.975	.316	-.055	Cen						
Acc	.379	.391	.122	.256	.978	.706	.408	-.053	.972	.975	.310	-.043	.993	Acc					
Per	.086	.070	.173	.131	.365	.255	.970	-.048	.351	.363	.943	-.035	.395	.396	Per				
PoI	.127	.141	-.113	-.116	.695	.465	.152	.009	.719	.724	.115	-.007	.696	.700	.156	PoI			
OR																	**OR**		
Cent	-.136	-.132	-.089	-.102	-.104	-.091	.037	-.023	-.117	-.120	.007	-.025	-.082	-.076	.062	-.106	Cen		
Acc	.395	.408	.136	.273	.990	.726	.390	-.047	.983	.984	.286	-.034	.978	.979	.367	.698	-.089	Acc	
Per	.073	.060	.105	0.96	.444	.315	.965	-.029	.425	.440	.901	-.010	.470	.474	.944	.210	.072	.460	Per
PoI	.295	.300	.077	.197	.864	.617	.571	-.023	.846	.858	.445	-.009	.855	.866	.553	.600	-.089	.879	.658

Table 4.14: Correlations of 2SFCA results for Vale of Glamorgan primary schools, using Spearman's Rank Correlation Coefficients.

Significance level (black = significant at < .001; green = significant at 1%; amber = significant at 5%; red = not significant at 5%).
Key: Overall high [ ] ; Network high [ ] .

NB. Lowest correlations are found in the results highlighted in red (not significant at 5%).

	Euclidean				ITN				UP				OSM				OR			
	Cent	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI
Eucl																				
Cent		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Acc	-28.427		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Per	-27.307	-28.193		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
PoI	-28.428	-28.428	-28.428		*< .001*	*< .001*	*< .001*	*.110*	*< .001*	*< .001*	*< .001*	*.139*	*< .001*	*< .001*	*< .001*	*.090*	*.001*	*< .001*	*< .001*	*.119*
ITN																				
Cent	-28.054	-27.838	-27.910	-28.422		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Acc	-28.428	-28.426	-28.423	-28.428	-28.185		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Per	-28.428	-28.428	-28.428	-28.428	-28.273	-22.610		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
PoI	-16.792	-19.570	-17.737	-1.599	-28.313	-28.428	-28.428		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
UP																				
Cent	-28.056	-27.838	-27.911	-28.423	-6.434	-28.393	-27.135	-28.428		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Acc	-28.428	-28.427	-28.424	-28.428	-26.730	-8.099	-19.824	-28.428	-28.339		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Per	-28.428	-28.428	-28.428	-28.428	-24.322	-23.630	-7.081	-28.428	-28.396	-22.127		*< .001*	*< .001*	*< .001*	*.061*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
PoI	-16.656	-19.412	-17.608	-1.479	-28.428	-28.428	-28.428	-7.268	-28.428	-28.428	-28.428		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
OSM																				
Cent	-28.075	-27.857	-27.928	-28.423	-3.227	-27.890	-27.812	-28.428	-4.783	-26.362	-23.765	-28.428		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Acc	-28.428	-28.426	-28.423	-28.428	-28.242	-12.282	-23.321	-28.428	-28.397	-3.756	-24.103	-28.428	-28.250		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
Per	-28.428	-28.428	-28.428	-28.428	-28.263	-22.161	-14.936	-25.087	-27.730	-18.089	-1.876	-28.428	-28.257	-23.054		*< .001*	*< .001*	*< .001*	*< .001*	*< .001*
PoI	-16.590	-19.472	-17.528	-1.694	-28.427	-28.427	-28.427	-5.265	-28.427	-28.427	-28.427	-4.910	-28.388	-28.388	-28.388		*< .001*	*< .001*	*< .001*	*< .001*
OR																				
Cent	-16.082	-19.073	-17.131	-3.247	-28.428	-28.428	-28.428	-19.471	-28.428	-28.428	-28.428	-15.039	-28.428	-28.428	-28.428	-11.800		*< .001*	*< .001*	*< .001*
Acc	-9.870	-14.280	-11.162	-15.336	-28.427	-28.428	-28.428	-27.724	-28.427	-28.428	-28.428	-28.305	-24.427	-28.428	-28.428	-27.335	-28.290		*< .001*	*< .001*
Per	-12.325	-16.352	-13.589	-11.426	-28.412	-28.428	-28.428	-26.867	-28.413	-28.428	-28.428	-27.170	-28.413	-28.428	-28.428	-26.367	-27.755	-23.409		*< .001*
PoI	-16.772	-19.583	-17.748	-1.557	-28.428	-28.428	-28.428	-7.553	-28.428	-28.428	-28.428	-6.039	-28.428	-28.428	-28.428	-4.723	-21.537	-28.356	-28.314	

Table 4.15: Differences between 2SFCA results for Cardiff primary schools. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001 level; green = significant at 1% level; red = not significant at 5% level).

	Euclidean				ITN				UP				OSM				OR			
	Cent	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI
Eucl																				
Cent		< .001	< .001	< .001	.793	.242	< .001	< .001	.920	.333	< .001	< .001	.220	.009	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-13.258		< .001	< .001	.446	.808	< .001	< .001	.268	.971	< .001	< .001	.921	.107	< .001	< .001	< .001	< .001	< .001	< .001
Per	-15.717	-11.409		< .001	.002	.007	< .001	< .001	.001	.006	< .001	< .001	.005	.071	< .001	< .001	< .001	< .001	< .001	< .001
PoI	-15.687	-15.774	-8.433		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
ITN																				
Cent	- .263	- .763	-3.114	-5.264		< .001	< .001	< .001	.774	< .001	< .001	< .001	.941	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-1.169	- .243	-2.714	-4.549	-8.017		< .001	< .001	< .001	.973	< .001	< .001	< .001	.640	< .001	< .001	< .001	< .001	< .001	< .001
Per	-12.505	-12.071	-9.964	-8.655	-15.850	-13.181		.703	< .001	< .001	< .001	.832	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
PoI	-10.574	-10.065	-7.386	-6.083	-9.913	-15.090	-.381		< .001	< .001	.439	< .001	< .001	< .001	.304	.001	< .001	< .001	< .001	< .001
UP																				
Cent	- .101	-1.107	-3.431	-5.605	-.287	-7.084	-15.756	-9.995		< .001	< .001	< .001	.013	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Acc	- .968	- .037	-2.745	-4.811	-7.593	-.033	-13.830	-9.473	-12.339		< .001	< .001	< .001	.039	< .001	< .001	< .001	< .001	< .001	< .001
Per	-12.404	-11.933	-9.950	-8.473	-14.250	-11.324	-3.520	-.774	-15.819	-15.846		.518	< .001	< .001	.129	< .001	< .001	< .001	< .001	< .001
PoI	-10.617	-10.112	-7.402	-6.129	-10.074	-9.398	-.212	-5.032	-10.161	-9.629	-.646		< .001	< .001	< .001	.001	< .001	< .001	< .001	< .001
OSM																				
Cent	-1.226	- .099	-2.810	-4.970	-.074	-4.856	-16.289	-10.037	-2.481	-3.725	-15.192	-10.187		< .001	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-2.610	-1.614	-1.806	-3.823	-8.867	-.468	-14.626	-9.283	-8.823	-2.067	-12.934	-9.446	-13.385		< .001	< .001	< .001	< .001	< .001	< .001
Per	-12.528	-12.123	-10.130	-8.859	-16.023	-13.672	-8.835	-1.028	-15.979	-14.788	-1.519	-.897	-16.822	-16.416		< .001	< .001	< .001	< .001	< .001
PoI	-12.612	-12.245	-9.889	-9.287	-16.226	-14.912	-4.965	-3.193	-16.419	-16.269	-4.537	-3.472	-16.338	-16.191	-4.148					
OR																				
Cent	-17.580	-17.584	-17.582	-17.589	-17.590	-17.470	-17.532	-17.444	-17.590	-17.590	-17.590	-17.589	-17.590	-17.590	-17.590	-17.590		< .001	< .001	< .001
Acc	-17.573	-17.582	-17.578	-17.588	-17.590	-17.468	-17.590	-17.588	-17.590	-17.590	-17.589	-17.589	-14.031	-17.590	-17.590	-17.589	-12.343		< .001	< .001
Per	-17.228	-17.316	-17.536	-17.584	-17.054	-17.367	-17.591	-17.588	-17.303	-17.439	-17.590	-17.589	-16.805	-17.205	-17.591	-17.589	-16.490	-16.404		< .001
PoI	-17.506	-17.542	-17.534	-17.581	-17.421	-17.403	-17.590	-17.588	-17.485	-17.538	-17.590	-17.588	-17.457	-17.551	-17.590	-17.589	-16.703	-16.462	-3.732	

Table 4.16: Differences between 2SFCA results for Vale primary schools. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001 level; green = significant at 1% level; amber = significant at 5% level; red = not significant at 5% level).

A further examination was carried out, assessing destination overlaps, as to whether the effects of these measures of accessibility went beyond those of travel distance and 2SFCA score and actually affected which of the destination features were identified as nearest. Destination overlap indicates to what extent the same supply feature (a primary school, for example) was identified as closest to each demand feature when the network or location method was varied. It may be expected that more numerous features, distributed widely around a densely-populated urban area, would be subject to having different destinations identified with a relatively small change of distance, and this expectation will be examined through the use of different features, with differing patterns of distribution and location. Destination overlap assessments were therefore carried out on all the alternative feature representations, and results for Cardiff primary schools are shown in Table 4.17, with those of Vale of Glamorgan primary schools shown in Table 4.18.

The tables indicate that according to this measure no two of the chosen datasets could be considered directly equivalent for the purposes of this exercise, as no combinations of data identified exactly the same destinations for all demand-side origins as any other set of data. In Cardiff a maximum of 98.3% was recorded (when distance to the perimeter using ITN was compared to distance to the perimeter using Open Roads), with a low of 63.9% between Euclidean PoI and OSM centroid, with the lowest network comparison 65.8% between ITN to PoI and OSM to perimeter.

Destination results for the Vale were generally higher, with an average overlap from all combinations of data of 85.2% in the Vale compared to 76.9% in Cardiff. The highest destination overlap for Vale primary schools was 99.8%, between centroids and PoI both measured on the ITN dataset. That figure equated to one OA out of 112 having a different nearest facility identified due to the difference in location method. The lowest overlap was 68.9%, measured using Euclidean distances to school access points versus OSM to the Points of Interest point. The lowest comparison using network distance was 77.9%, with OSM PoI point (again), and Urban Paths to centroids.

The greatest difference between the two areas was the 29% difference between PoI using ITN and perimeter using UP, highlighting the differences between the two datasets. The smallest difference was of 0.2% which was identified between PoI using ITN once more, this time compared to schools perimeters using OSM. The exact nature of the factors influencing such feature representations are demonstrated in the case studies in order to put forward an explanation for such trends, as described in Section 6.2.2.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	87.5	Acc																	
Per	95.4	86.5	Per																
PoI	85.4	82.0	82.8	PoI															
ITN					**ITN**														
Cent	72.8	69.5	72.1	64.7	Cen														
Acc	70.3	75.7	70.1	65.6	78.8	Acc													
Per	79.9	75.7	79.9	71.4	81.5	80.0	Per												
PoI	66.9	66.4	65.8	72.6	74.9	76.6	76.3	PoI											
UP									**UP**										
Cent	79.1	76.8	78.4	70.8	85.7	74.2	80.6	67.8	Cen										
Acc	77.3	84.1	77.0	71.8	75.2	87.6	80.3	71.5	82.7	Acc									
Per	83.3	79.6	84.0	75.2	75.9	74.1	90.3	70.8	84.3	83.8	Per								
PoI	73.7	74.7	72.2	79.8	68.7	70.8	75.1	84.5	76.7	79.9	79.1	PoI							
OSM													**OSM**						
Cent	72.9	69.8	72.3	63.9	86.4	77.6	82.4	66.9	79.2	76.2	76.4	73.7	Cen						
Acc	71.6	76.7	70.8	65.6	77.5	94.6	79.5	66.4	74.9	87.7	74.7	74.7	81.2	Acc					
Per	78.9	74.5	79.0	70.2	80.8	78.4	94.4	65.8	79.7	78.9	87.2	72.2	84.3	81.2	Per				
PoI	66.9	67.9	66.0	68.8	73.5	75.9	75.0	86.1	69.8	74.5	71.5	79.9	77.5	78.4	77.1	PoI			
OR																	**OR**		
Cent	73.3	69.4	72.5	65.0	96.8	78.8	81.4	74.2	83.6	74.6	75.6	68.0	85.5	77.6	81.0	72.7	Cen		
Acc	69.7	75.2	69.5	64.1	77.1	95.9	79.6	72.9	74.2	87.5	74.1	70.6	77.4	94.2	78.3	75.6	77.4	Acc	
Per	80.4	76.1	80.5	71.9	81.5	79.7	98.3	76.0	80.2	79.6	89.9	74.6	82.5	79.4	94.7	74.9	82.1	79.1	Per
PoI	66.6	65.9	65.5	72.3	74.1	76.6	75.4	95.7	67.1	71.1	70.8	82.9	72.9	74.0	74.2	85.2	74.4	73.6	75.5

Table 4.17: Destination overlaps (%) for Cardiff primary schools.

Key: Overall high ; Overall low ; Network high (if reqd) ; Network low (if reqd) .

NB. If overall high or low involves network comparisons, then separate network high or low will not be required.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	92.7	Acc																	
Per	94.4	95.4	Per																
PoI	94.2	91.0	93.7	PoI															
ITN					**ITN**														
Cent	80.1	78.9	77.4	77.9	Cen														
Acc	81.1	77.9	78.9	77.9	87.6	Acc													
Per	86.2	83.5	83.7	70.6	85.4	85.2	Per												
PoI	80.6	77.4	77.4	78.2	99.8	94.4	86.9	PoI											
UP									**UP**										
Cent	86.2	83.5	83.7	82.8	88.1	85.4	85.2	87.9	Cen										
Acc	85.2	85.7	84.0	82.3	86.4	89.6	85.7	86.2	93.2	Acc									
Per	86.6	83.7	85.4	83.0	83.3	83.5	91.5	99.8	88.6	90.5	Per								
PoI	82.8	80.6	81.6	84.5	86.4	86.7	84.2	86.7	91.0	92.0	86.4	PoI							
OSM													**OSM**						
Cent	77.4	74.8	74.8	75.7	92.0	89.1	85.7	92.0	81.1	80.8	82.8	82.3	Cen						
Acc	77.4	77.4	75.7	74.5	90.5	95.1	87.9	90.5	83.5	86.6	84.2	83.5	90.5	Acc					
Per	82.0	79.6	80.8	79.4	87.9	87.6	94.2	87.6	85.4	85.7	90.0	84.5	88.8	90.0	Per				
PoI	71.4	68.9	69.7	72.3	86.7	88.3	80.6	86.7	77.9	78.9	86.7	82.8	87.9	89.1	83.5	PoI			
OR																	**OR**		
Cent	81.0	77.6	77.9	77.9	97.3	94.4	86.9	97.1	85.6	85.2	97.3	84.2	92.7	89.1	86.9	84.9	Cen		
Acc	80.8	79.6	78.1	77.4	93.4	96.6	87.6	93.4	85.6	89.5	93.4	85.4	88.1	93.4	87.6	85.9	92.2	Acc	
Per	82.2	78.6	80.0	79.6	89.5	89.3	97.1	89.8	85.4	85.9	89.5	86.4	87.8	88.3	94.9	82.2	89.3	88.3	Per
PoI	74.5	71.8	72.3	75.5	89.1	90.8	81.1	89.3	80.3	82.0	89.1	85.7	85.4	85.7	81.6	93.7	88.1	88.6	83.5

Table 4.18: Destination overlaps (%) for Vale of Glamorgan primary schools.

Key: Overall high ; Overall low ; Network high (if reqd) ; Network low (if reqd) .

NB. If overall high or low involves network comparisons, then separate network high or low will not be required.

As outlined in section 4.5 (relating to network comparisons) the choice of network representation has a considerable impact on accessibility results, both in terms of distance, 2SFCA scores and on destination overlaps. However, the choice of feature location method also had a considerable effect. When the results for all location representations for primary schools were combined, the averages were as shown in Table 4.19. This indicates that (depending on the network used) by changing the method by which a feature (primary schools, in this case) is represented, while keeping the points of origin constant (OA population-weighted centroids), the nearest feature to each origin changes in up to 23% of the cases. In the best case, when looking at the average outcome, over 6% of OA centroids identify a different destination.

	Euc	**ITN**	**UP**	**OR**	**OSM**
Cardiff	86.6	78.0	81.1	77.0	80.0
Vale	93.6	89.9	90.3	88.3	88.3

Table 4.19: Destination overlaps for primary schools (averaging the results of the four location methods, for each network).

These results were compared to those of the other types of destination features in order to assess how representative these findings were, or whether the total numbers and/or distribution of destinations had any effect on the degree of overlap, or on levels of correlation or indications of difference.

4.3.2 Secondary schools

The results from secondary schools were collated, analysed and compared to those of primary schools, as both types of feature are represented in OS Sites dataset and have multiple occurrences in the study area. Both also contribute to the active travel to schools debate (and therefore suitable for a continuation of the primary schools accessibility analysis on pedestrian journeys), and both are also accessed from home locations, therefore the demand-side representations provided by OA centroids (which relate to night-time populations) are valid journey origins.

Secondary schools were the least numerous of the five features considered in both Cardiff and the Vale, and were distributed in a ‘dispersed’ pattern (see Table 4.4) within both areas. The facilities were generally large in size (compared to primary schools) and had large catchment areas taking in several ‘feeder’ primary schools. Cardiff's coverage figures (see Table 4.2) had an average of one school per 7.1km^2, a relatively small area, albeit in an urban context with high population density, with the Vale having one school per 37.75km^2, a contrastingly large area. As with primary schools, it appeared that the population of the Vale was better served by secondary schools, with the population per school in the Vale approximately 17% of that in

Cardiff (14037 people per school in the Vale, 16480 people per school in Cardiff), a pattern reflected when the coverage figure for school-age population was considered, with each secondary school in Cardiff and the Vale covering an average of 1339 and 1179 pupil, respectively.

To assess similarity between datasets, correlations were conducted using Spearman's Rank Correlation Coefficients, and the results shown in Tables 4.20 and 4.21. None of the distance results for either Cardiff or the Vale conformed to normal distribution. As with Cardiff primary schools, the overall level of correlations for Cardiff secondary schools was strong. The highest correlation was recorded as .998 between ITN network distance to perimeter and Open Roads network to perimeter, again showing the close relationship between ITN and Open Roads that was evident with primary schools. The lowest correlation was .781, for OSM perimeter versus OSM centroid, which still indicated a moderate to strong relationship, but which was a lower figure even than those found when using Euclidean distances (which were amongst the lowest comparators up to this point). 'Internal' comparison (comparing the four location methods using the same network) showed that the UP dataset achieved an average correlation of .971, with even the lowest (OSM) highly correlated at .846. This again indicated that altering the location method still resulted in strong correlations, suggesting similarities between sets of results.

Correlation tests on the outputs from Vale of Glamorgan secondary schools (Table 4.21) were all significant at the 1% level. The Vale correlations had a high of .997, indicating near-perfect correlation between Euclidean-measured distances to centroids and Euclidean to perimeter, indicating that the ranking of results was very similar. The highest network correlation was .992, for two separate comparisons: ITN distance to access point and ITN to PoI; and Open Roads distance to access point and Open Roads to PoI. As these datasets were derived from a common base then strongly correlated results may have been expected. The lowest correlation was .802, for Euclidean distance to centroid versus OSM to PoI, which still represented a reasonably strong correlation. The lowest found in comparing network datasets only was the .860 between ITN perimeter and OSM PoI point. The lowest correlations recorded were still indicative of strong correlations.

Comparisons between the results of the four different locations using the same network again showed a narrow range of high correlations, with UP again returning the highest of .952 and Open Road the lowest with .927, both higher than Cardiff, and both indicating very strong correlation. The pattern of results between Cardiff and the Vale were dissimilar and thus limited the transferability of findings.

These results for schools imply that rural contexts increase the level of relationship between the datasets. The results of distance accessibility were then tested for differences, to ascertain if the increased levels of correlation in the Vale of Glamorgan translated into fewer statistical differences between the datasets. The Friedman test was applied to the each set of results and it was found there was a statistically significant difference in the distance results for both Cardiff (chi-sq = 13643.113, p = < .001) and the Vale (chi-sq = 5552.315, p = < .001). Accordingly, Tables 4.22 and 4.23 show the results of applying multiple Wilcoxon paired comparison tests to the data. Outcomes which were not statistically significant at the < .001 level were highlighted according to their associated significance levels. The vast majority of the results from both Cardiff and the Vale exhibited statistically-significantly differences: 96% of Cardiff results and 92% of Vale comparisons were significantly different at the < .001 level.

A high correlation and an insignificant Wilcoxon score (certainly outside the 5% level) would indicate a level of similarity between pairs of data obtained through the distance assessment of accessibility, and there is less difference, and therefore more similarity, between the results obtained from the Vale of Glamorgan area. At this stage it is postulated that the greater travel distances in the Vale resulted in a diminution of effects caused by network differences and locational representation options.

The results of the 2SFCA calculations were subject to the same tests of correlation as distance results, to ascertain if this type of accessibility measure was subject to the same effects as those of distance. None of the2SFCA data conformed to normal distribution, therefore Spearman's rank correlations were applied. As with correlations of distance results from Cardiff, all the Spearman correlations of the 2SFCA results were statistically significant at the 1% level, though the correlations were not as high. The highest figure was the .999 recorded for Euclidean centroid and Euclidean access point and the highest network correlation was .985 between ITN to access points and Open Roads to access points. The lowest correlation was .140 for Euclidean to perimeter versus UP to perimeter. The lowest comparison for network datasets was .394 between UP to PoI and Open Road to perimeter. Although still statistically significant at the 1% level, these results indicated a weak correlation between 2SFCA results. Cardiff results are shown in Table 4.24, Vale results in Table 4.25, with discussion in Section 6.2.2.

The pattern of correlations for the Vale of Glamorgan was slightly different compared to that of Cardiff, with a high of .996 between Euclidean distances measures using centroids and access points. The highest network correlation was .981 between ITN PoI and Open Roads PoI, again emphasising the close relationship between ITN and PoI datasets. There were, however, two correlations for 2SFCA results in the Vale that were not statistically significant, even at the 5% level, both involving Euclidean perimeter comparisons: with OSM to perimeter; and with Open

Roads to perimeter. The lowest network correlation was .529 between ITN to centroids and UP to perimeter. The highest 'internal' network comparison (comparing the results from all four location alternatives with the same network) used Open Roads, with a correlation of .842 (though the equivalent Euclidean comparison had an average correlation of .952). When 2SFCA scores were tested for differences, there was a significant Friedman score for both Cardiff's (chi-sq = 15068.618, p = < .001) the Vale (chi-sq = 6107.508, p = < .001), therefore paired comparisons were conducted, the results of which are shown in Tables 4.26 and 4.27.

The results indicated that a large majority of the 2SFCA results from Cardiff exhibited statistically significant differences. 81% of comparisons were significantly different at the < .001 level. Of the comparisons which did not have differences significant at this level, 23 out of the 37 involved PoI points as one (or both) of the comparators. 14% of Vale results were not significant at the < .001 level. Several combinations which produced the non-significant 2SFCA differences matched those of Cardiff, indicating an overall similarity between sets of results. Whether these differences or similarities in distance and 2SFCA affect the choice of nearest feature is addressed in Tables 4.28 and 4.29 of destination overlap results.

As with primary schools, destination overlaps were calculated for all OA centroids. Destination overlap for Cardiff secondary schools ranged from 98.5% (compared between ITN using the PoI as the location method, and Open Roads also using PoI as location method) to a low of 60.2%, found when comparing OSM using Sites centroid to Euclidean PoI, the same combination achieving the lowest results in Cardiff's primary schools. The lowest destination overlap found using network datasets was 61.7% found comparing OSM perimeter and UP PoI. The average overlap for all combinations was 77.5%, slightly higher than for Cardiff primary schools.

With none of the comparisons achieving a destination overlap of 100%, the indications are that, according to this single measure, no two of the chosen datasets could be considered directly equivalent for the purposes of consistently identifying a nearest destination feature. For the same features and datasets in the Vale, however, the highest possible destination overlap of 100% was achieved, between ITN measured to perimeter and Open Roads measured to perimeter. The same combination of datasets achieved the highest destination overlap figure for Cardiff primary schools, indicating that the high overlap may not be feature dependent. The lowest overlap was 78.4%, measured using Euclidean distances to school centroids versus OSM perimeters. The lowest comparison using network distance was 80.6%, with two combinations having the same figure: OSM perimeter versus UP centroid; and OSM centroids versus Open Roads perimeter. The average destination overlap was 87.5%, considerably higher than the figure for Cardiff secondary schools, and slightly higher than those for Vale primary schools. Comparison to the other three types of destination feature will be made in subsequent sections.

Eucl	**Eucl**																		
Cen	Cent																		
Acc	.995	Acc																	
Per	.980	.975	Per																
PoI	.979	.968	.976	PoI															
ITN					**ITN**														
Cen	.850	.862	.843	.827	Cen														
Acc	.866	.868	.860	.848	.966	Acc													
Per	.936	.924	.939	.922	.913	.955	Per												
PoI	.881	.895	.876	.897	.932	.932	.939	PoI											
UP									**UP**										
Cen	.944	.951	.938	.927	.931	.910	.936	.919	Cen										
Acc	.948	.958	.944	.939	.907	.917	.935	.922	.979	Acc									
Per	.965	.955	.965	.950	.896	.897	.952	.913	.971	.978	Per								
PoI	.934	.947	.929	.955	.881	.884	.925	.947	.961	.971	.963	PoI							
OSM													**OS**						
Cen	.820	.822	.809	.794	.934	.887	.873	.888	.881	.858	.862	.839	Cen						
Acc	.810	.847	.806	.792	.921	.892	.869	.909	.866	.871	.860	.855	.896	Acc					
Per	.804	.806	.809	.796	.810	.837	.858	.841	.823	.842	.823	.808	.781	.810	Per				
PoI	.853	.861	.846	.875	.866	.880	.907	.951	.878	.882	.873	.910	.860	.861	.870	PoI			
OR																	**OR**		
Cen	.851	.860	.848	.840	.988	.932	.912	.942	.922	.904	.896	.891	.921	.914	.800	.873	Cen		
Acc	.887	.896	.885	.875	.958	.970	.947	.967	.930	.943	.924	.916	.911	.926	.872	.915	.958	Acc	
Per	.936	.924	.939	.921	.908	.918	.998	.936	.932	.932	.950	.921	.867	.869	.857	.904	.910	.946	Per
PoI	.879	.982	.874	.894	.937	.936	.936	.995	.920	.923	.913	.943	.894	.905	.844	.948	.950	.973	.934

Table 4.20: Correlations of distance results for Cardiff secondary schools.
(Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

Key: Overall high ; Overall low ; Network high (if reqd) ; Network low (if reqd) .

NB. If overall high or low involves network comparisons, then separate network high or low will not be required.

Eucl	**Eucl**																		
Cen	Cent																		
Acc	.955	Acc																	
Per	.997	.961	Per																
PoI	.971	.993	.972	PoI															
ITN					**ITN**														
Cen	.856	.892	.857	.895	Cen														
Acc	.822	.916	.831	.896	.910	Acc													
Per	.946	.933	.954	.939	.908	.882	Per												
PoI	.819	.909	.826	.894	.916	.992	.875	PoI											
UP									**UP**										
Cen	.916	.924	.916	.934	.967	.880	.924	.887	Cen										
Acc	.898	.959	.906	.943	.889	.967	.904	.960	.909	Acc									
Per	.948	.978	.955	.976	.908	.920	.953	.913	.944	.954	Per								
PoI	.895	.947	.901	.940	.894	.954	.899	.962	.922	.988	.944	PoI							
OSM													**OS**						
Cen	.845	.894	.846	.894	.967	.916	.888	.923	.948	.892	.921	.898	Cen						
Acc	.809	.899	.816	.886	.896	.984	.862	.992	.866	.953	.903	.953	.907	Acc					
Per	.835	.890	.836	.890	.945	.925	.883	.918	.912	.897	.907	.883	.957	.911	Per				
PoI	.802	.890	.809	.879	.898	.978	.860	.990	.871	.944	.898	.952	.913	.990	.907	PoI			
OR																	**OR**		
Cen	.863	.901	.864	.904	.990	.901	.917	.908	.964	.889	.916	.893	.959	.886	.934	.890	Cen		
Acc	.836	.929	.845	.910	.902	.988	.894	.980	.881	.963	.932	.949	.909	.972	.921	.967	.909	Acc	
Per	.901	.948	.909	.944	.933	.944	.961	.935	.929	.930	.975	.920	.940	.923	.934	.923	.942	.956	Per
PoI	.832	.921	.839	.907	.909	.980	.885	.988	.886	.957	.924	.957	.916	.979	.914	.979	.917	.992	.947

Table 4.21: Correlations of distance results for Vale secondary schools.
(Using Spearman’s Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

Key: Overall high ; Overall low ; Network high (if reqd) ; Network low (if reqd) .

NB. If overall high or low involves network comparisons, then separate network high or low will not be required.

	Euclidean				ITN				UP				OSM				OR			
	Cent	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI
Eucl																				
Cent		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-6.195		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Per	-28.428	-27.160		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
PoI	-3.779	-9.277	-27.742		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
ITN																				
Cent	-28.356	-28.319	-28.428	-27.734		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	.173	< .001	< .001	< .001
Acc	-27.210	-27.427	-28.424	-26.415	-18.836		< .001	< .001	.781	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Per	-21.776	-21.456	-28.295	-19.416	-28.342	-25.851		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
PoI	-28.280	-28.398	-28.427	-28.390	-10.691	-22.941	-28.428		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
UP																				
Cent	-28.322	-28.245	-28.428	-27.395	-19.400	- .278	-20.808	-20.989		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	.004	< .001	< .001
Acc	-25.988	-26.245	-28.423	-24.430	-25.608	-22.045	-9.007	-27.471	-22.971		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Per	-19.759	-19.851	-28.359	-16.513	-28.357	-27.513	-12.975	-28.329	-28.430	-22.636		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
PoI	-28.214	-28.369	-28.428	-28.384	-5.040	-7.739	-22.777	-23.126	-9.554	-25.637	-28.428		< .001	< .001	.371	< .001	< .001	< .001	< .001	< .001
OSM																				
Cent	-27.994	-27.798	-28.195	-27.415	-5.073	-16.922	-27.626	-4.961	-17.634	-24.265	-27.939	-7.596		< .001	< .001	-1.850	.136	< .001	< .001	.001
Acc	-27.638	-28.140	-28.187	-27.196	-5.916	-15.283	-26.104	-13.545	-11.256	-25.036	-27.432	-2.763	-9.813		< .001	< .001	< .001	< .001	< .001	< .001
Per	-27.661	-27.542	-28.180	-26.870	-5.529	-6.583	-26.030	-11.929	-6.429	-18.740	-26.199	- .895	-8.802	-4.584		< .001	< .001	< .001	< .001	< .001
PoI	-27.844	-27.968	-28.194	-28.032	-6.806	-17.209	-27.193	-7.242	-15.293	-24.286	-26.495	-11.640	-1.850	-8.405	-8.525		< .001	< .001	< .001	.448
OR																				
Cent	-28.340	-28.310	-28.428	-28.115	-1.364	-20.876	-28.017	-7.940	-18.187	-26.042	-28.154	-8.195	-1.492	-9.097	-7.620	-3.596		< .001	< .001	< .001
Acc	-26.939	-27.334	-28.419	-26.040	-21.951	-5.772	-24.367	-25.170	-2.849	-19.253	-26.727	-9.977	-20.016	-18.438	-9.040	-19.531	-23.939		< .001	< .001
Per	-21.481	-21.287	-28.244	-19.178	-28.385	-25.369	-3.978	-28.395	-21.016	-9.196	-11.507	-22.874	-27.421	-26.236	-26.177	-27.262	-28.425	-25.122		< .001
PoI	-28.281	-28.407	-28.428	-28.393	-8.340	-22.054	-28.195	-10.871	-19.512	-27.278	-28.311	-15.874	-3.281	-12.084	-10.315	- .759	-6.878	-25.442	-28.413	

Table 4.22: Differences between distance results for Cardiff secondary schools. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001 level; green = significant at 1% level; red = not significant at 5% level).

	Euclidean				ITN				UP				OSM				OR			
	Cent	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI
Eucl																				
Cent		< .001	< .001	.052	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-5.882		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Per	-17.589	-17.589		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
PoI	-1.944	-10.244	-17.277		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
ITN																				
Cent	-17.551	-17.558	-17.588	-17.549		< .001	< .001	< .001	< .001	< .001	< .001	< .001	.715	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-16.532	-17.583	-17.589	-17.104	-10.156		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	.062	< .001	< .001	< .001	< .001	< .001
Per	-13.046	-13.822	-17.488	-12.294	-17.591	-17.570		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
PoI	-17.384	-17.587	-17.588	-17.572	-6.881	-16.892	-17.558		.034	< .001	< .001	< .001	.001	< .001	< .001	.038	< .001	< .001	< .001	< .001
UP																				
Cent	-17.553	-17.550	-17.589	-17.542	-14.638	-4.147	-16.141	-2.122		< .001	< .001	< .001	< .001	.467	< .001	< .001	< .001	< .001	< .001	.126
Acc	-15.962	-17.589	-17.589	-16.816	-14.512	-12.893	-10.395	-17.151	-12.275		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Per	-10.398	-14.062	-17.510	-11.072	-17.589	-17.550	-8.093	-17.555	-17.589	-17.591		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
PoI	-17.287	-17.589	-17.589	-17.580	-12.172	-2.165	-14.573	-13.502	-6.882	-16.983	-17.577		< .001	.001	.976	< .001	< .001	.007	< .001	< .001
OSM																				
Cent	-17.498	-17.524	-17.588	-17.481	- .365	-8.690	-17.435	-3.225	-9.601	-13.120	-17.570	-9.729		< .001	< .001	.195	.170	< .001	< .001	< .001
Acc	-17.180	-17.583	-17.589	-17.439	-7.937	-5.613	-16.907	-9.979	- .727	-13.096	-17.515	-3.206	-5.014		< .001	< .001	< .001	< .001	< .001	< .001
Per	-16.519	-17.075	-17.587	-16.812	-11.246	-1.864	-12.540	-7.721	-4.923	-5.901	-15.410	- .030	-12.074	-5.182		< .001	< .001	.146	< .001	< .001
PoI	-17.453	-17.588	-17.589	-17.579	-4.714	-13.309	-17.328	-2.075	-3.566	-15.890	-17.522	-10.751	-1.295	-12.530	-8.260		< .001	< .001	< .001	.001
OR																				
Cent	-17.546	-17.557	-17.588	-17.544	-8.334	-9.460	-17.506	-5.568	-12.179	-14.029	-17.482	-11.434	-1.371	-7.122	-10.494	-3.802		< .001	< .001	< .001
Acc	-16.452	-17.582	-17.589	-17.071	-10.529	-5.711	-16.715	-16.961	-4.776	-11.532	-17.201	-2.675	-9.042	-6.411	-1.455	-13.650	-10.191		< .001	< .001
Per	-13.195	-15.411	-17.471	-13.750	-17.589	-17.523	-2.167	-17.548	-14.475	-8.250	-10.496	-13.145	-17.442	-16.929	-12.615	-17.344	-17.589	-17.571		< .001
PoI	-17.343	-17.586	-17.588	-17.572	-6.886	-15.264	-17.258	-5.030	-1.532	-16.358	-17.437	-11.606	-3.826	-9.134	-7.283	-3.272	-6.145	-16.918	-17.528	

Table 4.23: Differences between distance results for Vale secondary schools. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001 level; green = significant at 1% level; amber = significant at 5% level; red = not significant at 5% level).

Eucl	**Eucl**																		
Cen	Cent																		
Acc	.999	Acc																	
Per	.989	.989	Per																
PoI	.994	.994	.992	PoI															
ITN					**ITN**														
Cen	.290	.288	.222	.276	Cen														
Acc	.273	.272	.207	.258	.929	Acc													
Per	.343	.342	.302	.338	.853	.832	Per												
PoI	.246	.244	.209	.265	.766	.787	.690	PoI											
UP									**UP**										
Cen	.240	.239	.173	.227	.913	.913	.776	.759	Cen										
Acc	.215	.214	.152	.203	.839	.891	.750	.745	.916	Acc									
Per	.351	.348	.345	.354	.631	.582	.803	.480	.585	.540	Per								
PoI	.172	.172	.140	.193	.645	.690	.570	.886	.756	.798	.418	PoI							
OSM													**OSM**						
Cen	.268	.267	.201	.254	.930	.931	.797	.751	.932	.858	.588	.676	Cen						
Acc	.248	.248	.182	.234	.891	.949	.788	.745	.898	.899	.548	.692	.936	Acc					
Per	.333	.331	.291	.327	.849	.827	.977	.676	.774	.751	.800	.565	.813	.806	Per				
PoI	.229	.228	.187	.245	.753	.763	.636	.913	.793	.737	.447	.841	.819	.789	.645	PoI			
OR																	**OR**		
Cen	.275	.274	.207	.262	.979	.941	.838	.785	.927	.856	.615	.667	.940	.902	.833	.766	Cen		
Acc	.273	.272	.209	.260	.932	.985	.841	.803	.911	.892	.596	.703	.926	.935	.836	.764	.948	Acc	
Per	.379	.377	.367	.376	.674	.627	.840	.486	.598	.550	.965	.394	.627	.589	.835	.457	.660	.639	Per
PoI	.246	.245	.212	.266	.760	.773	.680	.972	.749	.736	.493	.892	.738	.727	.669	.879	.783	.795	.494

Table 4.24: Correlations of 2SFCA results for Cardiff secondary schools.
(Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

Key: Overall high ; Overall low ; Network high (if reqd) ; Network low (if reqd) .

NB. If overall high or low involves network comparisons, then separate network high or low will not be required.

Eucl	**Eucl**																		
Cen	Cent																		
Acc	.996	Acc																	
Per	.908	.912	Per																
PoI	.993	.995	.908	PoI															
ITN					**ITN**														
Cen	.462	.469	.221	.488	Cen														
Acc	.489	.495	.252	.516	.966	Acc													
Per	.218	.229	.164	.250	.670	.686	Per												
PoI	.406	.413	.188	.446	.944	.949	.696	PoI											
UP									**UP**										
Cen	.478	.486	.246	.504	.948	.941	.651	.908	Cen										
Acc	.483	.492	.261	.510	.928	.944	.671	.905	.977	Acc									
Per	.127	.140	.133	.158	.529	.532	.900	.564	.569	.601	Per								
PoI	.386	.395	.181	.428	.891	.904	.678	.945	.928	.937	.606	PoI							
OSM													**OSM**						
Cen	.396	.403	.187	.417	.915	.906	.691	.881	.897	.883	.573	.851	Cen						
Acc	.439	.447	.211	.463	.958	.954	.677	.916	.932	.914	.552	.876	.939	Acc					
Per	.149	.160	.069	.166	.634	.620	.755	.599	.633	.623	.707	.575	.744	.682	Per				
PoI	.334	.341	.130	.374	.899	.903	.692	.949	.863	.859	.573	.915	.920	.918	.653	PoI			
OR																	**OR**		
Cen	.461	.469	.221	.484	.976	.943	.643	.909	.962	.941	.539	.885	.893	.939	.633	.862	Cen		
Acc	.476	.481	.237	.503	.948	.980	.661	.931	.950	.951	.531	.908	.884	.932	.609	.884	.958	Acc	
Per	.147	.158	.089	.174	.692	.669	.891	.689	.706	.702	.855	.688	.722	.708	.823	.692	.717	.686	Per
PoI	.392	.398	.171	.432	.930	.934	.673	.981	.920	.914	.563	.954	.865	.901	.590	.935	.928	.948	.706

Table 4.25: Correlations of 2SFCA results for Vale secondary schools.
(Using Spearman's Rank Correlation Coefficients; black = significant at the 0.01 level; red = not significant at the 5% level).

Key: Overall high ; Overall low ; Network high (if reqd) ; Network low (if reqd) .

NB. Lowest correlations are found in the results highlighted in red (not significant at 5%).

	Euclidean				ITN				UP				OSM				OR			
	Cent	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI
Eucl																				
Cent		.009	< .001	< .001	< .001	< .001	< .001	.262	< .001	< .001	< .001	.872	< .001	< .001	< .001	.550	< .001	< .001	< .001	.163
Acc	-2.605		< .001	.011	< .001	< .001	< .001	.288	< .001	< .001	< .001	.911	< .001	< .001	< .001	.577	< .001	< .001	< .001	.180
Per	-20.863	-20.832		< .001	< .001	< .001	< .001	.120	< .001	< .001	< .001	.018	< .001	< .001	< .001	.049	.306	.213	< .001	.210
PoI	-4.328	-2.528	-25.135		< .001	< .001	< .001	.199	< .001	< .001	< .001	.727	< .001	< .001	< .001	.435	< .001	< .001	< .001	.114
ITN																				
Cent	-28.335	-28.336	-28.296	-28.341		.001	< .001	< .001	< .001	.008	< .001	< .001	.003	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-28.366	-28.366	-28.347	-28.382	-3.272		< .001	< .001	< .001	< .001	< .001	< .001	.026	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Per	-28.407	-28.406	-28.405	-28.416	-11.930	-10.846		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
PoI	-1.121	-1.063	-1.557	-1.284	-28.429	-28.428	-28.429		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	.011	< .001	< .001	< .001
UP																				
Cent	-28.371	-28.371	-28.352	-28.388	-5.628	-3.866	-16.461	-28.428		.002	< .001	< .001	.004	.003	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-28.393	-28.392	-28.382	-28.404	-2.671	-5.314	-15.718	-28.428	-3.054		< .001	< .001	.437	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Per	-28.424	-28.424	-28.424	-28.424	-12.568	-11.515	-5.609	-28.428	-16.724	-15.867		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
PoI	- .161	- .112	-2.375	- .349	-28.428	-28.428	-28.429	-5.608	-28.429	-28.429	-28.428		< .001	< .001	< .001	.066	.977	.280	< .001	< .001
OSM																				
Cent	-28.367	-28.367	-28.348	-28.384	-2.929	-2.224	-9.468	-28.427	-2.841	- .777	-10.873	-28.428		.104	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-28.359	-28.360	-28.341	-28.379	-7.557	-10.001	-8.656	-28.427	-2.964	-4.650	-10.346	-28.428	-1.628		< .001	< .001	< .001	< .001	< .001	< .001
Per	-28.406	-28.406	-28.405	-28.416	-12.276	-10.887	-7.355	-28.429	-16.410	-15.768	-5.931	-28.428	-10.059	-8.288		< .001	< .001	< .001	< .001	< .001
PoI	- .597	- .557	-1.966	- .781	-28.428	-28.428	-28.428	-5.434	-28.427	-28.425	-28.427	-1.836	-28.428	-28.428	-28.429		< .001	< .001	< .001	.002
OR																				
Cent	-3.698	-3.652	-1.023	-3.886	-28.429	-28.428	-28.428	-2.539	-28.428	-28.428	-28.428	- .029	-28.427	-28.428	-28.429	-6.078		.974	< .001	.007
Acc	-3.860	-3.809	-1.246	-4.066	-28.429	-28.429	-28.429	-3.939	-28.428	-28.428	-28.428	-1.080	-28.428	-28.429	-28.429	-4.360	- .032		< .001	.124
Per	-10.949	-10.859	-7.509	-11.101	-28.413	-28.422	-28.429	-16.222	-28.428	-28.428	-28.428	-16.837	-28.424	-28.427	-28.429	-15.095	-14.155	-13.647		< .001
PoI	-1.396	-1.339	-1.253	-1.579	-28.429	-28.428	-28.429	-3.758	-28.428	-28.428	-28.428	-7.038	-28.427	-28.427	-28.429	-3.049	-2.680	-1.536	-13.689	

Table 4.26: Differences between 2SFCA results for Cardiff secondary schools. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001; green = significant at 1%; amber = significant at 5%; red = not significant at 5%).

	Euclidean				ITN				UP				OSM				OR			
	Cent	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI	Cen	Acc	Per	PoI
Eucl																				
Cent		.148	< .001	.081	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-1.445		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Per	-13.084	-12.683		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
PoI	-1.747	-3.396	-13.476		< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
ITN																				
Cent	-13.358	-13.342	-11.001	-13.499		.874	< .001	< .001	< .001	.020	< .001	< .001	.452	.167	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-13.331	-13.292	-10.872	-13.470	- .159		< .001	< .001	.154	< .001	< .001	< .001	.041	.974	< .001	< .001	< .001	< .001	< .001	< .001
Per	-15.158	-15.140	-14.682	-15.331	-9.272	-7.610		< .001	< .001	< .001	< .001	< .001	< .001	< .001	.935	< .001	< .001	< .001	< .001	< .001
PoI	-16.645	-16.648	-16.970	-16.671	-17.600	-17.603	-17.598		< .001	< .001	< .001	.015	< .001	< .001	< .001	.101	< .001	< .001	< .001	< .001
UP																				
Cent	-13.564	-13.529	-11.134	-13.702	-4.202	-1.426	-8.613	-17.595		.009	< .001	< .001	.070	.138	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-13.189	-13.130	-11.082	-13.334	-2.333	-3.615	-9.355	-17.595	-2.611		< .001	< .001	.003	.960	< .001	< .001	< .001	< .001	< .001	< .001
Per	-15.083	-15.063	-14.656	-15.260	-8.004	-7.659	-3.871	-17.595	-10.661	-12.052		< .001	< .001	< .001	.581	< .001	< .001	< .001	< .001	< .001
PoI	-16.787	-16.772	-17.005	-16.812	-17.597	-17.597	-17.596	-2.438	-17.597	-17.598	-17.597		< .001	< .001	< .001	.850	.863	.414	< .001	.001
OSM																				
Cent	-13.131	-13.083	-11.097	-13.226	- .752	-2.046	-8.272	-17.602	-1.814	-2.955	-6.980	-17.597		.027	< .001	< .001	< .001	< .001	< .001	< .001
Acc	-13.252	-13.207	-11.040	-13.405	-1.383	- .033	-8.786	-17.599	-1.481	- .050	-7.871	-17.596	-2.213		< .001	< .001	< .001	< .001	< .001	< .001
Per	-15.126	-15.111	-14.690	-15.278	-10.387	-9.698	- .082	-17.601	-10.225	-11.140	- .551	-17.597	-12.051	-11.169		< .001	< .001	.005	< .001	< .001
PoI	-16.674	-16.639	-16.876	-16.659	-17.597	-17.599	-17.600	-1.641	-17.594	-17.594	-17.595	- .189	-17.602	-17.602	-17.601		.565	< .001	< .001	.009
OR																				
Cent	-16.690	-16.695	-16.918	-16.720	-17.581	-17.580	-17.556	-3.647	-17.596	-17.596	-17.595	- .172	-17.558	-17.556	-17.558	- .575		.271	< .001	.258
Acc	-16.707	-16.706	-16.940	-16.729	-17.599	-17.604	-17.578	-10.320	-17.595	-17.596	-17.595	- .816	-17.582	-17.579	-17.582	-2.803	-1.100		< .001	< .001
Per	-15.848	-15.827	-16.635	-15.819	-16.575	-16.734	-17.589	-11.333	-16.912	-17.183	-17.600	-10.402	-16.440	-16.606	-17.587	-11.225	-11.440	-9.622		< .001
PoI	-16.642	-16.645	-16.966	-16.667	-17.599	-17.602	-17.598	-10.499	-17.595	-17.595	-17.595	-3.193	-17.601	-17.599	-17.601	-2.595	-1.132	-6.260	-11.102	

Table 4.27: Differences between 2SFCA results for Vale secondary schools. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001; green = significant at 1%; amber = significant at 5%; red = not significant at 5%)

Eucl	**Eucl**																		
Cent	Cen																		
Acc	86.9	Acc																	
Per	84.9	92.7	Per																
PoI	71.7	72.1	71.6	PoI															
ITN					**ITN**														
Cent	82.0	76.6	74.8	64.9	Cen														
Acc	76.5	81.2	76.0	64.3	92.9	Acc													
Per	72.8	73.0	75.5	60.6	92.5	88.2	Per												
PoI	60.4	62.2	60.9	81.4	69.5	69.1	71.1	PoI											
UP									**UP**										
Cent	89.2	87.7	87.5	66.5	90.0	85.7	83.2	63.1	Cen										
Acc	88.6	87.9	88.0	68.2	89.3	89.1	85.5	65.7	93.7	Acc									
Per	89.0	86.5	90.2	66.9	89.0	86.4	85.1	64.2	91.6	93.2	Per								
PoI	64.9	66.3	64.5	88.2	66.8	66.8	65.7	91.1	66.4	69.2	67.3	PoI							
OSM													**OSM**						
Cent	71.1	80.3	80.1	60.2	88.8	85.0	84.8	63.6	84.2	84.0	84.8	61.8	Cen						
Acc	81.1	76.2	74.5	63.1	90.1	96.9	85.7	68.3	81.5	84.9	82.2	66.1	74.9	Acc					
Per	74.9	79.6	81.3	61.7	82.0	80.7	80.6	62.9	75.7	74.7	77.2	61.7	82.0	80.9	Per				
PoI	61.2	62.5	61.9	82.1	68.1	67.4	63.0	89.9	63.1	65.4	63.5	85.1	62.9	67.6	68.4	PoI			
OR																	**OR**		
Cent	82.7	82.1	83.2	65.8	94.2	88.6	86.9	71.0	81.2	86.9	87.3	68.8	84.4	86.6	79.2	69.6	Cen		
Acc	83.0	83.1	82.7	64.3	92.4	93.2	92.9	72.7	81.9	90.8	87.7	69.7	85.1	90.7	82.1	66.6	89.5	Acc	
Per	87.5	85.6	88.1	67.5	91.5	87.5	86.4	64.2	83.3	90.4	91.9	65.8	85.2	86.6	79.3	65.6	89.0	88.6	Per
PoI	61.4	62.7	62.0	82.4	70.2	69.8	70.8	98.5	63.9	66.7	65.2	91.2	63.2	69.1	63.7	89.1	72.0	73.6	65.3

Table 4.28: Destination overlaps (%) for Cardiff secondary schools.

Key: Overall high ; Overall low ; Network high (if reqd) ; Network low (if reqd) .

NB. If overall high or low involves network comparisons, then separate network high or low will not be required.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	87.6	Acc																	
Per	96.6	86.2	Per																
PoI	97.6	87.6	96.1	PoI															
ITN					**ITN**														
Cent	83.3	80.8	80.6	82.0	Cen														
Acc	84.5	87.9	83.3	82.8	84.0	Acc													
Per	93.2	83.0	92.7	93.0	84.0	87.4	Per												
PoI	85.0	88.3	82.3	84.2	86.7	90.0	83.7	PoI											
UP									**UP**										
Cent	86.4	84.0	83.7	85.2	94.9	87.4	86.9	86.7	Cen										
Acc	89.6	92.0	87.4	87.9	87.9	93.2	87.9	92.5	90.3	Acc									
Per	94.7	83.0	93.2	93.4	84.0	86.6	97.1	83.7	87.9	89.1	Per								
PoI	87.1	88.6	84.5	85.9	89.8	90.3	86.4	95.9	90.3	95.6	87.4	PoI							
OSM													**OSM**						
Cent	81.6	85.7	93.5	79.9	93.5	84.0	83.3	85.0	90.0	87.1	85.0	85.2	Cen						
Acc	78.6	89.3	82.8	84.2	81.1	97.6	86.7	90.5	82.8	93.7	86.4	90.8	80.8	Acc					
Per	78.4	85.0	92.2	92.7	84.0	87.6	96.4	81.3	80.6	86.7	94.4	84.0	80.7	87.4	Per				
PoI	85.7	89.1	84.0	86.9	87.4	88.1	84.5	95.6	87.6	91.3	84.5	93.9	86.2	89.1	82.5	PoI			
OR																	**OR**		
Cent	83.3	80.8	80.6	82.0	99.3	84.2	84.2	85.9	95.1	87.1	84.2	89.1	93.4	84.0	83.3	86.9	Cen		
Acc	85.0	88.4	82.5	83.3	83.5	96.1	86.9	93.0	86.9	92.7	86.2	89.8	83.0	94.7	85.2	90.5	83.7	Acc	
Per	93.2	83.0	92.7	93.0	84.0	87.4	100	83.7	86.9	87.9	97.1	86.4	80.6	87.6	96.4	84.5	84.2	86.9	Per
PoI	85.2	88.1	82.5	84.0	86.9	90.3	83.5	99.8	86.9	81.1	84.0	96.1	85.2	90.8	81.1	95.4	86.2	93.2	83.5

Table 4.29: Destination overlaps (%) for Vale of Glamorgan secondary schools.

Key: Overall high ; Overall low ; Network high (if reqd) ; Network low (if reqd) .

NB. If overall high or low involves network comparisons, then separate network high or low will not be required.

As with primary schools (see Table 4.19), when average destination overlaps were calculated for all location methods the results were as per Table 4.30. With secondary schools, the destination overlaps using the OSM network were markedly lower than those using the other networks in both Cardiff and the Vale, which did not mirror the results for primary schools. In some respects, a simpler network would return higher levels of overlap, perhaps indicating that OSM has the most complex network, but UP (the most detailed OS network used in this instance) returns figures close to the highest of all networks. Even Euclidean distances (the simplest, most straightforward of all the networks) only had 80% overlaps for Cardiff, despite having the highest percentage for the Vale and for primary schools in both areas.

	Euc	ITN	UP	OR	OSM
Cardiff	80.0	80.6	80.2	79.7	72.8
Vale	92.0	86.0	90.1	86.3	84.5

Table 4.30: Destination overlaps for secondary schools (averaging the results of the four location methods, calculated using stated network).

In the case of the Vale (and to a lesser extent, Cardiff) secondary schools were located on the periphery of densely populated areas and one would assume gave few opportunities for small changes in location or network distance to result in an alternative destination becoming closer. However, the schools were assessed by the NN measure (detailed in Table 4.4) as being in a 'dispersed' pattern, again suggesting fewer opportunities for alternative destinations. This will be tested when other features are compared which were also assessed as dispersed (sports centres) or assessed as clustered (GP surgeries). At this point it can be asserted that, in general, the use of different datasets do tend to identify a substantial number of different destinations in the context of assessing accessibility through proximity as outlined in Sections 4.3.1 and 4.3.2, but that some specific combinations achieved a 100% match in destinations (as in the use of ITN and Open Roads in identifying the boundary of the nearest secondary school).

4.3.3 GP surgeries, sports centres and community hubs

Considering GP surgeries gave an opportunity to look at results from a feature whose numbers were the median of the five features under consideration. As GP surgeries were not included as a feature of the OS Sites dataset they were represented by point locations only (not polygons); no analysis was conducted using centroids, access points or perimeters. As no comparisons were made with respect to how this supply-side feature was represented, the reporting of correlation, differences and destination overlap aspects of this feature are made in the Network Comparisons section, 4.5. Although the distribution and location of the supply-side features may have some influence on results, the main differences will be caused by the use of the different networks.

The same situation as GP surgeries applies to sports centres as a supply-side feature in that they are not included in the Sites dataset and are therefore represented only by points, in this case using OS Points of Interest, therefore all results for sports centres are reported in section 4.5, Network Comparisons. In summary, sports centres were assessed as distributed randomly in Cardiff and dispersed in the Vale (as per Table 4.4), the only feature to be assessed as such in Cardiff. As with GP surgeries, Cardiff had (approximately) three times as many sports centres as the Vale.

The final category of features to be examined was community hubs. The presentation of results will use the approach adopted for the other four features. As with GP surgeries and sports centres, community hubs were not included in the OS Sites dataset and were only represented by point locations, in this case taken from OS Points of Interest dataset. Community hubs were the second most numerous features to be examined, and in both Cardiff and Vale were assessed as 'clustered,' the only feature in the Vale to be classified clearly as such. All results from community hub analysis will be affected solely by network issues, therefore the results are reported in section 4.5, Network Comparisons.

In summarising this section so far, it is apparent that different features will return different absolute accessibility figures. The aim of this thesis was to quantify how OS datasets perform at representing different sets of features in distance and/or FCA-type models and how the performance differs from dataset to dataset, with a view to assessing how useful the datasets may be in these particular contexts. This was considered primarily by looking at whether there were indications of similarity or difference in the patterns of those results. For example, did some features have similarities with others, or was there a scaling-up or scaling-down factor that could be applied to some or other features that may be used to predict their particular accessibility? This will be addressed by comparing different features' results, and then looking at whether there were significant similarities or differences between the results. For example, a high correlation and lack of significant difference would indicate a degree of similarity between datasets, which may in turn inform decisions on which dataset to use in which circumstances, or inform users of the potential choices available.

4.3.4 Demand-side using OS Address products

Alternative sources of supply-side data were explored, as detailed in Chapter 3, and as one of the potential alternative datasets had specific issues with schools it will be discussed here. OS Address Layer 2 was found not to possess sufficient information to locate the various features under examination here, but AddressBase Premium, with its detailed classification scheme, was used to compare to results of accessibility to secondary schools to the Sites and Points of Interest datasets. With the relatively low numbers of secondary schools, some discrepancies were immediately apparent, the most obvious being the greater number of schools mapped with ABP. Despite there being different classifications for state and non-state secondary schools (CE04SS and CE04NS, respectively) the NS suffix was not used at all in Cardiff or the Vale (though subsequent checks found NS used elsewhere in the wider South Wales area, but not in the Cardiff or Vale study areas nor within an 8km buffer around both areas. Several private, fee-paying schools were included in the ABP selection, thus not matching the selections from Points of Interest, and omitting a level of precision implied from the classification scheme. Although ABP was capable of identifying schools, and other supply-features, the complexity of the data and the inconsistencies considerably reduced its usability in terms of Efficiency (particularly convenience and speed of access) but particularly in terms of Satisfaction (particularly quality and consistency), despite the dataset's high Effectiveness.

Table 4.31 illustrates the effect of the inclusion and/or exclusion of private schools on one type of analysis conducted for this thesis, using destination overlaps for comparison. The table shows the destination overlaps found using OAs as the demand point and ABP to locate the supply points. The Open Roads accessibility exercise was repeated, once with private schools omitted (that is, only using the schools identified by the WAG as state secondary schools) and once with ABP as supplied, including four private schools. There is a considerable difference in destination overlap results due to the differences between datasets showing, at face value, the same features and highlighting the need for standardisation and consistency in terms of completion of attributes.

	Euclidean	**ITN**	**UP**	**OSM**
Open Rds (no private schools)	80.1	98.8	89.7	89.0
Open Rds (with private schools)	58.0	68.1	63.4	61.3

Table 4.31: Effect of including private schools on destination overlaps (%) for Cardiff secondary schools when using AddressBase Premium to locate supply-side features.

A comparison between ABP and the Sites dataset for secondary schools resulted in the outcomes in Table 4.32. The results do not show the high levels found with other combinations, the high in this case being 87.1% comparing centroids mapped from Sites measured by Euclidean distances to those mapped from the ABP data. Using networks, the highest figure was the 86.4% between Sites access points and ABP locations, both using ITN with Urban Paths. The lowest figure was for boundary points in Sites compared to ABP points, both using OSM.

Located using Address Base	Located using OS Sites														
	Euclidean			ITN			ITN_UP			OSM			OpenRoads		
Eucl	87.1	**77.2**	*85.7*	71.8	**73.8**	*83.3*	75.0	**78.2**	*83.3*	69.7	**74.8**	*83.3*	71.8	**73.8**	*83.3*
ITN	77.2	**80.6**	*74.8*	79.4	**83.7**	*76.5*	79.4	**85.2**	*76.5*	76.5	**83.7**	*74.5*	78.6	**84.0**	*76.5*
UP	78.9	**80.3**	*76.5*	80.6	**82.0**	*77.2*	81.1	**86.4**	*78.2*	77.7	**82.0**	*75.2*	79.9	**82.3**	*77.2*
OSM	78.4	**81.8**	*76.9*	81.1	**81.8**	*78.2*	81.3	**85.0**	*78.2*	78.2	**82.8**	*76.2*	80.6	**82.5**	*78.2*
OR	77.7	**80.6**	*75.2*	79.9	**84.2**	*76.5*	79.9	**85.7**	*76.9*	76.9	**84.2**	*74.5*	79.1	**84.5**	*76.5*

Table 4.32: Comparison of AddressBase Premium and Sites destination overlaps for Vale secondary schools. Plain text = centroid; **Bold** = nearest access point; *Italic* = nearest boundary point.

4.3.5 Summary of supply-side comparisons

In order to help identify differences (or, more accurately, the lack thereof) Table 4.33 aggregates all Wilcoxon results by supply-side location method, within which there was considerable variation in the differences recorded. If lack of statistical difference was considered as a proxy of similarity, then the comparisons of centroids to Point of Interest points were the most similar, closely followed by the combination of centroids to access points. The comparisons of centroids to perimeters were those with the greatest amount of statistically significant differences, by some margin. This may indicate that although the generalisation of polygonal features to be represented by centroids is an accepted part of geographical analysis, any assumption that (particularly large) features can be so generalised without affecting accessibility assessments may be erroneous.

	Centroid			Access Point			Perimeter			Points of Interest		
Sig level	>5%	5%	1%	>5%	5%	1%	>5%	5%	1%	>5%	5%	1%
Centroid	12	2	2									
Access Point	19	6	7	7	4	-						
Perimeter	1	-	4	4	-	2	7	-	1			
PoI	21	5	7	9	2	2	9	2	-	14	3	3

Table 4.33: Comparing networks and occurrences of less-significant and non-significant differences across all (1560) Wilcoxon tests involving schools.

Although stating what combination was 'most similar' it should be emphasised that even the highest numbers in Table 4.33 were but a small proportion of the overall number of tests conducted (as was seen in the Tables showing all the permutations of paired comparisons: Tables 4.11, 12, 15, 16, 22, 23, 26 and 27, from which the summarised figures in Table 4.33 have been taken). In every case, the vast majority of results indicated there were statistically-significant differences between the sets of distance and 2SFCA accessibility results.

4.4 Demand-side comparisons

As was shown in Table 4.3 there were several alternative demand points used in these studies, however the main focus was on using UK census population-weighted output area centroids (OAs) as the representation of points of origin in such models. One issue encountered when assessing nearest distance and 2SFCA accessibility was that OA polygons and OA population-weighted centroids were supplied in separate datasets, with a mismatch between how the centroids were ordered in their particular dataset compared to how the polygons were ordered in the other when loaded into ArcGIS. It was simple to assume they did match and therefore use the GIS FID (FID is the ArcGIS Shapefile Feature ID automatically generated at the creation of a Shapefile) reference to match output from one directly to the other, which would be incorrect. Fortunately both sets of data also carried a unique census reference, common to the polygons and their points, therefore care was taken to use this reference and Join any resultant data in ArcGIS rather than use the results in the order they were output. This added a further step, specifically in the mapping of results. A factor that added uncertainty to the accessibility calculations was that some Arc tools had the ability to add identifying fields that were then recorded as part of the output (as with OD-matrix outputs), and some did not (Generate Near Table, for example), even though some of the tools undertook very similar processes.

4.4.1 Demand-side using Code-Point

As was set out in Chapter 3, not all accessibility exercises were carried out using all the alternative demand-side sources due to the finite time available and with the main focus of this study on representations of supply-side features and network datasets. As an example, a selection of accessibility assessments was made for GP surgeries using OS Points of Interest. These were carried out using OS Code-Point as the demand-side dataset, and the outputs compared to those using OA centroids. The background to the Code-Point dataset was given in Chapter 3, where it was explained that it had the potential to be used as a representation of population, and in this example offered the option of locating population at a further step of disaggregation compared to using OA centroids.

Figure 4.34 shows the destination overlaps obtained from using Code-Point as demand centres for GP surgeries, compared to the results obtained using OAs as demand points, when using distance as the accessibility measure. None of the data was normally distributed. Destination overlaps were lower for Cardiff with Code-Point (by a small margin, with an average of 85.8% with Code-Point and 86.7% with OAs), with the situation reversed in the Vale (average overlap 90.0% with Code-Point versus 89.1% with OAs). Correlations were generally slightly higher using Code-Point, though this was not universal across all combinations, with averages of .920

versus .915 and .963 versus .948 for Code-Point compared to OAs for Cardiff and the Vale, respectively. These results are discussed more fully in Chapter 6.

Cardiff (using Code-Point)

	Euclidean	ITN	UP	OR	OSM
Euclidean		*.864*	*.938*	*.862*	*.849*
ITN	79.6		*.928*	*.996*	*.968*
UP	84.5	88.1		*.924*	*.905*
Open Roads	79.0	97.1	86.8		*.965*
OSM	76.8	90.7	84.5	91.2	

Cardiff (using OAs)

	Euclidean	ITN	UP	OR	OSM
Euclidean		*.842*	*.937*	*.841*	*.829*
ITN	80.1		*.915*	*.995*	*.966*
UP	85.1	89.6		*.914*	*.945*
Open Roads	80.3	97.3	88.7		.967
OSM	77.4	91.5	85.7	91.7	

Vale (using Code-Point)

	Euclidean	ITN	UP	OR	OSM
Euclidean		*.927*	*.955*	*.930*	*.932*
ITN	82.9		*.972*	*.999*	*.988*
UP	84.5	96.6		*.974*	*.964*
Open Roads	82.9	99.1	96.2		*.989*
OSM	83.8	92.1	90.1	91.8	

Vale (using OAs)

	Euclidean	ITN	UP	OR	OSM
Euclidean		*.899*	*.945*	*.907*	*.908*
ITN	82.0		*.954*	*.994*	*.988*
UP	85.0	96.1		*.961*	*.945*
Open Roads	82.3	98.8	95.4		*.981*
OSM	82.3	90.8	88.1	90.0	

Table 4.34: Destination overlaps and correlations of distance for accessibility to GP surgeries, using Code-Point data for demand and PoI for supply. Below diagonal = Destination Overlap (%). Above diagonal = Spearman's rank correlation coefficient. All correlations were significant at the 0.01 level.

Cardiff results indicate a slight increase in destination overlaps, possibly due to the greater number of destination options and their proximity to the population centres. The greater distances in the Vale and the pattern of surgeries resulted in an increase in correlations and destination overlaps. Once again there appears to be a geographical difference, although slight, between the urban and rural areas.

High correlations were generally reflected by high destination overlap values, with the comparisons between ITN and Open Roads showing a particularly strong relationship in Cardiff (.996 and 97.1% using Code-Point) and especially the Vale (.999 and 99.1%). The comparison between OSM and ITN in both areas shows the strong similarity in performance between the two networks in this situation.

The lowest overlap figures in both areas came from comparisons using Euclidean distance. No comment will be made in this thesis as to which is the 'better' measure to use, but the differences between Euclidean and network distances and the differences in destinations identified will be emphasised, suggesting that great care be taken when comparing any accessibility studies that use network or Euclidean distances in their models and generalise as if no difference exists in results between the two.

4.5 Network comparisons

As an illustration as to how the various network datasets differ, the distance from each supply-side feature to its nearest neighbour was measured and the results presented in Table 4.35. These figures give a further indication of how the features were distributed within their respective areas.

All network and location data used in Table 4.35 was taken from a 'snapshot' of data taken in January 2014 apart from OS Open Roads, the data for which was obtained in April 2015, the month it was launched and made publicly available. The biggest difference in the figures reported in Table 4.33 related to Euclidean distances, with the average distance between sports centres in the Vale nearly three times that of Cardiff. When Euclidean was excluded, Open Roads showed the largest Cardiff-Vale difference, with Vale distances nearly 140% of those of Cardiff. The smallest differences were not exhibited by the most numerous feature (primary schools) but by GP surgeries, for which Vale distances were around a third greater than those of Cardiff.

Between networks, the biggest difference was seen in the results for Cardiff sports centres, with the Open Roads average distance between sports centres over 84% greater than that of Euclidean distance, with the Vales larges difference being the 68% difference between (again) Open Roads and Euclidean. The smallest difference was 33% between UP and Euclidean for Vale sports centres. From these results, using a relatively small sample number, the relatively-simple conversion factors between Euclidean and network distance of approximately 20% found by Martin and Williams in Bristol (1992) and Love and Lindquist (1995) in Illinois seem very low by comparison, and the results here were beyond the highest of those found by Burkey (2012) of 32% in southern USA. The average distances for primary schools, for example, indicated a conversion factor of .60 and over for Cardiff, and a minimum of .38 for the Vale (both comparing UP), and equivalent figures for ITN of .79 and .69 for Cardiff and the Vale, respectively, well over the conversion factors suggested in the studies cited here.

	Cardiff		Vale	
a) Primary schools	**Tot dist (m)**	**Average (m)**	**Tot dist (m)**	**Average (m)**
Euclidean	47644	512	61222	1249
UP	75567	813	84339	1721
OSM	83609	899	88830	1813
ITN	85150	916	88634	1809
Open Roads	84736	911	88639	1809
b) Secondary schools	**Tot dist (m)**	**Average (m)**	**Tot dist (m)**	**Average (m)**
Euclidean	23070	1099	21345	2372
UP	35191	1676	32941	3660
OSM	38575	1837	30931	3437
ITN	39986	1904	33320	3702
Open Roads	42421	2020	36004	4000
c) GP surgeries	**Tot dist (m)**	**Average (m)**	**Tot dist (m)**	**Average (m)**
Euclidean	39414	625	19354	922
UP	53256	845	26749	1274
OSM	59069	938	26317	1253
ITN	60405	959	27594	1314
Open Roads	60510	960	27544	1313
d) Sports Centres	**Tot dist (m)**	**Average (m)**	**Tot dist (m)**	**Average (m)**
Euclidean	24806	800	23675	2367
UP	41495	1339	31550	3155
OSM	42741	1378	32513	3251
ITN	45646	1472	31855	3185
Open Roads	45789	1477	35287	3529
e) Community hubs	**Tot dist (m)**	**Average (m)**	**Tot dist (m)**	**Average (m)**
Euclidean	35024	461	26779	687
UP	48208	634	35874	920
OSM	49594*	661*	38210	980
ITN	52073	685	38164	979
Open Roads	52912	696	38436	986

Table 4.35: Distances between facilities, using different networks: a) Primary schools; b) secondary schools; c) GP surgeries; d) Sports centres; e) Community hubs.
* One facility was not connected to this network.

The figures from network distances from the different sources had ITN with Urban Paths (referred to as Urban Paths or UP through this chapter) returning by far the lowest figure, and being considerably lower than ITN alone. More remarkable was the Open Roads figure being lower than ITN for Cardiff primary schools (and very close to the ITN average figure for GP surgeries and sports centres) and only very slightly higher in the Vale. This could be due to Open Roads being automatically generalised from large-scale data (Ordnance Survey, 2015f), therefore some smoothing could, conceivably, have reduced overall distances. A more likely reason is Open Road containing more recent data than that of ITN (and UP). The performance of OSM was at the lower end of expectations, returning a distance higher than UP but less than ITN for Cardiff, and the worst by a small margin in the Vale. Again, the greater geographical distances encountered in the Vale seemed to exercise a smoothing function. The much-vaunted inclusivity of OSM in urban locations was not fully achieved in Cardiff, apparently due to the poor coverage and updating levels in (but especially around the outskirts of) the city. As was mentioned in Chapter 3, some roads were missed from the OSM dataset and ways/edges with missing links or incorrect joins were a found through the data, and though coverage for urban areas in general was reported as thorough and improving (Haklay, 2010b), the coverage and quality in Cardiff appeared poor compared to that reported in larger cities such as London or Hamburg, of which more detail will be given in Section 6.4.4.

The network distance figures for secondary schools from the different sources did not follow the same pattern as exhibited for other features, with OSM returning a figure considerably less than that of all three OS datasets. This was due to differences in representing blocked-up roads, and will be discussed in more detail in Section 5.3. Although the OSM figures for Vale GP surgeries were lower than those of ITN and UP, the differences were relatively small (eg 21m lower than UP). No error was apparent in the other datasets and the inclusion of some rural footpaths may have contributed to OSM’s lower return. Vale sports centres were approximately two and a half times the distance apart as those in Cardiff, a considerably larger difference to than that found with primary and secondary schools and GP surgeries.

The network distances between community hubs were very similar, confirming their highly-clustered distribution in both Cardiff and the Vale. In Cardiff there was one discrepancy with OSM where one community hub facility was not connected to the network, which is discussed in more detail in Section 5.3. The total lengths measured in this part of the analysis were therefore smaller than would be expected, but the divisor was adjusted accordingly in order to obtain a comparable average.

4.5.1 Network correlations and differences – distance

Table 4.9 reported the results of correlations between sets of distance results for Cardiff primary schools. The two network datasets with the highest average correlation were ITN and Open Roads with an average correlation of .884. As Open Roads was derived from the same underlying data as ITN, they would be expected to have a relatively high correlation. The average correlation between UP and ITN was high at .839, but may have been expected to be higher, as the UP dataset consisted of the ITN road network with an additional dataset of footpaths (which is illustrated visually in Figure 5.2(a) and (b) which shows the UP edges added on to the ITN network. These results indicated that the addition of pathways did have an effect on distance accessibility results. Correlation results from Vale primary schools were shown in Table 4.10 and were generally higher than those obtained for Cardiff. As with Cardiff, the network datasets with the highest correlation was ITN and Open Roads with .938, indicating a very high correlation.

As outlined in section 4.3.1, some Wilcoxon results indicated an absence of significant difference in results for Cardiff primary schools. Results from the OSM and the Open Roads datasets had 6 out of 16 cross-comparisons with a statistical significance outside the < .001 level (5 of which were outside the 5% level for OSM versus Open Roads, and 4 out of the 6 for OSM versus ITN), as did the comparisons between OSM and ITN networks, and both had similar patterns in terms of which positional representation produced similar results. With both these networks the Sites centroids and PoI points pairing had non-significant differences, which suggest, considering the high correlations levels, a high level of similarity between the results. Whether these networks and features could be considered practically interchangeable (in the context of accessibility studies) will be explored further in order to ascertain if, in despite of several differences in terms of content, quality, trust and reputation, these datasets were effectively as useful and usable as each other and in which circumstances the use of one may be preferred to the other.

General trends indicated that, when all methods of location were included, the two datasets with the highest correlation were ITN and Open Roads (as was the case with the earlier distance measures) with an average correlation of .811, somewhat lower than with the equivalent distance measure. ‘Internal’ comparison (using the four location methods measured with the same network) showed that the OSM dataset achieved a correlation of .759, though even the lowest (UP) at .726 was only slightly lower.

4.5.2 Network correlations and differences – 2SFCA

As seen from Table 4.14 (results of comparison of 2SFCA scores for Vale of Glamorgan primary schools), a wide range of results affected the general trends. (To recap, 2SFCA scores were calculated using the plug-in tool described in Section 3.2 and using a custom-built Arc Model, using all locational alternatives for supply and using the relevant school-age population attributed to OA centroids as demand). The highest correlation found, when all methods of location were included, was between ITN with Urban Paths and OSM with an average of only .475, with the highest 'internal' comparison (using the four location methods measured with the same network) being found using the OSM dataset, with 0.556 (though the equivalent Euclidean comparison had a correlation of .952). The use of the potentially more sophisticated method of calculating accessibility highlighted some considerable differences not readily apparent when using the simpler distance measures.

4.5.3 Network correlations and differences – destination overlaps

Destination overlaps, with results shown in Tables 4.17 and 4.18, also gave an indication of which networks produced the most similar, and most divergent, results. For example, the Cardiff primary school maximum overlap of 98.3% was achieved when distance to perimeters using ITN was compared to distance to the perimeter using Open Roads, indicating the relatively small, practical effects of using these datasets as alternatives. This figure is the equivalent of 18 OAs out of Cardiff's 1077 having a different destination identified as closest to them when the networks were varied.

Taking into account all methods used to locate the primary schools, the average destination overlap figure when networks were compared are shown in Figure 4.36. Changes in network had a considerable effect on the specific destination identified as nearest to each OA centroid. The highest figure in both areas once again highlighted the closer similarities between the results from ITN and Open Roads (with data for Open Roads derived from that of ITN). The results for the Vale were all higher than those for Cardiff, reflecting the greater 'choice' of destinations offered in Cardiff to the more numerous supply-side features in an area with a higher density of demand-side points. The Vale results had a highest figure of 91.4% compared to Cardiff's 82.1%, and averages of all results were 84.3% and 76.2%, respectively.

The relatively low results in comparisons involving Euclidean measurement indicates the considerable effects on results caused by the use of Euclidean distance compared to any of the four networks used in this study, particularly in the Cardiff geographical context. Whereas

Martin and Williams (1992) and Love and Lindquist (1995) identified a static conversion factor of 20% for Euclidean to network distance, the results here (for distance and destination overlap) indicate a considerable variation depending on what network dataset is used as the comparator. Burkey (2012) found a range of factors from 26 to 32%, depending on context. This study also indicates a wide difference in Euclidean to network factors, which changes depending on the nature of the area examined, the features used to measure the distances, and the networks used.

	Euc	**ITN**	**UP**	**OR**	**OSM**
Euc	86.6				
ITN	71.2	78.0			
UP	77.4	77.1	81.1		
OR	71.1	82.1	76.5	77.0	
OSM	71.0	78.8	76.9	80.0	79.9

a) Cardiff

	Euc	**ITN**	**UP**	**OR**	**OSM**
Euc	93.6				
ITN	79.2	89.9			
UP	83.8	87.3	90.3		
OR	77.8	91.4	86.9	88.3	
OSM	75.7	88.9	83.6	88.0	88.3

b) Vale of Glamorgan

Table 4.36: Average destination overlap (%) for all location methods, showing influence of network on primary school accessibility.

4.5.4 Secondary school comparisons

Similar processes were carried out using secondary schools as the supply-side feature, to ascertain whether number and distribution of features affected accessibility results, and the correlations between distance measures of accessibility were provided in Tables 4.20 and 4.21 for Cardiff and Vale secondary schools, respectively. From the Cardiff results, when all methods of location were included, the two network datasets with the highest correlation were (as with Cardiff primary schools) ITN and Open Roads, with an average correlation of .949. The close relationship between ITN and Open Roads (with Open Roads automatically generalised from the same large-scale base data used for ITN) was also confirmed with their strong correlation outcomes for Cardiff secondary schools using 2SFCA (as with similar networks and using identical supply and demand weightings, 2SFCA results would be expected to be very similar when the same locational method was used).

A similar comparison to Table 4.36 is given in Table 4.37 for secondary schools. As with primary schools, the results for the Vale of Glamorgan show higher levels of destination overlap than that of Cardiff. Differences were still caused by the use of different networks.
The high levels of destination overlap found with primary schools when comparing ITN and Open Roads was less marked when secondary schools were used, with ITN and UP returning a slightly higher figure for the Vale. The greater geographic distances in the Vale, along with fewer destination options, appear to result in less variation in choice of destination.

	Euc	ITN	UP	OR	OSM
Euc	80.0				
ITN	71.4	80.5			
UP	80.0	79.2	80.2		
OR	76.5	83.2	79.5	79.7	
OSM	72.0	78.6	74.7	77.9	72.8

a) Cardiff

	Euc	ITN	UP	OR	OSM
Euc	92.0				
ITN	85.4	86.0			
UP	87.9	89.5	90.1		
OR	85.5	89.3	88.6	86.3	
OSM	85.6	87.7	87.8	87.7	84.5

b) Vale of Glamorgan

Table 4.37: Average destination overlap (%) for all location methods, showing influence of network on secondary school accessibility.

4.5.5 GP comparisons

GP surgeries are not one of the features included in the Sites datasets, therefore no representation of their polygons, along with access points, were available. In this case the only locational representation for GP surgeries used in this study was taken from OS Points of Interest (PoI) dataset.

The distance between facilities (Table 4.35) provided a view as to how the facilities were spread in relation to each other throughout the study areas, with (on average) Vale surgeries approximately one and a half times the distance apart as Cardiff surgeries, a pattern generally similar to those found with primary and secondary schools. Cardiff surgeries were classified as ‘clustered’ according to the NN method (Table 4.4), again similar to primary schools, though those in the Vale did not conform to that area’s assessment of random distribution of primary schools, with surgeries graded between clustered and dispersed.

Table 4.38 shows the results of correlations of distance calculations for Cardiff. As was the case with previously-reported features, none of the distance results for either Cardiff or the Vale conformed to normal distribution. Correlations of distance for Cardiff were all significant at the 1% level, with ITN and Open Roads once more having the highest correlation of .995 and OSM and Euclidean the lowest at .829. The lowest network correlation was in comparing OSM to UP results at .891. Even this lowest correlation reflected strongly-correlated data. The OSM network produced strongly correlated results when compared to both ITN and Open Roads in Cardiff, indicating very high similarity between ranks of results relating to this feature in Cardiff. Comparisons will be made to the equivalent results for Vale GP surgeries.

	Euclidean			
Euclidean		**ITN**		
ITN	.842		**UP**	
UP	.937	.915		OR
OR	.841	.995	.914	
OSM	.829	.966	.891	.967

Table 4.38: Correlations of distance results for Cardiff GP surgeries. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

	Euclidean			
Euclidean		**ITN**		
ITN	.899		**UP**	
UP	.945	.954		**OR**
Open Roads	.907	.994	.961	
OSM	.908	.988	.945	.981

Table 4.39: Correlations of distance results for Vale GP surgeries. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

Correlations of distance for the Vale (Table 4.39) were also all significant at the 1% level, with ITN and Open Roads again having the highest correlation of .994 (very similar to Cardiff) and ITN and Euclidean the lowest at .899. The lowest network correlation was OSM to UP at .945, once again the same combination as Cardiff, and again reflected strongly correlated sets of results for this feature. OSM was again highly correlated to ITN and OR, at levels greater than those of Cardiff. Implications of these results will be discussed in Section 6.4.

Friedman tests were applied to all sets of distance results, and despite the strong correlations the Friedman tests found that every combination of network distance had statistical differences in both counties (for Cardiff chi-sq = 2149.765, p = < .001; for the Vale chi-sq = 895.384, p = < .001). Table 4.40 therefore shows the results of applying Wilcoxon paired comparison tests to these results, with those found to be not significant at the < .001 level highlighted, along with their associated significance levels. Table 4.41 shows the corresponding results for the Vale.

	Euclidean	**ITN**	**UP**	**OR**	**OSM**
Euclidean		*< .001*	*< .001*	*< .001*	*< .001*
ITN	-28.335		*< .001*	*< .001*	*.030*
UP	-28.313	-18.705		*< .001*	*< .001*
Open Roads	-28.304	-8.004	-12.980		*< .001*
OSM	-28.121	-2.168	-15.411	-4.345	

Table 4.40: Differences between distance results for Cardiff GP surgeries. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001; amber = significant at 5%).

As seen in Table 4.40 not all Wilcoxon results for Cardiff were significant at the < .001 level, with the comparison between ITN and OSM significant at the 5% level, indicating a less-strong difference between those two sets of results. All results for the Vale, however, were significant at the < .001 level, indicating a statistically significant difference between the results of distance calculations when using different combinations of networks, suggesting that no two network datasets would be interchangeable in this context.

	Euclidean	**ITN**	**UP**	**OR**	**OSM**
Euclidean		*< .001*	*< .001*	*< .001*	*< .001*
ITN	-17.589		*< .001*	*< .001*	*< .001*
UP	-17.589	-11.242		*< .001*	*< .001*
Open Roads	-17.585	-6.434	-8.117		*< .001*
OSM	-17.546	-6.803	-4.158	-5.117	

Table 4.41: Differences between distance results for Vale GP surgeries. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (all results significant at the < .001 level).

When 2SFCA results were compared (Table 4.42) in order to assess whether the datasets performed differently when exposed to an alternative measure of accessibility, correlations between networks in Cardiff were again high, ranging from a maximum of .976 for ITN and Open Roads (the same combination as was highest in distance measures) to a minimum of .030 for Euclidean versus ITN. The lowest network correlation was .865 between UP and OSM. Comparisons of Euclidean with all networks were very low, but all were still statistically significant at the 1% level, indicating perhaps the less-precise nature of this particular statistical tool (as per the explanation of the restricted choice of tests due to the nature of the data being tested, provided in Section 3.5) and also the weak correlations involved in comparing Euclidean 2SFCA results to those of network results.

	Euclidean			
Euclidean		**ITN**		
ITN	.030		**UP**	
UP	.083	.896		**OR**
Open Road	.048	.976	.897	
OSM	.075	.940	.865	.923

Table 4.42: Correlations of 2SFCA results for Cardiff GP surgeries. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

Vale 2SFCA results (Table 4.43) were more highly correlated than those of Cardiff, ranging from a high of .988 (ITN versus Open Roads) to a low of .612 (Euclidean and Open Roads), with the lowest network correlation being .956, for UP and OSM. The strong correlations for the ITN results indicated that they produced statistically similar 2SFCA results to the other three network datasets.

	Euclidean			
Euclidean		**ITN**		
ITN	.620		**UP**	
UP	.651	.962		**OR**
Open Roads	.612	.988	.960	
OSM	.627	.978	.956	.970

Table 4.43: Correlations of 2SFCA results for Vale GP surgeries. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

These high correlations for the Vale were, unusually, reflected in the Wilcoxon tests, with all of the 6 network combinations (all scores involving Euclidean measurements were statistically different) returning Z scores that were not significant at the 5% level, indicating there were no statistically significant differences between these combinations. This was a trend which would be repeated for sports centres (Section 4.5.6) and community hubs (Section 4.5.7), but not to the same extent as found with GP surgeries.

Destination overlaps highlighted how these statistical results affected actual outcomes involving the identification of the same destination, or a different one, depending on the combination of networks used. The destination overlaps are reported in Tables 4.46 and 4.47 for Cardiff and Vale GP surgeries, respectively.

	Euclidean	ITN	UP	OR	OSM
Euclidean		*< .001*	*< .001*	*< .001*	*< .001*
ITN	-27.508		*< .001*	*< .001*	*< .001*
UP	-27.497	-6.844		*< .001*	*< .001*
Open Roads	-27.593	-11.513	-5.509		*< .001*
OSM	-27.613	-3.659	-5.633	-4.533	

Table 4.44: Differences between 2SFCA results for Cardiff GP surgeries. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (all results significant at the < .001 level).

	Euclidean	ITN	UP	OR	OSM
Euclidean		< .001	< .001	< .001	< .001
ITN	-11.986		*.335*	*.284*	*.880*
UP	-11.899	- .965		*.555*	*.726*
Open Roads	-11.975	-1.070	- .591		*.241*
OSM	-11.727	- .151	- .351	-1.172	

Table 4.45: Differences between 2SFCA results for Vale GP surgeries. Below diagonal: Wilcoxon Z scores. Above diagonal: significance levels (black = significant at < .001; red = not significant at 5%).

	Euclidean	ITN	UP	OR
Euclidean				
ITN	80.1			
UP	85.1	89.6		
Open Roads	80.3	97.3	88.7	
OSM	77.4	91.5	85.7	91.7

Table 4.46: Destination overlaps (%) for Cardiff GP surgeries.

	Euclidean	ITN	UP	OR
Euclidean				
ITN	82.0			
UP	85.0	96.1		
Open Road	82.3	98.8	95.4	
OSM	82.3	90.8	88.1	90.0

Table 4.47: Destination overlaps (%) for Vale of Glamorgan GP surgeries.

The combination which produced destination overlap results with the highest value in both Cardiff and the Vale was that of ITN and Open Roads, with 97.3% and 98.8%, respectively. As with distance results, the ITN and Open Roads comparisons were very similar, another effect of the common source of base data from which both networks were derived. The lowest value was common to both areas, 80.1% when comparing Euclidean to ITN in Cardiff, and 82.0% for the same combination in the Vale. Vale results again showed generally higher levels of overlap than Cardiff for the majority of combinations. The larger geographical areas in the Vale, combined with fewer alternative destinations, was a possible reason behind this pattern. Similar case studies using other types of destination feature will be conducted in order to compare results with the pattern found here.

The results for GP surgeries, shown above, highlight the influence the choice of network had on the outcomes of various typical accessibility measures obtained using GIS processes, and by employing several different networks in a multitude of calculations, the sensitivity of the processes to variations in network input is apparent. In looking at accessibility to GP surgeries, the differences between Cardiff and Vale results were particularly striking. Whether more rural network characteristics seem to result in fewer differences is a pattern which is repeated with other features will now be addressed.

4.5.6 Sports centre comparisons

Sports centres were the fourth type of feature to be examined in this exercise. As with GP surgeries, sports centres were only located using OS Points of Interest, therefore the tables for correlations, differences and destination overlaps were considerably simplified compared to those of schools. Similarities between results of the GIS analyses were examined first, followed by an assessment of difference, before looking at destination overlaps. None of the distance results for either Cardiff or the Vale conformed to normal distribution.

	Euclidean			
Euclidean		**ITN**		
ITN	.877		**UP**	
UP	.938	.930		**OR**
OR	.877	.985	.928	
OSM	.884	.960	.914	.944

Table 4.48: Correlations of distance results for Cardiff sports centres. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

Correlations of distance for Cardiff (Table 4.48) were all significant at the 1% level, with ITN and Open Roads having the highest correlation of .985 and a tie for lowest with ITN and

Euclidean and Open Roads and Euclidean at .877. The lowest network distance correlation was the .914 for OSM and UP, and even this lowest correlation reflected highly-correlated data. These results were therefore strongly correlated, and generally similar to the equivalent results from Cardiff GP surgeries.

Correlations of distance for the Vale (Table 4.49) were also all significant at the 1% level, with ITN and OSM having the highest correlation of .996 and a tie for lowest with the same two pairs as for Cardiff: ITN and Euclidean at .923; the same correlation as OSM and Euclidean. The lowest network correlation was again OSM and UP at .972 (the same combination as the lowest network correlation using GP surgeries), once again the same combination as Cardiff. Correlations were higher overall than those from Cardiff, reflecting very strong correlations with this particular dataset.

	Euclidean			
Euclidean		**ITN**		
ITN	.923		**UP**	
UP	.954	.973		**OR**
OR	.928	.995	.971	
OSM	.923	.996	.972	.991

Table 4.49: Correlations of distance results for Vale sports centres. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

Friedman tests were applied to the sets of distance results and it was found there was a statistically significant difference for both counties (for Cardiff chi-sq = 2251.834, p = < .001; for the Vale chi-sq = 905.355, p = < .001). Table 4.50 shows the results of applying Wilcoxon paired comparison tests to the data. Results which were not significant at the < .001 level were highlighted, along with their associated significance levels. Table 4.51 show the corresponding results for the Vale.

All paired comparisons for Cardiff were significant when tested by Wilcoxon, at the < .001 level. These results indicated once again that despite high levels of correlation there were significant differences between the distance results for the Cardiff sports centre dataset.

The Wilcoxon tests for the Vale found once again that every combination of network and Euclidean distance bar two had statistical differences, and all but those two were significant at the < .001 level. The two non-significant results were OSM compared to ITN and OSM compared to Open Roads, neither of which combinations were significant at the 5% level. These two combinations also had very strong correlations (see Table 4.49), but the ITN-OR comparison which also had a very strong correlation was found to have differences significant at the < .001 level. This result suggests that when less-precise statistical tests of correlation are applied (and with the data used here the less-precise Spearman's was the most appropriate test to use), care must be taken before inferences of similarity are made.

	Euclidean	ITN	UP	OR	OSM
Euclidean		*< .001*	*< .001*	*< .001*	*< .001*
ITN	-28.322		*< .001*	*< .001*	*< .001*
UP	-28.361	-20.546		*< .001*	*< .001*
Open Roads	-28.339	-7.210	-17.311		*< .001*
OSM	-28.027	-6.848	-15.279	-3.788	

Table 4.50: Differences between distance results for Cardiff sports centres. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (all results significant at the < .001 level).

	Euclidean	ITN	UP	OR	OSM
Euclidean		*< .001*	*< .001*	*< .001*	*< .001*
ITN	-17.583		*< .001*	*< .001*	*.681*
UP	-17.581	-12.130		*< .001*	*< .001*
Open Roads	-17.583	-3.687	-10.708		*.674*
OSM	-17.580	- .412	-10.635	- .421	

Table 4.51: Differences between distance results for Vale sports centres. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001; red = not significant at 5%).

In terms of 2SFCA measures, correlations in Cardiff (Table 4.52) were more varied, ranging from a maximum of .981 for ITN and Open Roads (same combination as was highest in distance measures and for GP surgeries) to a minimum of .199 for Euclidean versus Open Roads. The lowest network correlation was .893, once again between UP and OSM. Comparisons of Euclidean with all networks exhibited weak correlation, but all were still statistically significant at the 1% level.

Vale 2SFCA results (Table 4.53) were more highly correlated than those of Cardiff, ranging from a high of .984 (ITN versus Open Roads) to a low of .683 (Euclidean and OSM), with the lowest network correlation being .961, for UP and OSM. The combinations of networks (excluding Euclidean distances) which produced the highest and lowest correlations matched those of Cardiff sports centres, and also the correlations of Vale GP surgeries. Euclidean compared to Open Roads was a combination always amongst the lowest correlations, with Euclidean compared to OSM also amongst the lowest.

	Euclidean			
Euclidean		ITN		
ITN	.217		UP	
UP	.201	.916		OR
Open Road	.199	.981	.920	
OSM	.210	.958	.893	.949

Table 4.52: Correlations of 2SFCA results for Cardiff sports centres. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

	Euclidean			
Euclidean		ITN		
ITN	.714		UP	
UP	.689	.970		OR
Open Road	.699	.984	.972	
OSM	.683	.971	.961	.962

Table 4.53: Correlations of 2SFCA results for Vale sports centres. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

When 2SFCA scores were tested for differences there was a significant Friedman score for Cardiff (chi-sq = 2187.483, p = < .001), therefore paired comparisons were conducted, the results of which are shown in Table 4.54. The Friedman test was repeated for the Vale of Glamorgan, with a significant score (chi-sq = 509.602, p = < .001). The results of paired comparison Wilcoxon tests on Vale 2SFCA data are shown in Table 4.55.

	Euclidean	ITN	UP	OR	OSM
Euclidean		*< .001*	*< .001*	*< .001*	*< .001*
ITN	-28.225		*< .001*	*< .001*	*< .001*
UP	-28.133	-7.655		*< .001*	*< .001*
Open Roads	-28.244	-6.091	-28.427		*< .001*
OSM	-28.353	-4.956	-15.279	-3.684	

Table 4.54: Differences between 2SFCA results for Cardiff sports centres. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (all results significant at the < .001 level).

The strong, statistically-significant correlations were, again, reflected in the Wilcoxon tests scores for the Vale, with 4 out of the 6 network combinations returning Z scores that were not significant at the < .001 level, indicating a less-strong statistical difference in these four datasets. UP with ITN and UP with Open Roads were significant at the 1% level, UP with OSM was significant at the 5% level, but ITN with OSM was not significant at the 5% level which indicates a lack of difference between the results. It was therefore assumed there was a degree of similarity between the 2SFCA scores measured using ITN and those measured using OSM. All other combinations, and all involving Euclidean results, were significant at the < .001 level.

	Euclidean	ITN	UP	OR	OSM
Euclidean		*< .001*	*< .001*	*< .001*	*< .001*
ITN	-11.830		*.001*	*< .001*	*.407*
UP	-12.289	-3.312		*.002*	*.039*
Open Roads	-11.596	-6.445	-3.141		*< .001*
OSM	-11.787	- .830	-2.061	-3.515	

Table 4.55: Differences between 2SFCA results for Vale sports centres. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001; red = not significant at 5%).

Destination overlap gave an indication of the identity of the nearest destinations when measured by the various networks. The results for Cardiff are given in Table 4.56 and for the Vale in Table 4.57. Destination overlaps for Cardiff produced results that had ITN with Open Roads returning the highest value of 94.1%, the same combination which produced the highest figure for GP surgeries. The lowest value was again the same combination as for surgeries, Euclidean to ITN, with a figure of 76.4%. The Vale of Glamorgan had a highest destination overlap figure of 99.8%, for ITN with Open Roads (the same combination that produced the highest overlap figure for Cardiff and Vale GP surgeries). The lowest was 84.0% found between Euclidean and OSM data, indicating that destination overlaps for Vale sports centres were higher than those of Cardiff. These results seem to contradict those which assessed the level of difference between the datasets, with the ITN-OR combination with the highest destination overlap here being assessed as having statistically-significant differences in both distance and 2SFCA results. The destination overlap provides another insight into the data, by showing if the numerical differences identified in statistical tests actually have a practical effect on another form of assessment.

	Euclidean	ITN	UP	OR
Euclidean				
ITN	76.4			
UP	85.5	82.5		
Open Roads	77.0	94.1	81.6	
OSM	77.8	88.1	82.8	83.1

Table 4.56: Destination overlaps (%) for Cardiff sports centres.

	Euclidean			
Euclidean		**ITN**		
ITN	84.5		**UP**	
UP	88.8	93.2		**OR**
Open Road	84.5	99.8	93.4	
OSM	84.0	95.4	91.3	95.6

Table 4.57: Destination overlaps (%) for Vale of Glamorgan sports centres.

4.5.7 Community hub comparisons

Community hubs were the fifth and final type of feature to be considered in this analysis. In assessing the accessibility results relating to distance to nearest destination from each demand-side point (in this case census OA centroids), the levels of correlation between results was assessed, and the outcomes shown in Tables 4.58 and 4.59, for Cardiff and the Vale of Glamorgan, respectively. None of the distance results for Cardiff nor the Vale conformed to normal distribution.

	Euclidean			
Euclidean		**ITN**		
ITN	.840		**UP**	
UP	.927	.911		**OR**
OR	.840	.996	.910	
OSM	.836	.972	.891	.971

Table 4.58: Correlations of distance results for Cardiff community hubs. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

Correlations of distance results for Cardiff were all significant at the 1% level. ITN and Open Roads once again had the highest correlation, this time with the strongly-correlated value of .996, while the lowest was OSM and Euclidean at .836, still relatively high. The lowest network distance correlation was the .891 for OSM and UP, the same combination that was the lowest network correlation for sports centres.

Correlations of distance for the Vale were also all significant at the 1% level, with both ITN and OSM *and* ITN and Open Roads having the highest correlation of .989. The lowest correlation was between Euclidean and OSM with 0.854, still a relatively strong result. The lowest network correlation was, once again, OSM and UP at .918 (the same combination as the lowest network correlation using GP surgeries and sports centres), also the same combination as Cardiff's lowest figure.

Friedman tests were applied to the entire sets of results and it was found there was a statistically significant difference in the distance results for both Cardiff and the Vale (chi-sq = 2169.989, p = < .001; and chi-sq = 853.996, p = < .001, respectively). Tables 4.60 and 4.61 show the results of applying Wilcoxon paired comparison tests to the Cardiff and to the Vale data. Any results not statistically significant at the < .001 level were highlighted, along with associated significance levels.

	Euclidean			
Euclidean		ITN		
ITN	.865		UP	
UP	.935	.931		OR
OR	.870	.989	.934	
OSM	.854	.989	.918	.978

Table 4.59: Correlations of distance results for Vale community hubs. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

	Euclidean	ITN	UP	OR	OSM
Euclidean		*< .001*	*< .001*	*< .001*	*< .001*
ITN	-28.382		*< .001*	*.015*	*.016*
UP	-28.394	-17.824		*< .001*	*< .001*
Open Roads	-28.370	-2.425	-15.381		*.016*
OSM	-28.097	-2.406	-12.458	-2.420	

Table 4.60: Differences between distance results for Cardiff community hubs.
Below diagonal: Wilcoxon Z scores. Above diagonal: significance (black = significant at < .001 level; amber = significant at 5% level).

When tested for differences using Wilcoxon, three paired comparisons were found not to have highly-significant differences: ITN with OSM; ITN with Open Roads; and Open Roads with OSM. All three were significant at the 5% level, though the other 7 comparisons were all significant at the < .001 level. These results indicated once again that despite high levels of correlation there were significant differences between some of the distance results for Cardiff community hubs. The Wilcoxon tests for the Vale found once again that all but two combinations had statistical differences significant at the < .001 level, the two being OSM versus ITN (significant at 1%) and OSM versus Open Roads, which was not significant at 5%. The Wilcoxon results along with a strong correlation indicated that results from Open Roads and OSM were very similar. This was a combination which had a low level of difference in some other measures (such as for sports centres). It was, however, unexpected to find similarities between the two datasets, though where OSM appeared similar to ITN then perhaps similarities to OR would also be expected. It was assumed that OSM, with its capacity to map even the most informal footpaths, would outperform ITN in most situations, and have significant differences, but in the Vale where OSM coverage may be poorer, the number of paths mapped may not be that great, and if only roads are mapped (and many of the UKs roads were bulk-uploaded to OSM from other data sources) then OSM and ITN would appear very similar.

	Euclidean	ITN	UP	OR	OSM
Euclidean		*< .001*	*< .001*	*< .001*	*< .001*
ITN	-17.553		*< .001*	*< .001*	*.005*
UP	-17.565	-10.110		*< .001*	*< .001*
Open Roads	-17.533	-9.501	-6.012		*.571*
OSM	-17.522	-2.796	-5.277	- .567	

Table 4.61: Differences between distance results for Vale community hubs. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001; red = not significant at 5%).

When 2SFCA was used as the measure of accessibility rather than distance, in order to assess whether the datasets (in this case the four networks, Euclidean measurement and the five different types of destination feature) perform differently compared to assessments using distance) the results of testing for statistical similarities and differences were as shown in the following tables. Firstly, correlations of the 2SFCA outcomes were as per Table 4.62 for Cardiff, and 4.63 for the Vale.

Correlations for community hubs in Cardiff were very similar (though slightly stronger) than those for sports centres. The network correlations for the Vale were again very similar, but slightly stronger, than their sports centre equivalents.

	Euclidean	ITN	UP	OR
Euclidean				
ITN	.277			
UP	.251	.921		
Open Road	.280	.988	.921	
OSM	.245	.959	.897	.971

Table 4.62: Correlations of 2SFCA results for Cardiff community hubs. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

	Euclidean			
Euclidean		**ITN**		
ITN	.471		**UP**	
UP	.482	.978		**OR**
Open Road	.437	.988	.975	
OSM	.453	.970	.968	.973

Table 4.63: Correlations of 2SFCA results for Vale community hubs. (Using Spearman's Rank Correlation Coefficients; all coefficients significant at the 0.01 level).

Correlations from Cardiff were somewhat lower and more varied than those of the Vale. The highest Cardiff figure was .988 for ITN and Open Roads (same combination as was highest in distance measures and for surgeries and sports centres). The minimum was .245 for Euclidean versus OSM. The lowest network correlation was .897, again between UP and OSM. Comparisons of Euclidean with all networks were relatively low for this feature, but all were statistically significant at the 1% level. The results of 2SFCA assessments for the Vale (Table 4.63) were generally more highly correlated than those of Cardiff, ranging from a high of .988 (ITN versus Open Roads) to a low of .437 (Euclidean and open Roads), with the lowest network correlation being .968, for UP and OSM.

When tested for differences using Friedman, both Cardiff and Vale 2SFCA results were found to have significant differences (chi-sq = 2114.800, p = < .001 for Cardiff, (chi-sq = 1163.734, p = < .001 for the Vale), therefore paired comparisons were conducted using Wilcoxon, the results of which are shown in Tables 4.64 and 4.65.

	Euclidean	ITN	UP	OR	OSM
Euclidean		*< .001*	*< .001*	*< .001*	*< .001*
ITN	-27.936		*< .001*	*< .001*	*< .001*
UP	-28.009	-6.680		*< .001*	*.129*
Open Roads	-27.972	-9.958	-4.197		*.149*
OSM	-27.983	-4.155	-1.517	-1.443	

Table 4.64: Differences between 2SFCA results for Cardiff community hubs. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001; red = not significant at 5%).

All but two combinations of Cardiff 2SFCA data had statistically significant differences at the < .001 level: OSM with UP; and OSM with Open Roads. Both were not significant at the 5% level. Neither combination was one of the highest correlations, meaning that one set of results cannot be relied on to provide a full picture of the situation regarding differences or similarities of the results of using this data.

	Euclidean	ITN	UP	OR	OSM
Euclidean		*< .001*	*< .001*	*< .001*	*< .001*
ITN	-16.284		*.003*	*< .001*	*.487*
UP	-16.283	-3.019		*< .001*	*.807*
Open Roads	-12.724	-17.592	-17.591		*< .001*
OSM	-16.363	- .696	-.244	-17.591	

Table 4.65: Differences between 2SFCA results for Vale community hubs. Below diagonal: Wilcoxon Z scores. Above diagonal: significance level (black = significant at < .001; green = significant at 1%; red = not significant at 5%).

The high correlations of the Vale were, again, reflected in the difference tests, this time with three out of the six network combinations returning Wilcoxon Z scores that were not significant at the < .001 level. UP with ITN was significant at the 1% level; both OSM with ITN and OSM with UP were not significant at the 5% level. All other combinations, and all those involving Euclidean results, had differences significant at the < .001 level.

Destination overlaps would provide an indication of the differences and similarities in a practical application, and the results for community hubs in Cardiff and the Vale showed considerable variation, as per Table 4.66 and 4.67.

Destination overlaps for Cardiff produced results which showed the combination of ITN and Open Roads again returning the highest value, of 96.5%. The lowest value was Euclidean and OSM with a figure of 72.4%. The lowest network overlap was 77.3% between UP and OSM, which may not have been expected due to OSM's ability to map roads and paths, and so appearing to have more in common with UP than, say, ITN. This does not appear to be the case in this instance, suggesting considerable differences between the two. Previous results which indicate relatively low coverage of OSM may also apply here, and further discussion will be detailed later, in Section 6.4.4.

	Euclidean	ITN	UP	OR
Euclidean				
ITN	74.0			
UP	76.1	85.2		
Open Roads	74.2	96.5	84.0	
OSM	72.4	84.8	77.3	84.7

Table 4.66: Destination overlaps (%) for Cardiff community hubs.

	Euclidean			
Euclidean		**ITN**		
ITN	75.2		**UP**	
UP	81.3	89.8		**OR**
Open Road	76.0	98.3	89.6	
OSM	74.5	91.7	84.2	90.5

Table 4.67: Destination overlaps (%) for Vale of Glamorgan community hubs.

The Vale of Glamorgan's highest destination overlap figure was 98.3%, for ITN with Open Roads (the same combination that produced the highest overlap figure for Cardiff and Vale GP surgeries, for Cardiff and Vale sports centres, and for Cardiff community hubs). The lowest was 74.5% between Euclidean and OSM data, the same combination as the lowest result for Vale sports centres and Cardiff community hubs. The lowest network comparison was 84.2% for UP and OSM, a repeat of the lowest Cardiff combination.

4.5.8 Destination overlap compendium

A summary of all destination overlap results for the five features is provided in Table 4.68, with the identities of the combinations which produced the highest and lowest destination overlap values. Note that results using Euclidean distance were not included in this particular table, and combinations which did include Euclidean distances were generally much lower than the various minima noted in the 'Low' columns of Table 4.68. Those lower combinations which involved Euclidean combinations are summarised in Table 4.69. The repeated appearance of Euclidean distance in the 'lowest' results, and paired with different comparators, provides a further indication of the wide differences in results obtained when using Euclidean measures and that, according to this study, there is no single simple conversion or comparison factor with which to convert it to a useful network distance.

The abbreviations used in Tables 4.68 and 4.69, are as follows:

- acc OS Sites access points;
- cen OS Sites centroids;
- per OS Sites polygon perimeter;
- PoI Point location taken from OS Points of Interest dataset.
- ITN OS Integrated Transport Network
- UP OS ITN plus Urban Paths
- OR OS Open Roads network dataset
- OSM OpenStreetMap network dataset

	Cardiff				Vale			
	High	**Networks**	**Low**	**Networks**	**High**	**Networks**	**Low**	**Networks**
Prim schools	98.3	ITN - OR (per-per)	65.8	ITN-OSM (PoI-per)	99.8	ITN – UP (PoI - per) ITN-ITN (cen - PoI)	77.9	UP – OSM (cen – PoI)
Sec schools	98.5	ITN - OR (PoI-PoI)	61.7	UP – OSM (PoI – per)	100	ITN – OR (per – per)	80.6	UP – OSM (cen – per) OR – OSM (per – cen)
GP surgeries	97.3	ITN - OR	85.7	UP - OSM	98.8	ITN - OR	88.1	UP - OSM
Sport centres	94.1	ITN - OR	81.6	UP - OR	99.8	ITN - OR	91.3	UP - OSM
Comm hubs	96.5	ITN - OR	77.3	UP - OSM	98.3	ITN - OR	84.2	UP - OSM

Table 4.68: Summary of destination overlap results (%), excluding combinations involving Euclidean distances.

	Cardiff		Vale	
	Low	**Networks**	**Low**	**Networks**
Prim schools	63.9	Eucl – OSM (PoI – cen)	68.9	Eucl – OSM (acc – PoI)
Sec schools	60.2	Eucl – OSM (PoI – cen)	78.4	Eucl – OSM (cen – per)
GP surgeries	77.4	Eucl – OSM	82.0	Eucl - ITN
Sport centres	76.4	Eucl - ITN	84.0	Eucl – OSM
Comm hubs	72.4	Eucl – OSM	74.5	Eucl – OSM

Table 4.69: Lowest destination overlap results (%).

Although different features may return different, absolute accessibility figures, it is also important to consider the further question as to what effect the networks have on both absolute and relative accessibility. Different networks were compared using different destination features and the outcomes compared. This chapter has reported the results for each accessibility case study and on some aggregations and collations of results in order to compare and contrast the outcomes of the various exercises and use these outcomes to identify issues with the datasets involved. Through these comparisons, and identification of issues, an indication of the degree of interchangeability or otherwise of the data will be identified.

4.5.9 Network issues

Some general observations could be made regarding the geospatial data used, following their use in GIS processes and subsequent statistical analysis. For example, the findings from accessibility research reveals that there was no replication of results between any two networks used in the context to the spatial analyses conducted here. When compared, there were important contrasts between datasets, and these contrasts were more marked in some combinations (as reported in the above sections). The comparisons between ITN and OSM networks had the largest number of differences NOT significant at the < .001 level, followed closely by two other combinations: OSM and Urban Paths; OSM and Open Roads. (Table 4.70 shows the aggregated Wilcoxon results for both distance and 2SFCA). As Open Roads was derived from the same base data used to produce ITN it may have been expected that the levels of difference would be lower. In fact the Open Roads – ITN combination had, by some margin, the greatest number of differences identified as statistically significant at the < .001 level, despite also returning strong correlations in many instances. It is entirely possible that the rankings of the results (as used in Spearman) in this specific comparison were similar, but that the differences between the datasets were such that they were also statistically significant. It is re-emphasised that in these circumstances, relying on the one statistical test may not be sufficient when attempting to identify similarities and differences.

Sig level	**Euclidean**			**ITN**			**UP**			**Open Roads**			**OSM**		
	>5 %	5%	1%	>5 %	5%	1%	>5 %	5%	1%	>5 %	5%	1%	>5 %	5%	1%
Eucl	5	1	1												
ITN	9	-	2	3	4-	2									
UP	8	1	2	9	4	3	2	1	2						
OR	7	-	1	4	2	-	8	1	3	3	1	1			
OSM	8	1	2	17	8	6	16	3	5	15	4	6	3	1	1

Table 4.70: Comparing networks and numbers of less-significant and non-significant differences.

Specific network issues (and some general observations regarding the network datasets used here) are discussed in more detail in Chapter 6, where potential reasons for the observed trends are provided in relation to the provenance of the data and the application task in hand.

4.6 Supplementary analyses

This section examines a variety of aspects relating to the accessibility studies and the processes used for this thesis. Though not directly related to any one specific case study, these analyses still contribute towards the aim and objectives of this thesis relating to underlying issues regarding the data utilised and the processes used, and therefore contributes to the overall understanding to the usability of the specified geospatial datasets. Section 4.6.1 proposes a method of unifying the various tabular and statistical results into one overall score, so providing a convenient and easily-comprehended factor which summarises many separate statistical outcomes.

4.6.1 Utility Factor

Section 3.13 describes the Utility Factor as a method of summarising the tabular and statistical results from the various usability analyses and presenting them in one easily-comprehended figure. This figure indicates the potential interchangeability of each pair of datasets, hence their relative usability, in a given context. The Utility Factors resulting from the calculations of Equation 3, as applied to the results of this thesis, are provided in Tables 4.71 to 4.90, applied to measures of both distance and of 2SFCA. A simple classification system has been applied to the tables, highlighting Factors over 90 in green, and those over 80 (but less than 90) in amber. These notional splits are intended to show the higher results, and any particular split may be chosen to represent: interchangeable to a high degree; interchangeable to a lesser degree; down to a category of not interchangeable. The levels chosen would reflect the context of the use of the data, with lower levels being set when importance or risk is classified as low. In the case of this thesis, it is suggested here that any factor under 80 is deemed 'not usable' in place of another dataset listed here, and over 90 classed as 'interchangeable' or as 'useful.' When compared with the tabular and mapped results, there is some overlap between the factors marked here as useful and those with high correlations, low levels of difference and high destination overlaps.

It is emphasised that the Utility Factor applies to the datasets used in the context of the research for this thesis and for the particular GIS tasks conducted. For use with other tasks it would have to be adapted. However, in any comparison of results it would be expected that indications of correlation would be obtained (Spearman, in this case), and it is suggested here that a statistical indication of difference should also be obtained (Wilcoxon was used here), along with some measurement of the practical effect of the use of the different datasets (in this case destination overlap was used.

The results of the Utility Factor bear some similarity to those of correlations and difference (as would be expected), but the frequency of 'similar' datasets being recognised is relatively low. They are still concentrated on the diagonals, indicating that the method of representation of supply-side location has a major influence of levels of similarity. This is confirmed through the results of PoI point features such as GP surgeries and sports centres, where similar results were obtained with almost all network datasets, but not when compared to Euclidean distances. The indication here was that in those particular contexts, the network datasets had a high degree of interchangeability, and were therefore similarly usable.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	69	Acc																	
Per	67	55	Per																
PoI	82	65	57	PoI															
ITN					**ITN**														
Cent	34	31	32	30	Cen														
Acc	34	41	32	32	57	Acc													
Per	54	47	47	48	46	47	Per												
PoI	30	29	28	34	65	57	43	PoI											
UP									**UP**										
Cent	44	41	42	39	63	58	52	48	Cen										
Acc	43	53	42	41	45	65	55	43	61	Acc									
Per	64	55	55	57	39	40	72	36	51	51	Per								
PoI	41	41	39	46	48	55	49	62	68	61	48	PoI							
OSM													**OSM**						
Cent	33	29	31	29	75	57	46	57	57	45	39	51	Cen						
Acc	34	41	32	32	56	90	48	49	58	68	41	58	58	Acc					
Per	53	46	46	47	46	47	90	37	52	54	72	47	47	48	Per				
PoI	30	30	29	33	62	57	43	80	50	46	37	59	69	58	44	PoI			
OR																	**OR**		
Cent	35	31	33	31	86	59	47	67	65	46	39	49	74	57	47	62	Cen		
Acc	33	41	32	32	54	81	48	53	59	72	40	56	55	90	47	56	56	Acc	
Per	55	48	47	48	46	47	88	42	51	54	78	48	46	48	91	42	47	46	Per
PoI	30	28	28	34	60	55	42	82	47	41	35	63	59	53	42	77	64	52	41

Table 4.71: Utility factors, Cardiff primary schools, using distance measurements.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	62	Acc																	
Per	69	62	Per																
PoI	58	55	56	PoI															
ITN					**ITN**														
Cent	13	11	12	7	Cen														
Acc	23	25	23	12	32	Acc													
Per	26	25	27	13	32	61	Per												
PoI	17	14	15	26	52	25	25	PoI											
UP									**UP**										
Cent	14	12	13	8	78	28	32	45	Cen										
Acc	24	27	25	13	25	76	59	17	29	Acc									
Per	27	26	28	13	29	53	81	19	31	63	Per								
PoI	19	15	16	28	46	21	22	76	53	21	22	PoI							
OSM													**OSM**						
Cent	13	11	11	7	81	29	30	45	72	23	27	48	Cen						
Acc	22	25	23	12	30	81	59	21	28	79	52	21	31	Acc					
Per	26	25	26	13	31	59	79	23	30	59	82	21	32	61	Per				
PoI	20	17	18	26	50	25	25	78	46	19	20	70	55	27	27	PoI			
OR																	**OR**		
Cent	22	18	20	24	69	31	32	58	58	24	26	55	59	30	31	61	Cen		
Acc	35	35	35	20	30	68	55	23	28	59	50	20	30	65	54	25	30	Acc	
Per	39	35	39	26	31	55	70	25	30	53	62	23	29	54	66	26	33	59	Per
PoI	17	13	15	26	51	24	24	88	45	17	19	76	49	22	23	77	57	23	24

Table 4.72: Utility factor, Cardiff primary schools, using 2SFCA measurements.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	81	Acc																	
Per	59	65	Per																
PoI	67	63	50	PoI															
ITN					**ITN**														
Cent	46	44	42	36	Cen														
Acc	45	48	44	38	72	Acc													
Per	52	52	50	44	58	61	Per												
PoI	36	38	36	50	57	49	47	PoI											
UP									**UP**										
Cent	59	59	57	43	66	78	61	45	Cen										
Acc	61	61	58	47	58	62	72	43	70	Acc									
Per	68	65	61	53	55	54	70	40	63	70	Per								
PoI	42	44	42	59	55	54	46	65	57	49	46	PoI							
OSM													**OSM**						
Cent	38	44	42	31	78	61	51	53	59	52	49	47	Cen						
Acc	43	43	39	33	78	72	52	53	61	53	48	55	60	Acc					
Per	40	42	43	33	62	62	48	45	57	49	43	49	57	62	Per				
PoI	35	36	35	49	54	48	40	79	46	42	39	68	53	53	54	PoI			
OR																	**OR**		
Cent	47	47	47	37	92	64	55	61	60	56	54	56	76	71	57	58	Cen		
Acc	51	52	50	40	68	85	65	52	74	68	58	57	60	67	64	48	64	Acc	
Per	63	61	58	49	57	58	83	42	60	76	77	46	51	53	47	41	56	62	Per
PoI	37	44	37	50	60	50	46	87	46	43	41	72	54	54	47	84	63	53	42

Table 4.73: Utility factor, Cardiff secondary schools, using distance measurements.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	85	Acc																	
Per	66	72	Per																
PoI	68	70	53	PoI															
ITN					**ITN**														
Cent	1	0	-5	0	Cen														
Acc	-1	-1	-6	-2	83	Acc													
Per	4	4	1	3	68	64	Per												
PoI	14	15	12	21	33	35	29	PoI											
UP									**UP**										
Cent	-4	-4	-10	-4	77	75	51	30	Cen										
Acc	-6	-6	-12	-6	73	75	51	30	83	Acc									
Per	6	6	5	5	45	40	64	13	38	36	Per								
PoI	11	11	7	17	24	27	19	76	31	36	9	PoI							
OSM													**OSM**						
Cent	-1	-1	-7	-2	80	77	60	30	76	71	41	24	Cen						
Acc	-3	-3	-8	-3	73	82	60	31	71	72	37	27	69	Acc					
Per	4	4	1	3	60	58	73	25	46	44	57	17	58	59	Per				
PoI	14	14	10	19	32	32	22	77	32	30	10	70	34	34	25	PoI			
OR																	**OR**		
Cent	20	19	16	15	65	58	48	54	52	50	29	46	55	53	43	49	Cen		
Acc	19	19	16	14	60	65	52	56	51	55	27	48	55	59	45	48	85	Acc	
Per	24	23	26	18	36	30	48	21	26	24	63	15	29	26	44	20	46	45	Per
PoI	14	15	12	21	33	34	28	92	30	30	14	75	29	31	25	76	54	57	23

Table 4.74: Utility factor, Cardiff secondary schools, using 2SFCA measurements.

	Euclidean	ITN	UP	OR
Euclidean				
ITN	45			
UP	56	65		
OR	45	89	70	
OSM	42	86	63	85

Table 4.75: Utility factor, Cardiff GP surgeries, distance

	Euclidean	ITN	UP	OR
Euclidean				
ITN	59			
UP	65	81		
OR	60	92	84	
OSM	60	84	80	84

Table 4.77: Utility factor, Vale GP surgeries, distance

	Euclidean	ITN	UP	OR
Euclidean				
ITN	-20			
UP	-16	74		
OR	-18	84	75	
OSM	-16	83	69	80

Table 4.76: Utility factor, Cardiff GP surgeries, 2SFCA

	Euclidean	ITN	UP	OR
Euclidean				
ITN	41			
UP	45	92		
OR	41	97	91	
OSM	42	89	84	86

Table 4.78: Utility factor, Vale GP surgeries, 2SFCA

	Euclidean	ITN	UP	OR
Euclidean				
ITN	45			
UP	56	60		
OR	46	86	62	
OSM	47	79	63	75

Table 4.79: Utility factor, Cardiff sports centres, distance

	Euclidean	ITN	UP	OR
Euclidean				
ITN	-5			
UP	-7	69		
OR	-6	87	52	
OSM	-6	80	61	76

Table 4.80: Utility factor, Cardiff sports centres, FCA

	Euclidean	ITN	UP	OR
Euclidean				
ITN	63			
UP	69	79		
OR	64	96	81	
OSM	63	95	79	94

Table 4.81: Utility factor, Vale sports centres, distance

	Euclidean	ITN	UP	OR
Euclidean				
ITN	50			
UP	50	87		
OR	49	92	88	
OSM	47	92	86	89

Table 4.82: Utility factor, Vale sports centres, FCA

	Euclidean	ITN	UP	OR
Euclidean				
ITN	41			
UP	49	62		
OR	41	94	64	
OSM	40	80	59	80

Table 4.83: Utility factor, Cardiff community hubs, distance

	Euclidean	ITN	UP	OR
Euclidean				
ITN	52			
UP	62	75		
OR	53	88	78	
OSM	51	88	73	88

Table 4.85: Utility factor, Vale community hubs, distance

	Euclidean	ITN	UP	OR
Euclidean				
ITN	0			
UP	-2	73		
OR	0	86	74	
OSM	-3	78	68	81

Table 4.84: Utility factor, Cardiff community hubs, FCA

	Euclidean	ITN	UP	OR
Euclidean				
ITN	23			
UP	26	85		
OR	24	80	72	
OSM	22	88	81	72

Table 4.86: Utility factor, Cardiff community hubs, FCA

Eucl	Eucl																		
Cent	Cen																		
Acc	82	Acc																	
Per	77	77	Per																
PoI	92	80	75	PoI															
ITN					**ITN**														
Cent	54	53	51	52	Cen														
Acc	57	55	54	54	73	Acc													
Per	67	63	62	51	64	66	Per												
PoI	54	52	51	52	99	79	65	PoI											
UP									**UP**										
Cent	63	61	60	60	74	78	69	75	Cen										
Acc	64	65	62	62	66	74	74	66	78	Acc									
Per	72	67	67	69	59	61	79	71	67	70	Per								
PoI	61	59	59	63	69	78	68	70	83	79	66	PoI							
OSM													**OSM**						
Cent	52	50	49	50	85	78	65	85	69	63	59	68	Cen						
Acc	55	55	53	53	76	91	79	76	76	74	63	75	77	Acc					
Per	64	60	60	61	66	70	90	66	69	74	80	69	67	70	Per				
PoI	48	46	46	49	77	76	60	77	65	61	61	69	78	74	61	PoI			
OR																	**OR**		
Cent	55	53	52	52	88	80	65	88	75	66	69	68	87	75	66	76	Cen		
Acc	57	57	54	54	77	88	68	77	77	77	69	77	76	89	69	73	77	Acc	
Per	64	60	60	62	66	69	90	66	68	74	80	70	66	71	92	60	66	68	Per
PoI	50	49	48	51	79	74	59	80	66	62	62	71	75	70	59	89	81	72	61

Table 4.87: Utility factor, Vale primary schools, using distance measurements.

Eucl	**Eucl**																			
Cent	Cen																			
Acc	80	Acc																		
Per	71	75	Per																	
PoI	76	73	83	PoI																
ITN					**ITN**															
Cent	34	34	11	20	Cen															
Acc	27	28	12	17	57	Acc														
Per	0	-1	8	6	20	14	Per													
PoI	-16	-14	-13	-12	-15	-17	-5	PoI												
UP									**UP**											
Cent	37	36	11	21	87	55	19	-14	Cen											
Acc	33	35	10	19	78	64	21	-13	81	Acc										
Per	-6	-6	7	3	12	9	84	-5	12	13	Per									
PoI	-16	-15	-14	-13	-12	-11	-3	78	-13	-13	-3	PoI								
OSM													**OSM**							
Cent	31	32	10	18	90	59	21	-15	77	76	14	-13	Cen							
Acc	27	29	8	16	80	67	23	-13	74	83	15	-11	78	Acc						
Per	-3	-4	6	3	18	10	83	-5	16	18	84	-4	20	21	Per					
PoI	0	1	-15	-15	46	28	8	-2	43	44	6	-3	47	48	10	PoI				
OR																	**OR**			
Cent	-25	-24	-21	-22	-27	-25	-12	-19	-25	-25	-16	-17	-24	-22	-10	-24	Cen			
Acc	18	18	-3	8	76	53	19	-21	69	72	10	-18	74	75	17	45	-20	Acc		
Per	-8	-9	-6	62	24	13	77	-18	22	23	65	-16	27	27	73	3	-8	26	Per	
PoI	9	9	-7	2	61	40	32	-18	54	56	24	-16	58	59	31	40	-23	63	52	

Table 4.88: Utility factor, Vale primary schools, using 2SFCA measurements.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	79	Acc																	
Per	79	68	Per																
PoI	93	78	77	PoI															
ITN					**ITN**														
Cent	57	58	55	59	Cen														
Acc	55	65	55	60	68	Acc													
Per	76	66	72	76	61	62	Per												
PoI	55	65	54	60	73	74	59	PoI											
UP									**UP**										
Cent	64	63	62	65	78	73	66	75	Cen										
Acc	66	72	64	68	65	78	70	73	71	Acc									
Per	80	70	73	81	61	64	85	62	68	69	Per								
PoI	63	68	61	66	69	84	65	79	77	78	67	PoI							
OSM													**OSM**						
Cent	55	62	63	57	90	70	59	76	77	66	63	68	Cen						
Acc	50	65	53	60	66	91	60	81	71	77	63	84	69	Acc					
Per	53	61	61	67	70	79	73	68	70	73	71	74	67	75	Per				
PoI	54	64	53	61	74	74	58	93	73	72	61	79	78	77	68	PoI			
OR																	**OR**		
Cent	57	59	55	60	90	68	62	73	80	65	62	69	88	68	69	74	Cen		
Acc	57	67	55	62	67	89	63	75	72	79	66	83	68	86	77	75	68	Acc	
Per	72	66	68	75	64	67	94	64	68	74	84	68	62	66	78	63	65	68	Per
PoI	56	66	55	61	73	75	59	94	76	64	63	81	75	81	68	90	74	77	64

Table 4.89: Utility factor, Vale secondary schools, using distance measurements.

Eucl	**Eucl**																		
Cent	Cen																		
Acc	86	Acc																	
Per	75	68	Per																
PoI	95	84	74	PoI															
ITN					**ITN**														
Cent	27	27	9	29	Cen														
Acc	30	32	12	32	81	Acc													
Per	6	6	2	9	48	53	Per												
PoI	20	22	2	24	67	70	44	PoI											
UP									**UP**										
Cent	30	29	11	31	86	81	49	63	Cen										
Acc	31	33	13	33	80	85	51	67	86	Acc									
Per	-2	-1	-1	1	38	39	84	32	41	43	Per								
PoI	19	20	1	22	64	66	43	88	68	73	38	PoI							
OSM													**OSM**						
Cent	22	23	7	23	85	74	51	60	79	74	43	58	Cen						
Acc	24	28	8	28	77	93	51	67	76	86	41	64	74	Acc					
Per	0	1	-7	1	45	46	73	34	43	44	66	34	50	50	Per				
PoI	14	16	-3	18	63	64	44	89	60	62	34	86	64	66	39	PoI			
OR																	**OR**		
Cent	24	24	4	26	79	65	39	75	75	67	31	79	67	64	38	74	Cen		
Acc	26	28	6	28	64	77	42	77	67	72	31	81	59	72	37	77	79	Acc	
Per	-1	0	-7	1	44	44	72	48	47	47	66	50	45	47	62	49	51	51	Per
PoI	19	20	0	22	66	68	42	87	65	60	33	89	59	66	34	87	79	83	50

Table 4.90: Utility factor, Vale secondary schools, using 2SFCA measurements.

4.6.2 Comparison of travel distance and 2SFCA

In order to assess whether any relationship existed between the results of the two main approaches to measuring accessibility in this study, correlation tests were conducted on a limited sample of the results, in this case those of sports centres, considered typical. Although patterns of correlations and differences (as measured by Spearman and Wilcoxon tests, respectively) did not appear to show a great degree of similarity, if a relationship had existed between the results of the relatively simple distance measures and those from the more complex 2SFCA calculations, then researchers could reasonably use the lesser complex method, without the need for specialist tools (such as the 2SFCA plug-n or custom-built tools) or for gathering supply- and demand-level data. The results of the comparison are shown in Table 4.91.

(a) Cardiff

		2SFCA				
		Eucl	**ITN**	**UP**	**OSM**	**Open Roads**
Distance	**Eucl**	**- .009**	**- .045**	**- .024**	**- .057**	**- .037**
	ITN	**.003**	**- .079**	**- .041**	**- .084**	**- .080**
	UP	**.013**	**- .045**	**- .020**	**- .053**	**- .045**
	OSM	**.049**	**- .036**	**.013**	**- .028**	**- .039**
	OR	**.013**	**- .066**	**- .030**	**- .069**	**- .068**

(b) Vale

		2SFCA				
		Eucl	**ITN**	**UP**	**OSM**	**Open Roads**
Distance	**Eucl**	**- .158**	- .185	**- .157**	- 203	- .177
	ITN	**- .003**	**- .011**	**.009**	**- .029**	**- .003**
	UP	**.006**	**.020**	**.016**	**.002**	**.027**
	OSM	**- .019**	**- .011**	**- .005**	**- .030**	**- .003**
	OR	**.002**	**.006**	**.014**	**- .013**	**.007**

Table 4.91: Correlations between travel distance and 2SFCA using Spearman's rank correlations. Significance levels: black = sig at <.001; green = significant at 1%; amber = significant at 5%; red = not significant at 5%.

Results for 2SFCA and distance could not be compared directly as the former is a ratio and the latter an absolute value. However, a comparison of their rankings in a particular situation could be made, and the Spearman test would be applicable. The examination therefore looked at a comparison of distance and 2SFCA results for the same features, using the same network, to assess whether a statistical relationship existed between the two types of measure.

Overall, there were very low levels of correlation, with very few sets of results significant at the < .001 level. The pattern of correlation results differed between those of Cardiff and the Vale. Such weak levels of correlation suggested the probability of significant differences between the paired comparisons, which the results of paired Wilcoxon confirmed, with Z scores for Cardiff and the Vale, at -28.428 and -17.589, respectively, which indicated differences significant at the < .001 level. It was therefore concluded that when compared, results of accessibility using shortest travel distance and 2SFCA produced significantly differently ranked sets of results. Although identification of a simple conversion factor between distance and 2SFCA would have been convenient, the lack of a consistent relationship made this impossible. The results of this analysis indicate the strong influence of supply and demand weightings within the chosen thresholds on the 2SFCA results.

4.6.3 Destination overlaps – assessment of consistency

The outcomes of destination overlaps were reviewed to ascertain whether any combinations of networks or locational representations returned consistently high, or low, results. Table 4.92 represents an amalgamation of all destination overlap results from primary and secondary schools, for both Cardiff and the Vale. The table provides a 'heat map' of the combinations of data which resulted in the mean results as stated, with the yellow, amber and red cells indicating increasing levels of average destination overlap, enabling a simpler visual analysis of the 'hotter' combinations which have high overlap and those which are 'colder' (the blue cells) which have the lowest destination overlaps.

As reflected in the results reported throughout this chapter, it was postulated that many of the results for ITN and Open Roads combinations would have had high destination overlaps, as the Open Roads network was very similar to that of ITN. Less expected were the results from OSM which showed consistently high overlaps with the ITN destinations, and as noted when looking at destination overlaps earlier, there were particularly high values from OSM and ITN results in the Vale of Glamorgan, potentially due to there being less 'competition' between destinations, in that there were fewer alternative supply points within a relatively short distance of the closest feature. It was also intuitively assumed that the 'diagonals' in Table 4.92, comparing the same feature location method for different networks, would have the higher overlap figures, and this is borne out by the averages. Again, it should be expected that the lowest averages were concentrated in the comparisons involving Euclidean distances: all the other networks generally had a similar pattern of roads, with all main roads present in all datasets, with small differences in detail contributing to the changes in distance and destination; Euclidean measurements had the least in common when compared to all the others.

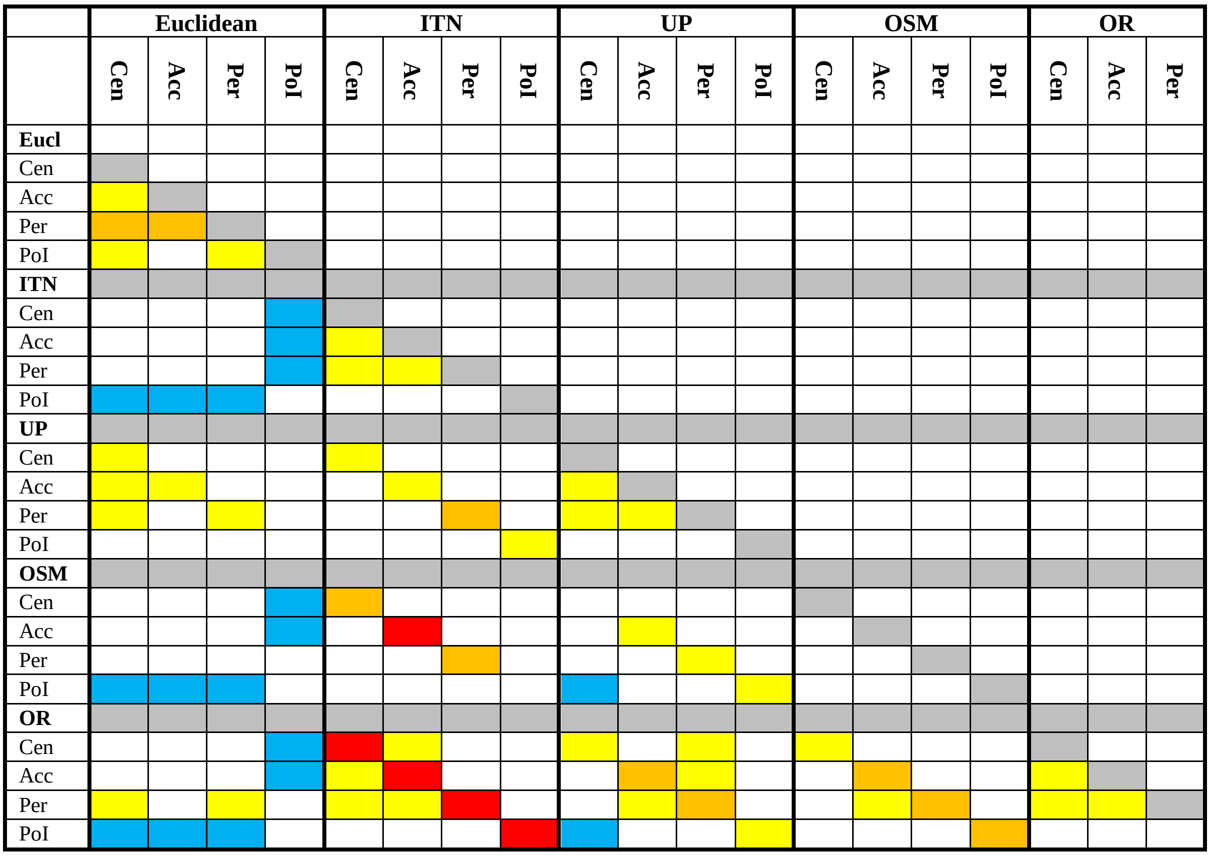


Table 4.92: Cardiff and Vale, primary and secondary schools: average destination overlap (%). Key: Blue = < 75%; White = 75-85%; Yellow = 85-90%; Amber = 90-95%; Red = 95-100%.

Results were averaged for all features (not just schools, with their four alternative methods of location), using Points of Interest locations, and the results shown in Table 4.93. Ranging from a maximum of 96.8% down to 77.9%, the averages provide a reasonable indication of the degree of similarity of nearest destinations. The gap between Euclidean and networked results are clear, but in many instances the averages obscure a considerable amount of variation. These results give an indication of the differences due to the network form of representation.

	Euclidean	ITN	UP	OSM
Euclidean				
ITN	78.9			
UP	84.0	89.5		
OSM	77.9	90.1	85.1	
Open Roads	78.9	96.8	88.9	89.9

Table 4.93: Average destination overlap figures for all Points of Interest locations for Cardiff.

4.6.4 Implications of changes to OSM on accessibility findings

As can be seen through the body of this thesis, the OS datasets that were the major subject of analysis were also compared to a third-party, VGI network dataset: OpenStreetMap (OSM). Although there were some conflicting views in the literature regarding the quality of VGI (Goodchild and Li, 2012; Haklay 2010b), there were strong indications that OSM was a rapidly-developing data source which was 'catching up' with official, government products that were seen as the gold standard in many countries (Haklay, 2010b). Although for the main case studies a 'snapshot' of OSM data was used to compare with snapshots of OS data taken at the same time (with the exception of Open Roads, which was launched in 2015), an examination as to the nature of the changes to the OSM networks over time could provide some information as to its quality and coverage. This would have relevance as to the usability of OSM, particularly as a competitor product to those of Ordnance Survey, and could also have implications for the findings presented earlier in this chapter.

A separate study was therefore made of the development of the OSM network in the study areas, conducted over a two year period, with comparisons of total network lengths in both Cardiff and the Vale of Glamorgan study areas. The results of this comparison are shown in Table 4.94.

a) OSM	**Jan 14**	**Jul 14**	**Jan 15**	**Jul 15**
Cardiff (m)	1,239,931	1,281,099	1,576,027	1,472,779
Change		+3.3%	+23.0%	-6.6%
Vale (m)	929,757	940,167	1,003,167	1,121,390
Change		+1.1%	+6.7%	+11.8%

b) ITN	**Jan 14**	**Jul 14**	**Jan 15**	**Jul 15**
Cardiff (m)	1,376,754	1,377,412	1,377,889	1,382,597
Change		+0.05%	+0.03%	+0.34%
Vale (m)	1,190,614	1,190,610	1,191,428	1,202,024
Change		-0.0003%	+0.07%	+0.9%

Table 4.94: Comparison of total network lengths (in metres) over two years of (a) OSM and (b) ITN, for both Cardiff and the Vale of Glamorgan, with year-on-year changes.

The differences between OSM and ITN over time are given in Table 4.95 and represented graphically in Figure 4.1, showing the gradual change through time of ITN, and the more radical movements in OSM data.

The results for OSM indicate considerable changes through time, especially compared to the relatively consistent total network length of ITN. The rapidly-evolving nature of OSM is particularly evident in the Vale of Glamorgan, where network lengths have increased radically over the two-year study period, indicating the increased amount of data added to the network in that time. Reasons for this trend are discussed later in this section.

Difference OSM - ITN	**Jan 14**		**Jul 14**		**Jan15**		**Jul 15**	
	Length (m)	%	Length (m)	%	Length (m)	%	Length (m)	%
Cardiff	-136,823	-11.0	-96,313	-7.5	+198,138	+12.6	+90,182	+6.1%
Vale	-270,171	-29.1	-250,443	-26.6	-188,493	-18.8	-80,634	-7.2%

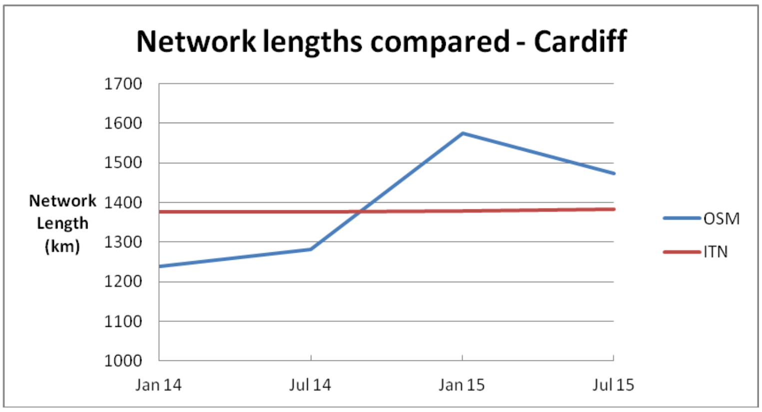
Table 4.95: Differences in total network lengths between OSM and ITN, in absolute terms (metres) and proportions (%),

The wide variations in OSM in Cardiff are partly indicative of classification issues, where a large amount of data was added between July 2014 and January 2015. The reduction in the following period could perhaps have been caused by incorrect additions being corrected (that is, removed) or where lengths had been reclassified out of the roads categories and in to other classifications (see Chapter 3 for the methodology of selecting network 'lengths' to be included in the assessment).

Lack of clarity on classifications, and lack of a clear ontology, casts a level of uncertainty on the selection of the elements with which to create a required network, causing potential mismatches with other networks from other providers, with no guarantee or assurance that the OSM network was the most appropriate or suitable to be use. OSM contributors do have a classification system (OpenStreetMap, 2016) in the form of a 'wiki,' which describes the listed 'tags' as 'commonly-used' or 'principle tags,' but there is no system compelling mappers to include any tags, or restrict the classifications they input. Indeed, the 'free' aspects of OSM ('free' in terms of FOSS) extend to the freedom to classify and tag as users see fit (Antoniou et al, 2010).

The issue of multiple parallel lines along some of Cardiff's main roads was mentioned in Chapter 3, where each lane in the carriageway was treated as a separate road edge, and the pavement had edges representing a footpath and a cycleway in each direction, resulting in one road being represented by 8 separate 'ways,' side by side, with each 'surplus' line having contributed to an erroneous, over-estimated, total. Although not affecting nearest destination figures (the nearest destination would be identified by whatever one way was shortest) this representation imposed an unnecessary computational load but, more importantly, illustrated the uncertainty contained in the map, with some contributors unclear as to the representation and classification of features, which has clear implications for usability.

a)



b)

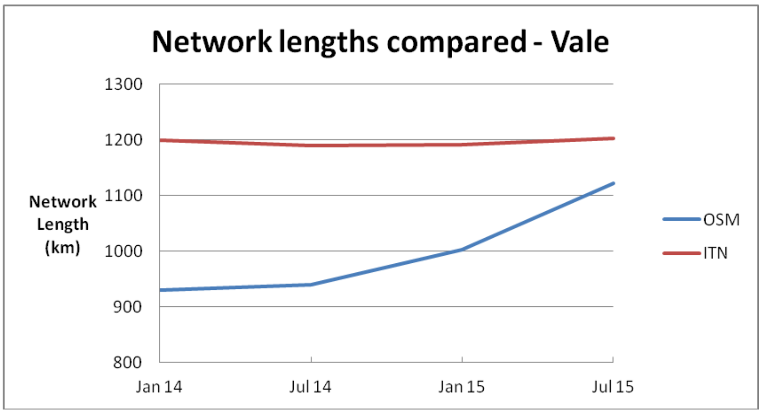


Figure 4.1: Comparison of total network lengths (in kilometres) of OSM and ITN over two years for (a) Cardiff and (b) Vale of Glamorgan.

Through visual examination the OSM dataset appeared to have many more paths and throughways within dense urban environments, with many alleys and walkways included in OSM that did not appear in ITN (between buildings and through shopping centres, for example). These were offset with ITN including some small roads and ways mapped in suburban and more rural districts which did not appear on the OSM network. One further observation was that in some areas where large car parks were a feature, the routes both into and around the car parks, including each individual parking space, was mapped in OSM. Although each length was only a few metres they were numerous, and around retail parks, for example, may have contributed to the larger overall total. The crowd-amending nature of OSM may also have meant that mappers with differing interpretations of how (for example) car parks should be represented could change the map of such areas at any time. This illustrated both the positive and negative aspects of VGI mapping: that information considered insignificant by some mapping agencies may be included in map datasets to be used by anyone who required it; and that OSM map content can vary day-by-day, resulting in a level of uncertainty in use when use is made of a spatial snapshot. It cannot be said with a strong degree of certainty that the results obtained using OSM in this study would be replicated in any other timeframe. Indeed, different results could have been obtained if the OSM network was downloaded the following day. Day-to-day variations in completeness and quality of OSM data have not yet been reported in the literature, and therefore appropriate suggestions as to future work have been made in Chapter 7.

In attempting to ascertain whether the level of updates of areas such as the Vale of Glamorgan were poor compared to larger urban areas, some difficulty was encountered in attempting to quantify numbers and times of amendments. In OSM the dates of amendments were given, but details of the content of changes was variable, with some users having provided full details of their amendments (for example, "Identifying and labelling a house, located on Eling Farm"), while others were vague, general, or gave no detail at all (for example, "Modified via wheelmap.org"). It was also impractical to check the amendment history of every node and way within the study areas (each had its own history, sometimes consisting of several changes in one day and many more over a longer period), therefore it was decided to use the number of active volunteer mappers at work in each area as a proxy for actual map updating activity. In order to access such data, online tools used to analyse OSM data were obtained from ItoWorld (http://www.itoworld.com/static/ito_tools.html). These tools enabled the data 'behind' OSM maps to be extracted, area by area. This data included figures for the number of users for the study areas, along with the total number of sessions logged. A 'session' was defined by Ito as "a series of edits by one user, with consecutive edits not more than one hour apart" (ItoWorld, 2015). It was accepted that some users may have made only one edit in a session, some may have made more than one. However, the figures were used to obtain a relative impression of activity over an area, rather than precise numbers.

The table and graphs below refer to the figures obtained in July 2015, and were obtained by using ItoWorld tools at the same zoom level for each area, as the tools obtained the data for the area of the OSM map visible on a screen, with there being no option of selecting a more-precise area. Table 4.96 compares the levels of activity for the study areas to other areas in the UK, with Figure 4.2 showing the results graphically.

	Vale	**Cardiff**	**Bristol**	**London**
No. of users	273	280	457	1560
Total sessions	2466	3360	5711	22580
Sessions - year to 14 July 2015	204	335	577	2163

Table 4.96: OSM users and sessions for the Vale of Glamorgan and Cardiff compared to the more urbanised areas of Bristol and London, sampling similarly-sized areas.

Table 4.96 and Figure 4.2 show the relatively low number of contributors and sessions in the two South Wales study areas compared to areas of the same size in other UK locations. Cardiff and the Vale had a similar number of users/contributors, and the Vale had a lower number of editing sessions than Cardiff. Bristol had over one and a half times their number of contributors with twice the number of editing sessions as the Vale, and over one and a half times the number of editing sessions as Cardiff. London has just under ten times the number of sessions as the Vale or Cardiff, and around six times the number of contributors.

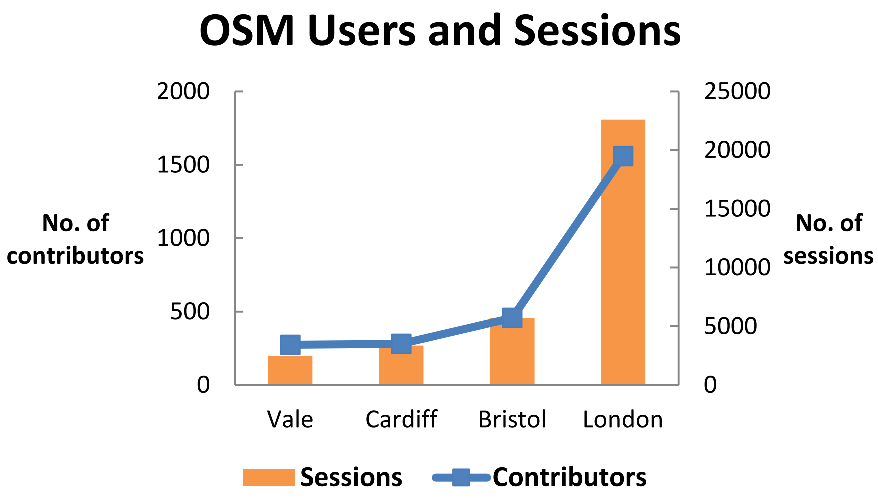


Figure 4.2: OSM users and sessions, showing activity levels for the study areas compared to Bristol and London, sampling similarly-sized areas.

Haklay (2010b) noted the increasing coverage of OSM as it caught up with 'official' map products, but also noted how coverage dropped off sharply as distance from main urban centres increased, while also noting that it was not uncommon to find OSM information gaps in highly populated areas. These findings were borne out by the figures stated above, and by the relative lack of sessions in the Vale of Glamorgan. A similar number of users in Cardiff have been more active, but in use the OSM network gave indications of other problematic issues. Further work will be required to isolate and identify these issues, particularly on the classifications of network lengths and the representation of roads and paths that have several and joint classifications (for example, a footpath that is also a cycle path). It was estimated that many of these issues were caused by input error, with data creators or editors not familiar with OSM classifications, or not realising the importance of classifications in further use and analysis.

It seemed intuitively correct that the degree of change within a rural area over a period of time would be less than that found in urban areas, but that some significant changes would occur. If OSM is assumed to be currently in a 'catch-up' phase compared to the gold-standard products of state mapping agencies and current low levels of change were maintained, it would seem OSM will remain lagging for some time yet. Little research has been conducted into any critical threshold of numbers of contributors required for crowd-sourced or VGI data to reach and maintain high levels of usability, but with the wide variation in user numbers and network lengths, it may be some time before OSM data becomes a trusted source of data for accessibility research purposes or essential tasks. Another danger is that OSM data is used with little awareness of its shortcomings, some of which are as outlined above, with decision makers simply accepting the map data as definitive without questioning its provenance (in line with Monmonier's 1996 assertion of map data being seen by non-experts as more authoritative than other information sources). Information and awareness therefore remain key issues when dealing with map data, and the use of OSM provides an appropriate illustration.

With respect to the use of OSM in the case studies conducted for this thesis, the implications of such longitudinal changes as identified within the 2-year period described above were considerable. Although the overall trend was gradual, short-term variations were dramatic. Such variation could affect network travel considerably and have a severe effect on accessibility assessment results, depending on the content and quality of the data at any particular time. As has been outlined in this section, the content and quality of OSM are two characteristics which cannot be predicted or accounted for at the time of use. Questions as to the completeness and logical consistency of OSM data, allied to a lack of metadata and of information as to producer reputation (that is, of the individual contributor), cast doubt on the authority and trust levels of the data (all these features being usability elements), if used in such analyses as the accessibility case studies carried out in this thesis. It could not be stated with any certainty, given these caveats, that the results obtained using OSM in this thesis from the data provided at the time would be the same if identical analysis was carried out on more up-to-date OSM data. There would also be the added danger that any snapshot or temporal slice of data would coincidentally include an element of extremely poor quality or mistakenly classified data, issues less likely to be encountered with proprietary data.

A potential area for future work with regard to OSM would be to conduct analysis on OSM data at various temporal cut-offs: in effect take snapshots of the same areas at different times, conduct typical GIS analysis and see if results change. For comparative purposes the same snapshots could be taken of proprietary GI (such as ITN or Open Roads) and the differences, if any, examined. In this study there was no attempt to use the OSM data obtained at two or more cut-off points for any type of analysis: the OSM data itself was compared over time. A potentially useful suggestion for the future would be if using OSM for any 'serious' analytical purpose: to get several snapshots of data beforehand from different times; measure it in some way (eg total network length); compare the results from each temporal cut-off; identify and discard any snapshots which exhibits erratic or extreme swings in results; and use one of the time slices without wide variation in the final analysis. This approach would reduce the chances of using one download and unknowingly obtaining one of the extreme variations, such as was found in the January 2015 download during this research.

4.7 Chapter summary

This chapter reported on the results of the multiple accessibility analyses, conducted to perform sensitivity analysis on the data relevant to supply-side features and network datasets. The outcomes of multiple statistical analyses on comparisons of the results of the accessibility analyses both on distance and 2SFCA measures were reported, with tables showing the aggregated results (with the results of visual analysis reported in Chapter 5).

For comparisons between distance measurements, all five features (primary schools, secondary schools, GP surgeries, sports centres and community hubs) in Cardiff, ITN and Open Roads had the highest correlations, and where there were multiple location options (that is for primary and secondary schools), the perimeter to perimeter comparisons between the same two networks were the highest correlating comparisons. For the Vale, the highs were more distributed, with ITN-ITN returning the highest values (centroids versus PoI and for access points versus PoI for primary and secondary schools, respectively. The other three features in the Vale all had ITN as one of the highest correlation pairs, with Open Roads and OSM both featuring in these comparisons.

For lowest correlations, initially it was thought that any comparisons with Euclidean distance would have the lowest outcomes, and this was indeed the case with all Cardiff features except for secondary schools, and was the case without exception for Vale features. When only network datasets were considered, the pattern was slightly different between Cardiff and the Vale. In the Vale, OSM occurred in the lowest comparisons for all features, with comparisons either to ITN or UP, with Cardiff having OSM compared to UP as lowest for three features, but with UP-Open Roads (access points versus PoI) for primary schools and OSM centroids compared to OSM perimeters for secondary schools. This indicated there was no single, common pattern between the networks in terms of high or low correlation. There were few similarities between the statistical outcomes for Cardiff and the associated outcomes for the Vale, in terms of distance correlations. This could possibly be due to the differing patterns of population between the two areas (urban versus rural) or to the different numbers and distribution of the destination features between the two areas.

With high correlations throughout the distance results, with relatively little variation, the results for differences would perhaps provide a wider range of results and therefore a clearer indication of any patterns that exist. For differences between nearest distances, there were no consistent patterns for Cardiff, though Open Roads PoI was not significantly different to OSM PoI or centroids for both primary and secondary schools. In the Vale the same pattern was not repeated, though for both sports centres and community hubs the OSM-Open Roads combination was not significant.

Results of 2SFCA correlations showed little in common between primary and secondary schools, nor between the results of schools between Cardiff and the Vale. The remaining three features, however, all had strong correlations, and all had similar patterns, with highs for ITN and Open Roads comparisons, and lows for UP and OSM comparisons, for both Cardiff and Vale across GP surgeries, sports centres and community hubs.

Statistical differences in 2SFCA scores exhibited a very different pattern for primary schools in Cardiff than in the Vale. In Cardiff, non-significant results (that is, results not significant at the 5% level) were concentrated in the comparisons involving PoI and Euclidean measurements. For the Vale, few PoI locations were involved in non-significant comparisons, the majority of which involved comparisons of similar feature locations using different networks (as seen on the diagonals of Table 4.14). This indicated that in for these supply-side features, in the more rural context of the Vale, when the location placement method (particularly Sites centroids to Sites access points) is the same but the network is varied, the outcomes show no significant differences. When the location method is varied and the networks remain the same, generally there were significant differences. Open Roads had only one non-significant 2SFCA difference for both Cardiff and Vale primary schools.

Again, there were few similarities between Cardiff and Vale 2SFCA differences for primary schools, with the Vale having even more non-significant results on the ‘diagonals’ (that is, between similar location methods measured using different networks). The outcome of Wilcoxon tests for GP surgeries for the Vale confirmed the ‘diagonal’ outcomes of schools, as for GP surgeries in the Vale all network combinations had non-significant results (ie not significant at the 5% level). No similar themes ran through all the features or across Cardiff-Vale comparisons, though the Vale results did have more non-significant results for difference.

There was an urban-rural split in 2SFCA results, with the Vale returning more non-significant results than Cardiff, indicating a higher level of statistical similarity. With regard to the distance overlaps, all five supply features in Cardiff returned the highest destination overlap figures for the ITN – OR comparison, as did the Vale, for all but secondary schools, which had UP – UP comparisons as the highest. In most cases, Euclidean – OSM comparisons had the lowest destination overlap, across all features and both areas. Exceptions were few, and were secondary schools in both areas (which both had OSM – OSM with the fewest overlaps) and

Vale GPs, which had the Euclidean – ITN combination with the lowest. Both primary and secondary schools had the same network combinations showing maximum and minimum overlap scores (when averaged for all feature locations) with, as stated above, Euclidean – OSM as the lowest combination and ITN – OR as the highest.

In one instance of similar patterns being identified between Cardiff and the Vale, when averaged for all location methods for primary schools, both Cardiff and Vale shared the highest and lowest combination, with Euclidean to Euclidean matching most, and Euclidean to OSM matching fewest. In considering networks, both areas had ITN and OR combinations having the highest return (82.1 for Cardiff and 91.4% for the Vale). For secondary schools, both areas had OSM comparisons between location methods as the lowest combination. The ITN – OR combination returned the highest destination overlap figures in both the Vale and Cardiff for GP surgeries, sports centres and community hubs. Despite the temporal differences between the ITN and Open Roads dataset, in the practical task of identifying nearest destinations they still returned the highest percentages compared to the other combinations. Euclidean-distance comparisons between location points varied considerably, and when averaged was only 93.6% for primary schools in the Vale, and only 86.6% in Cardiff, showing that the effect of changing how a feature was mapped was not only reflected in a change in distance, but also resulted in a different feature being identified as the nearest to a demand point in several cases. Other studies found destination overlaps of between 64.8% and 79.3% between OA centroids and green spaces in Cardiff when using Euclidean distances (Higgs et al, 2012), figures which reduced to between 45% and 60% when network distances were used, with both results dependent on what approach was used to identify the green space (centroid, access point or perimeter). Correlations fell from around 0.8 to 0.9 using Euclidean to around 0.6 to 0.8 range using networks. Both sets of results appeared considerably lower than those achieved in the case studies used in this thesis, probably due to the vastly greater number of green spaces (around 600) compared to the numbers of the five types of destination feature used here. Further implications of these findings to the usability of the data is addressed in Chapter 6.

Chapter 5 Results: Mapping and visualisation

5.1 Introduction

The tables and figures in this chapter looked at the numerical interpretation of the results from the various accessibility analyses. However, the results can also be presented in map format, giving a visual indication of the geographical distribution of locations with prescribed levels of accessibility. This section presents some of the previously-presented results in graphical terms, and also considers some of the underlying usability issues regarding the data used that impacts the visualisation of the results. Choropleth maps are used: these maps present statistical or numerical data, using a colour, shading or pattern scheme in order to show the level of values within defined areas (Oxford Dictionaries, 2015). They offer an easily-interpreted method of presenting a level of variability within a region, hence ideal for showing differing levels of accessibility between Output Areas, represented by polygons. Although OAs were the main units utilised to illustrate these results, other areal units will be used to compare impressions and usability issues.

Disadvantages of choropleth maps have been referred to previously in this thesis: issues of MAUP (the modifiable areal unit problem, as outlined in Chapter 3) and the Ecological Fallacy have to be kept in mind, or pointed out to non-specialist users. There are two issues to be aware of with respect to MAUP, as outlined by Openshaw and Taylor (1981): aggregation and zoning. An example of the aggregation problem is when population representations are aggregated from OAs into larger units, such as LSOAs. Resulting values such as averages, proportions, etc will alter from the smaller to the larger areas. Zoning issues occur when a large area is divided, and any various permutations of the sub-divisional borders would result in differing values being found. Openshaw and Taylor (1981) showed that such changes in scale or unit definitions altered findings in quantitative measures and in statistical tests (Horner and Murray, 2002). The Ecological Fallacy arises when a general observation derived from a group is applied at individual level. An example applied to this thesis could involve taking a distance measure of accessibility for a census OA to a primary school of, say, 600m, and assuming that every pupil in that area had a 600m commute to school. This is not necessarily the case, and the distance was calculated from one representative point (of which several different options could be available). Care has to be taken not to over-generalise or apply results in an overly specific way.

Other well documented issues with choropleth maps include the visual dominance of larger areas, which viewers tend notice rather than the information presented in the smaller areas.

These caveats should be kept in mind when considering the maps to follow, and the geographical awareness of the typical audience. It should also be noted that when loaded into ArcGIS and converted into shapefiles, the OA polygons and the OA centroids were not allocated identical FID numbers (unique identifiers of objects within shapefile attribute tables) in their respective layers. This meant that when using the accessibility results from the points an additional common reference had to be included in each set in order for the correct results to be mapped across from each point to the correct polygon. In this case the census references (variously termed CODE, GEO_CODE or GEO_LABEL in the data provided from the ONS) were used to link the two geographical layers, in order to prepare the results for presentation.

Cartograms are also used as an alternative visualisation technique to illustrate different ways of presenting the results obtained, particularly without the domination of larger, rural OAs and to take into account ‘empty’ map areas which arose with some results, and full explanations of these issues and how they arose will be given in the following paragraphs and sections. Cartogram are drawn so that the size of the features represented within it (whether they are countries, counties, cities, OA polygons or post code areas) are proportional to a measurable feature (Dorling, 1996), which in this case will be a measurement of accessibility. The advantages of cartograms in studies such as this are that they change the perspective of the map from the countryside to the town, by removing the relationship of size of (for example) OA polygons away from physical, geographical area towards matching all polygon units to the value of accessibility assessed. This is therefore a convenient visual tool with which to emphasise differences which may not be evident to the unaided eye, due to being effectively hidden in small spatial units within choropleth maps.

Any audience with geographic knowledge would be aware of the advantages and disadvantages of choropleth maps. In addition to the ease of interpretation mentioned in the previous paragraph, another advantage in this case was that the accessibility results were calculated using OA polygon centroids, therefore their equivalent polygonal unit of presentation already existed, and accurately reflected the actual areas from which the population data was taken. However, there was a degree of generalisation in the location of the centroids, whereby the characteristics of a polygon is represented by a single point. ‘Population-weighted’ meant that some OA centroids were not in the centre of their (sometimes extremely irregularly-shaped) area, and some were located on the extreme periphery, though the construction of the centroids, as outlined by the Office of National Statistics (2011) ensured they would be located within the polygon itself.

Decisions had to be made as to how the results were presented in the choropleth maps. For distance measures an absolute scale was used throughout, with splits at 400m, 800m, 1200m and 2400m, with one further category representing distances over 2400m. As mentioned in the Methodology chapter (Chapter 3), with an average walking speed of 4.8kph (3mph) these distance splits equate to walking times of 5, 10, 15 and 30 minutes, respectively. By using these values, comparisons of distances could be made between networks, between location methods, and between features, as required.

Results arising from the 2SFCA accessibility model were ratios, not absolute values. This meant that many of the comparisons which were made with distance results, for example comparing primary school results to results from secondary schools, could not be made directly. A quintile approach was taken (5 categories), with one set of results used to set the split for each network. This was a compromise situation, where the ‘best’ and ‘worst’ were comparable for each network and feature and any anomalous areas would be identifiable, but quantifiable comparisons between features or networks could not be made.

5.2 Mapping of accessibility results

5.2.1 Accessibility to primary schools within Cardiff and the Vale using distance

For brevity, only a subset of maps are reported here, which are intended to highlight key trends relating to accessibility or usability. The first example is shown in Figure 5.1, which shows accessibility classified by shortest travel distance from demand points (census OA centroids) to supply points (in this case Cardiff primary schools, mapped by OS Sites centroid). Primary schools in neighbouring LA areas are also shown, as school children can use adjacent schools. The problems with choropleth maps, as detailed in Section 5.1, are clear. The larger areas dominate the user’s vision and the smaller areas (in this case in the more densely populated areas of Cardiff) receive less attention. The ecological fallacy also applies to these large areas, with all points within these areas classified as (for example) over 2400m, despite the areas themselves being several kilometres wide. An actual household within this area could be well within the split limit, but all points within the area were classified with the same split as the OA centroid, which was the representative point. Bearing all that in mind, the map in Figure 5.1 appears intuitively correct overall, with the OAs closest to the school centroids generally in the lowest distance category. No OAs were in the highest distance category of over 2400m, and 55% of the OAs were within 400m.

The equivalent map for Euclidean distance to the perimeter of a primary school is shown in Figure 5.2. Again, no area is in the highest distance category, but 67% are within the lowest, most of which are smaller OAs, and less easy to identify by eye, showing the importance of using original data in conjunction with visual representation.

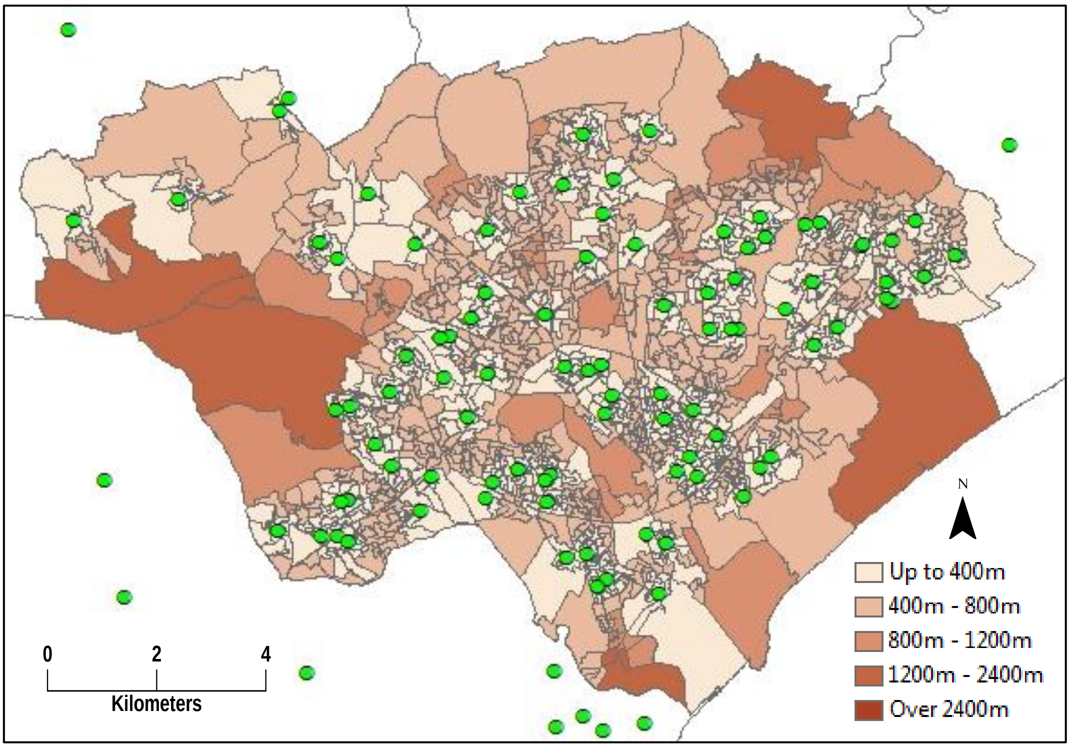


Figure 5.1: Map of accessibility to primary schools (in green) in Cardiff, measured using Euclidean distance to Sites centroids.

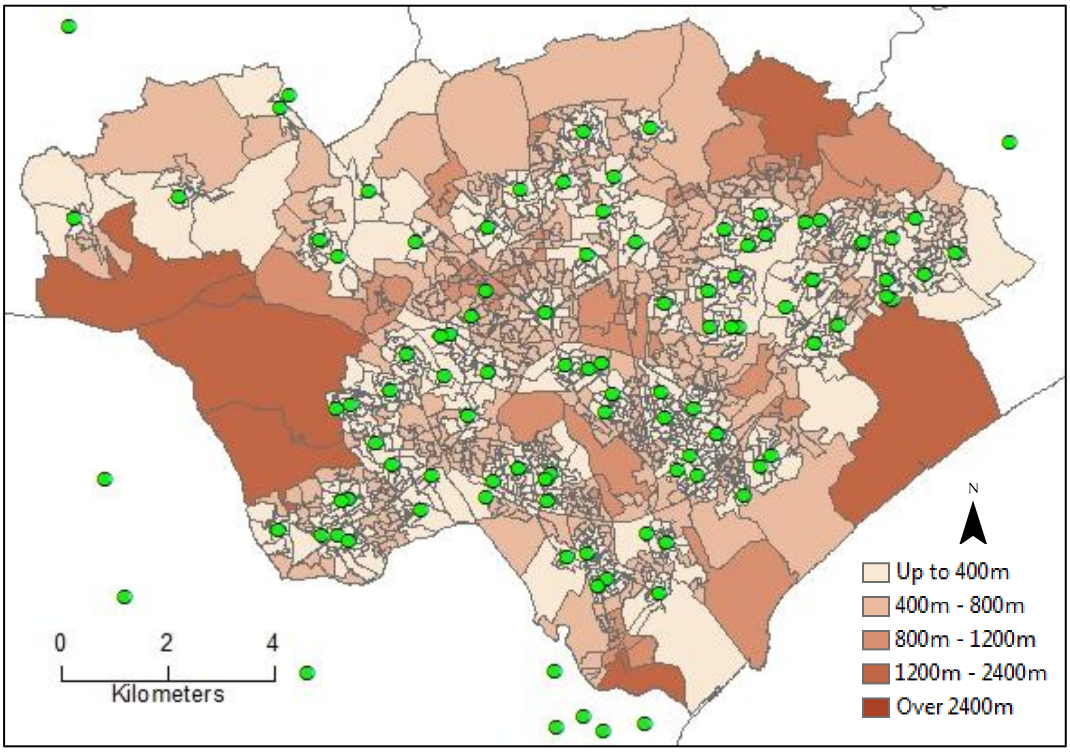


Figure 5.2: Map of accessibility to primary schools (in green) in Cardiff, measured using Euclidean distance to Sites perimeters.

According to the map in Figure 5.2 primary schools in Cardiff are highly accessibility, with all schools within 2400m (or 30 minutes walk) of the centroids of population, with two thirds of the demand points within a 5-minute walk. A feature such as primary schools would be expected to be extremely local to the population they serve. Network distances, however, should always be longer than their Euclidean equivalents, and this was borne out. The map showing ITN distances is at Figure 5.3, in this case to Sites centroids.

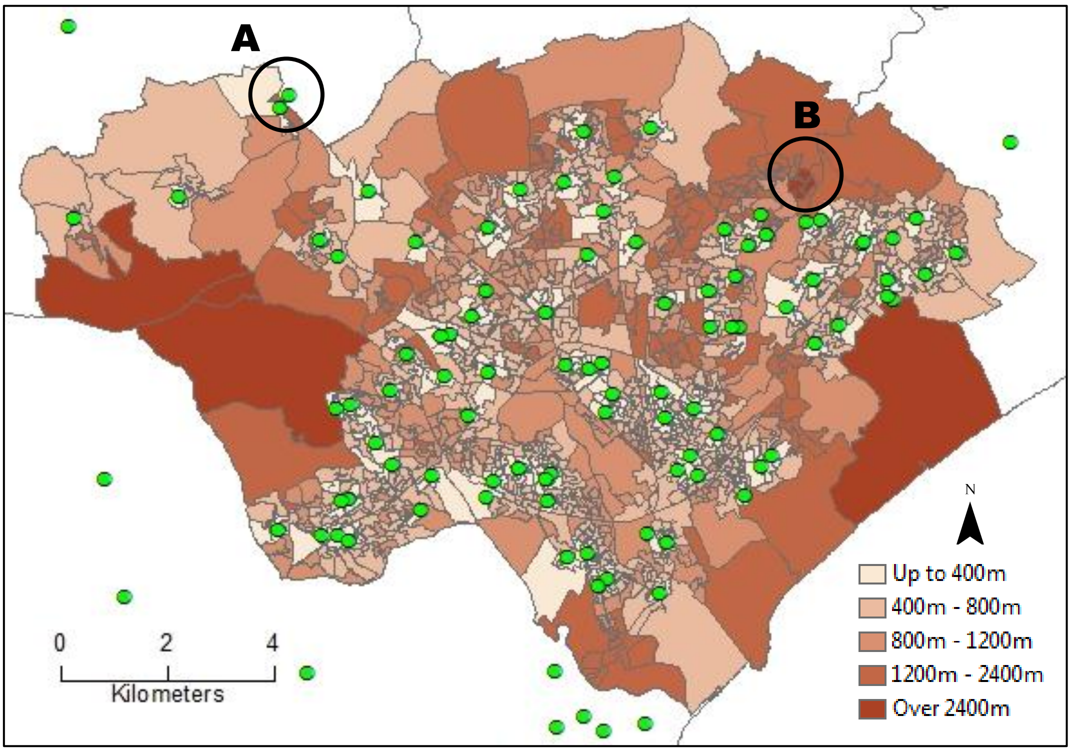


Figure 5.3: Map of accessibility to primary schools (in green) in Cardiff, measured using ITN distance to Sites centroids.

In Figure 5.3 a total of 8 OAs (0.8%) were over 2400m from their nearest facility while 240 (22%) were within 400m. These percentages represented the highest travel distances observed for primary schools. Compared to official government figures for Wales which reported that 91% of households had a primary school within a 15 minute walk, this map indicated that only 87% of OAs were within this limit.   When Urban Paths (UP) was included the figure rose to 93%.

The two areas labelled in Figure 5.3 indicate where a considerable change in category was noted. The area labelled ‘A’ is the area of Gwaelod, where one school lay across a physical barrier (the River Taff) in Taffs Well. The centroid of the OA was located on a lengthy dead-end road, therefore the shortest ITN distance to the school involved travelling in the opposite direction for over 500m before doubling back on the road on which the school was located. The area labelled ‘B,’ to the north of Llanedeyrn (an area highlighted in Section 6.4.4) was a cluster of crescent and cul-de-sac housing in which the centroids were located near the ends of roads, again meaning the shortest route entailed a doubling-back to main roads. The nature of the road network resulted in these areas having poorer accessibility than neighbouring areas which were actually located further away, in Euclidean terms, from any primary school.

The addition of Urban Paths is shown in Figure 5.4, with three OAs (0.3%) in the maximum distance category, and 28% in the minimum. The Gwaelod area (A) remained in the same distance category as the bridge across the river did not affect the distance to the nearest primary school, unchanged at 1366m. The eastern area cluster (B) was placed in a lower distance category, with a network of footpaths shortcutting the cul-de-sac journeys, enabling each centroid to identify various schools as the nearest destination, thus returning considerably lower distances.

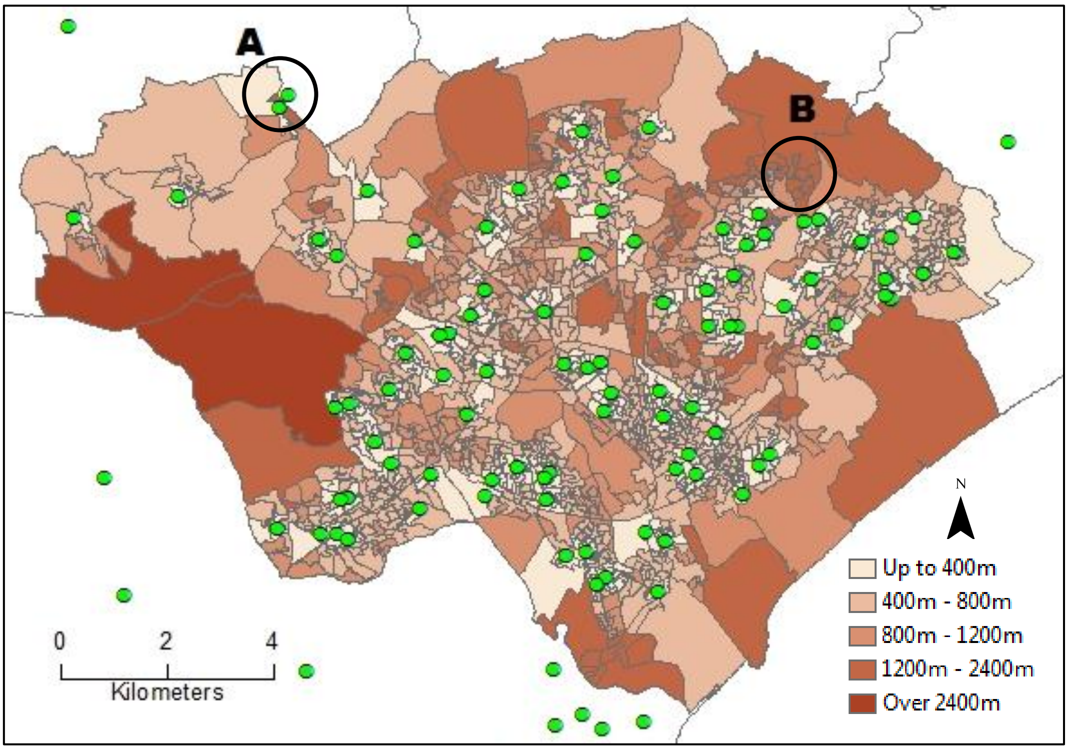


Figure 5.4: Map of accessibility to primary schools (in green) in Cardiff, measured using UP network distance to Sites centroids.

To continue with illustrating the effects of network on accessibility, Figure 5.5 shows OSM network distances to Sites centroids. This map has broad similarities to the ITN map (Figure 5.3) though some areas have considerable differences from ITN, and one such area is noted at 'C.'. This two-category change (though involving a large area, hence being more noticeable), was due to one footpath between blocks of houses being mapped in OSM and not on ITN, resulting in OSM reporting a 397m walk to school and ITN 1025m. Urban Paths mapped even more footpaths in the area, resulting in a 392m walking distance. Open Roads was only 5m longer than ITN.

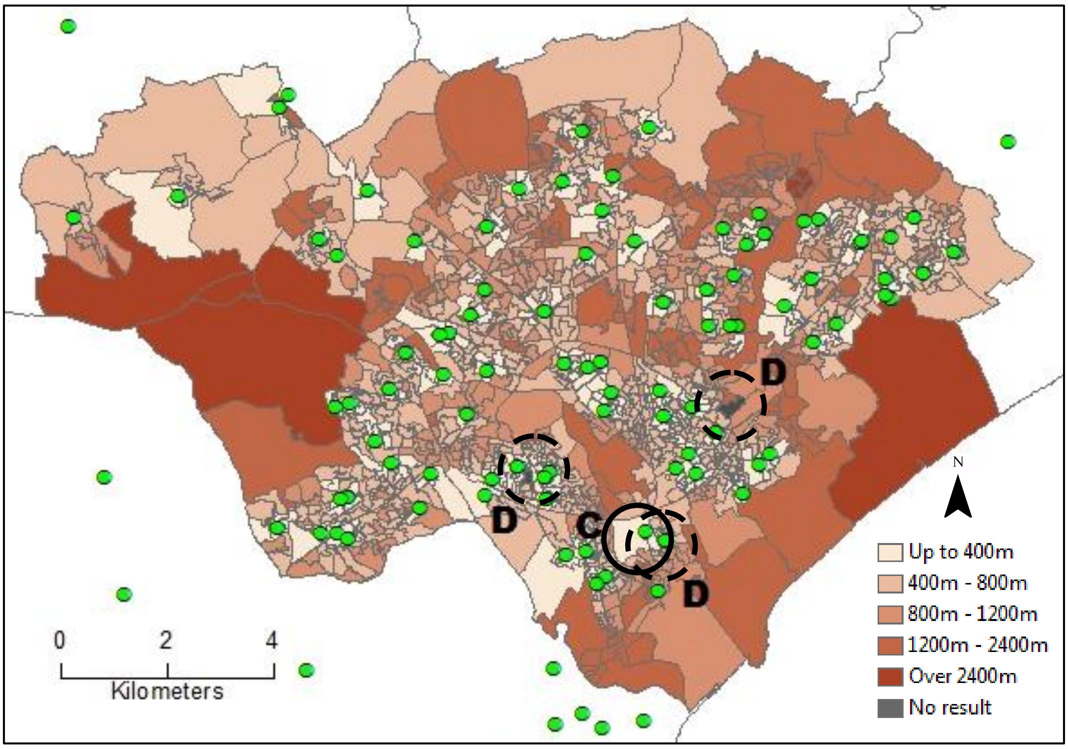


Figure 5.5: Map of accessibility to primary schools (in green) in Cardiff, measured using OSM network distance to Sites centroids. The OA with the considerable difference to ITN is labelled C; the OAs with 'nul' result are labelled D.

The OSM results had nine OAs in the highest category (0.8%) and 263 (24%) in the lowest. Three OAs returned no results, as the OA centroids were snapped to links that were 'islands,' examples of which are detailed in Section 6.4. Due to their small size they were barely noticeable in the densely populated inner-city areas of Cardiff and hence have small OA polygons, but were present in the Canton, Roath and Cardiff Bay areas (labelled 'D' in Figure 5.5). As they restricted the demand points, these three 'nil results' were repeated for every example involving the OSM network in Cardiff.

The OAs around Gwaelod (feature 'A' in Figures 5.3 and 5.4) did show considerable changes depending on network regarding GP surgeries, where cross-border travel permitted by pedestrian bridges improved accessibility considerably. Several OAs in north Radyr which were assessed as having poor accessibility using ITN also showed considerable improvement, again due to a footbridge being included in a network (see Figure 5.6 for details of the area, with the location of the pedestrian bridges illustrated in Figure 5.7).

To illustrate the effect of location method, the shortest network distances recorded for primary schools were those to the nearest perimeter point using Urban Paths, with three OAs (0.3%) in the longest distance category and 44% (476 OAs) in the shortest, as shown in Figure 5.8.

Although the larger polygons on the periphery of the study area dominate, the lighter tones nearer the centre can be discerned.

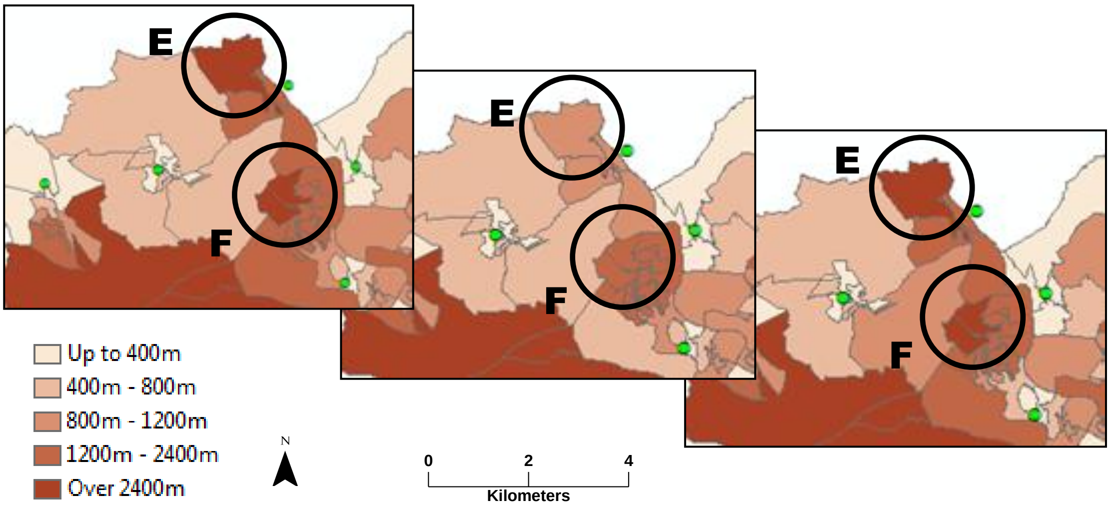


Figure 5.6: Accessibility by distance to GP surgeries around Gwaelod (E) and north Radyr (F) using (a) ITN; (b) UP; and (c) OSM; showing effect of including footbridges on network.

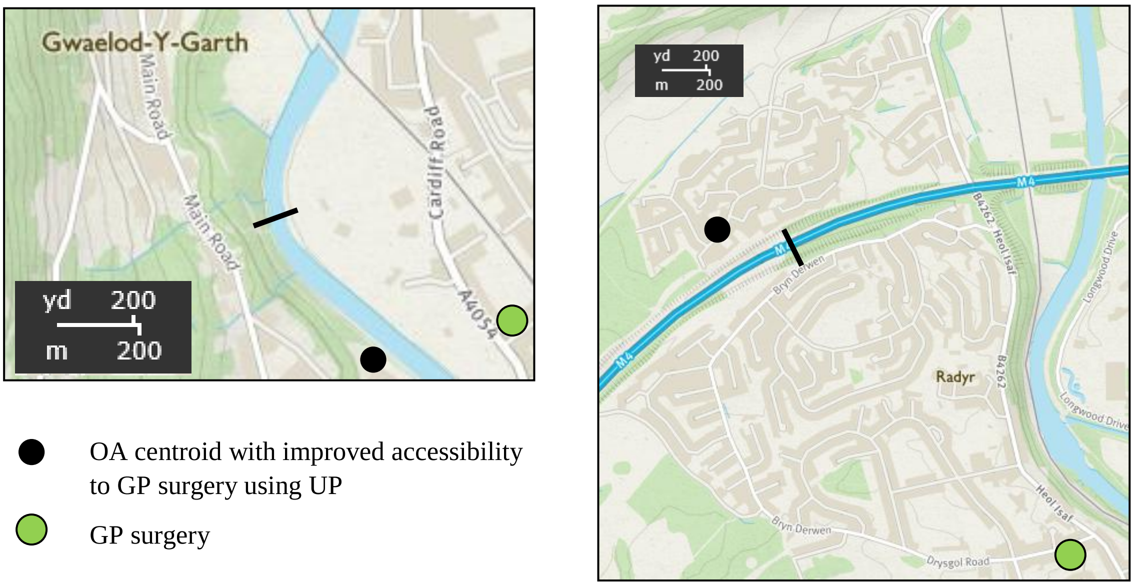


Figure 5.7: Illustration of location of pedestrian bridges in Gwaelod and Radyr, mapped in UP, and resulting in improved accessibility from several demand centres to certain supply features, such as GP surgeries. NB The location of the bridges have been visually enhanced as if kept to scale their narrowness rendered them indistinct.

Equivalent maps for the Vale of Glamorgan showed some of the issues involved when using and comparing statistical maps. Visually, the results were found not to be identical to those of Cardiff. The large size of the Vale as a county, and the large size of many of the OA polygons (due to the rural nature of most of the county) created different patterns of accessibility for primary schools. The two main population centres, Barry and Penarth, did have similar individual patterns to that of Cardiff, but the remainder of the county set challenges for the visual assessment of accessibility. The maps in Figure 5.9 and 5.10 illustrate the Euclidean distance measurements for the county, with more detailed views of Barry and Penarth.

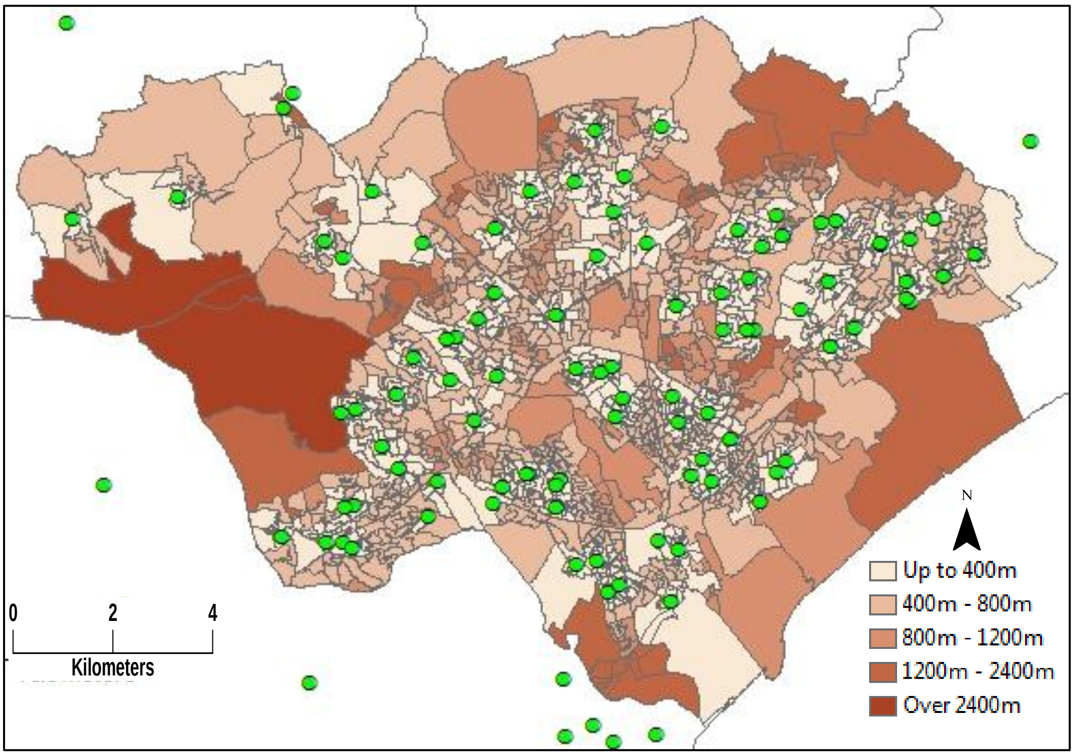


Figure 5.8: Map of accessibility to primary schools (in green) in Cardiff, measured using ITN with Urban Path network distance to Sites perimeters.

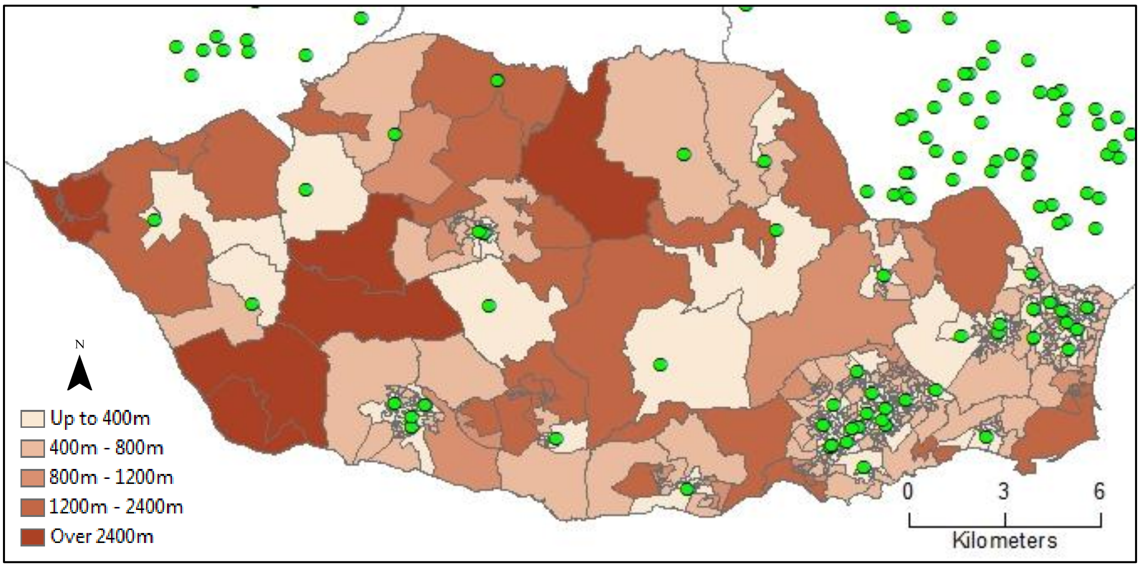


Figure 5.9: Map of accessibility to primary schools (in green) in the Vale of Glamorgan, measured using Euclidean distance to Sites centroids

These maps were typical of those resulting from visualisation of 'nearest distance' accessibility analysis. The sharpest changes found were examined further to identify the reasons for any dramatic improvement or deterioration in accessibility, changes which could be identifiable on a choropleth map. Examples from the use of other features will be given later, where such examples illustrate specific issues with data sets. However, comparison with the above distance accessibility maps will be made with those produced using 2SFCA results.

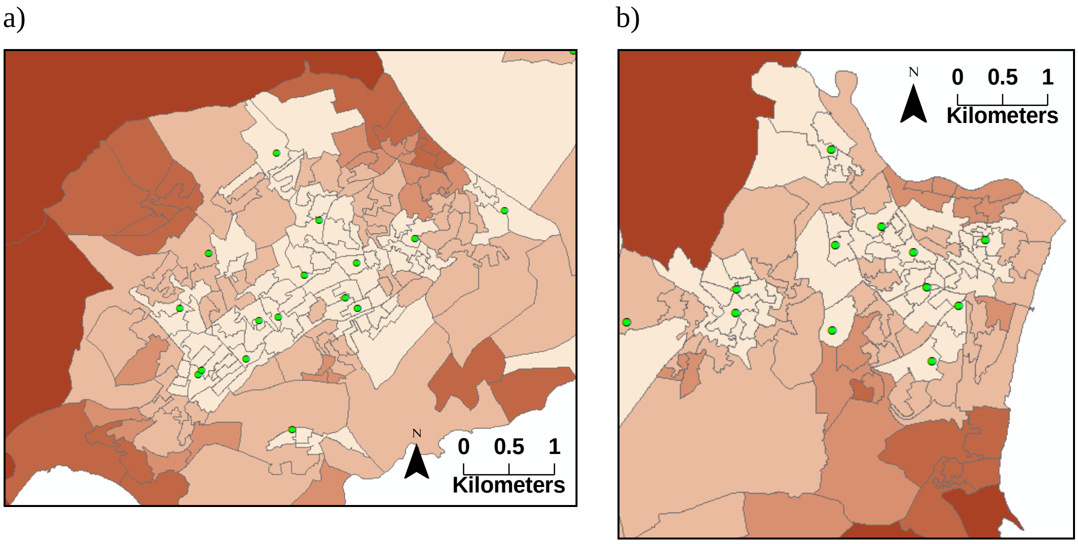


Figure 5.10: Map of accessibility to primary schools (in green) in the Vale of Glamorgan, measured using ITN with UP distance to Sites perimeters, showing detail of (a) Barry and (b) Penarth.

5.2.2 Accessibility to primary schools within Cardiff and the Vale using 2SFCA

In looking at the maps produced from a gravity model, it would have been expected to find concentric patterns of accessibility around supply points (as stated by McGrail and Humphreys, 2009), with levels decreasing with distance from the destination feature, as the populations falling within the most overlapping thresholds having the highest 2SFCA scores. The expected pattern would be similar to distance results but smoothed further. The number and distribution of features may affect 2SFCA patterns, but with no indications in the literature any influence would be reported here. Figure 5.11 shows the 2SFCA results for using ITN and Cardiff primary school centroids. A concentric pattern is clearly visible, with the highest areas of overlap between the schools also having the highest assessed accessibility.

The convention of using the darkest colours for the highest values has been reversed for these maps in order to reflect the assessed ‘best’ and ‘worst’ relative accessibility patterns. In the 2SFCA maps, the darkest colours have the poorest (lowest) accessibility; the lightest colours have the best (highest). In the case of Figure 5.11 the poorest accessibility areas were on the periphery of Cardiff, apart from the north west area, which exhibits as high a level of accessibility as the urban centre. Just outside these north west border of Figure 5.11 is a total of six primary schools in Rhondda Cynon Taff, which when added to those shown combine to give the north west of Cardiff a high level of assessed potential accessibility.

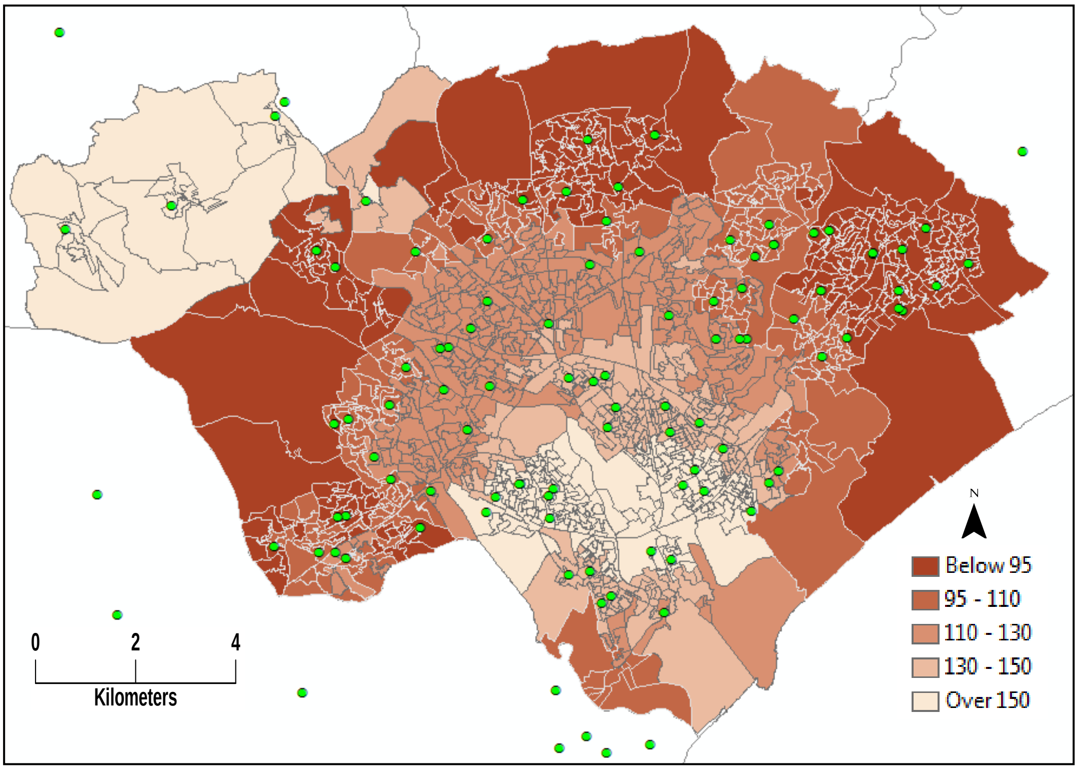


Figure 5.11: Map of 2SFCA accessibility to primary schools (in green) in Cardiff, measured using ITN, to Sites centroids.

The categories used in the 2SFCA map were quintiles, each category containing approximately 20% of OAs in Cardiff (before rounding). After rounding, the map in Figure 5.11 had 215 OAs (20%) in the lowest (poorest) category and 195 (18%) in the highest (most accessible) category. These rounded splits were retained and used for the measurements using access points and perimeters in order to help identify OAs which improved or deteriorated sharply, in terms of 2SFCA score. The 2SFCA scores in this series of maps were multiplied by a factor of 1000 so as to avoid the use of decimal points and improve clarity of image interpretation.

The dramatic change when using access points is obvious in Figure 5.12. In scenarios where there may be multiple points of access (to schools, for example) it would be the case that 2SFCA underestimates accessibility due to the fact that the algorithms use one supply-side access point (as explained in Chapter 3). This is relevant to the use of the OS Sites dataset, which provides (where relevant) data on all access points to features which appears to provide improved precision, but due to the limitations of the plug-in tool, actually adds to the preprocessing required before the access points can be used in order for main access points to be identified. The steps required to work around this problem involved the imposition of a major compromise, with each feature school being allocated a 'main' access point, defined as the main entrance available to pedestrians and identified, where required, by Google Street View (with the entrance with a large school sign, directions, and closest to the main administration buildings generally being identified as the main entrance). The removal of multiple access points from many of the schools served to reduce their accessibility, caused by an increase in travel distance to those features and a sharp reduction in the supply-side capacity levels (as the plug-in mistakenly identified each access point as a destination in its own right, and so overestimating accessibility), resulting in reduced potential accessibility as measured by 2SFCA. In order to illustrate the considerable impact on 2SFCA scores, Figure 5.12 shows (a) the 2SFCA scores to main access point of Cardiff primary schools using ITN and (b) the scores arising from the use of ALL pedestrian access points, while using the same plug-in parameters.

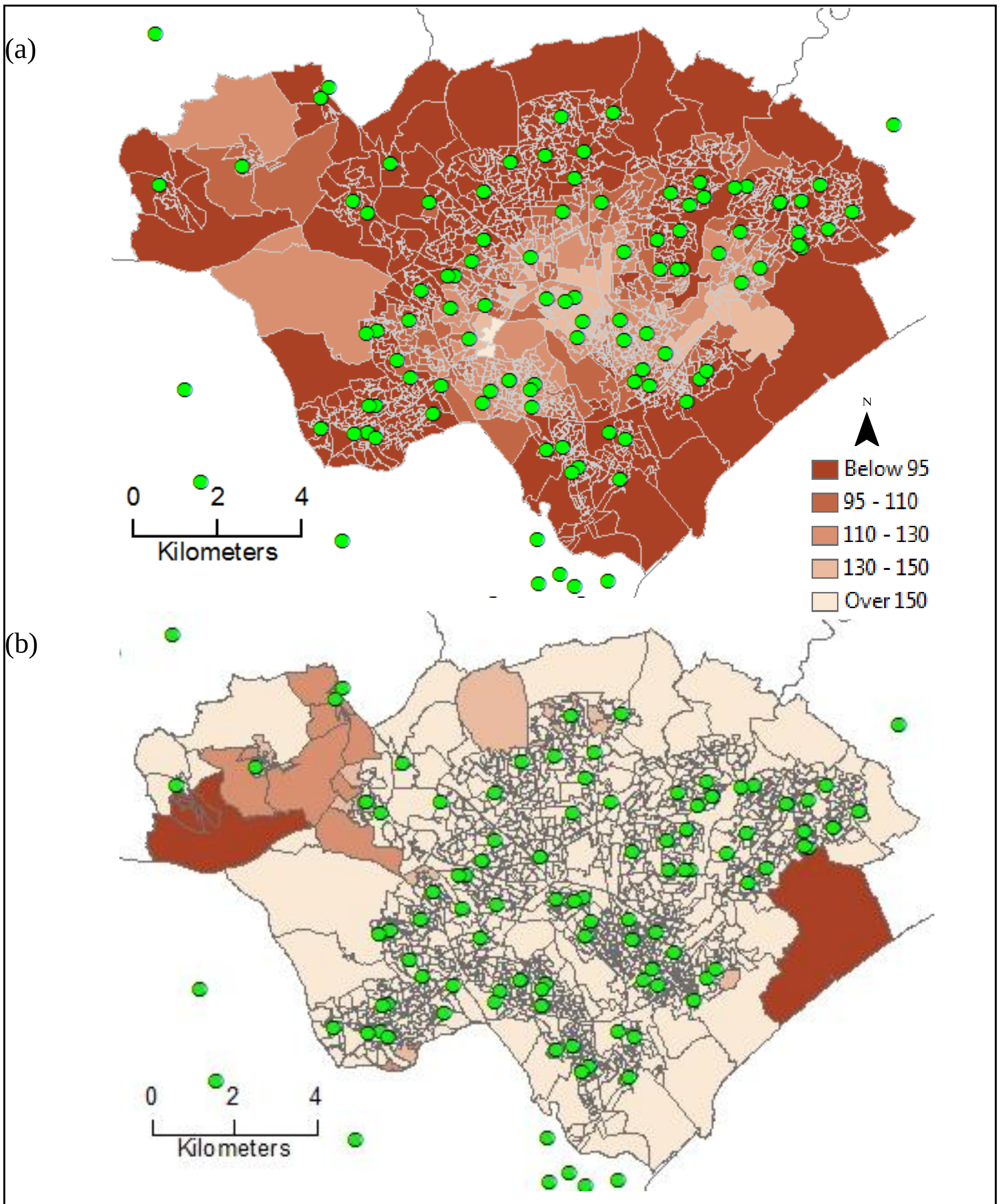


Figure 5.12: Map of 2SFCA accessibility to primary schools (in green) in Cardiff, measured using ITN to Sites: (a) main access points; (b) all pedestrian access points.

In Figure 5.12, using the same splits as Figure 5.11, 54% of OAs were in the poorest accessibility category, and only two OAs were in the highest. Using main perimeter points resulted in the map in Figure 5.13, which had 40% of OAs in the lowest-accessible category (fewer, in fact, than with main access points) and none in the best category. Both maps allocate the periphery of the Cardiff study area as having low accessibility to primary schools, with the areas of better accessibility located around the centre of the study area.

In both Figures 5.12 and 5.13 the large areas covered by the worst category tend to dominate the map, therefore a comparison was made by setting strict quintiles for the perimeter results for ITN, and the result is shown below in Figure 5.14. This approach enables a greater degree of detail to be discerned, therefore the quintile approach was taken with the bulk of the 2SFCA map results. These maps show, therefore, the 'worst' and 'best' OAs relative to each other.

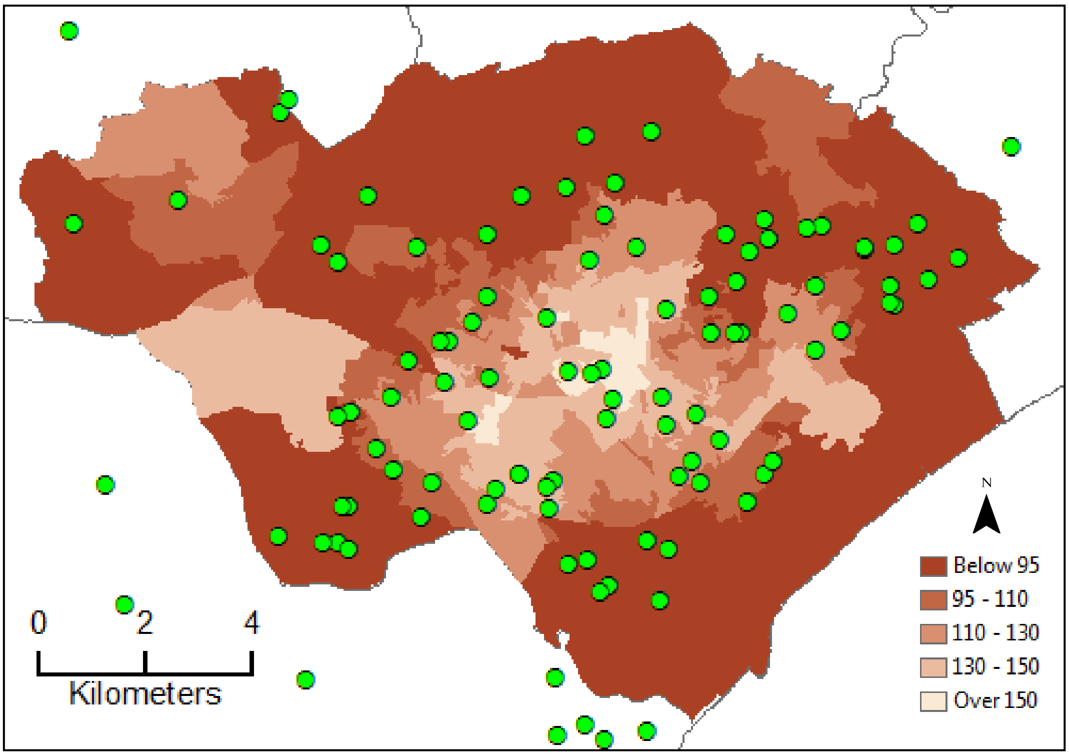


Figure 5.13: Map of 2SFCA accessibility to primary schools (in green) in Cardiff, measured using ITN, to Sites main perimeter points. Note that the OA boundary lines have been removed from this image, to improve clarity, particularly in the most densely populated areas.

Retaining the same split values across different feature representations and between networks resulted in larger areas falling within the same classification as shown around the periphery of Cardiff in Figure 5.13. Returning to the use of quintiles (rounded as in Figure 5.14) gives a clearer indication of differences in relative potential accessibility between OAs in Cardiff compared to each other, but even with this more-varied pattern, the distribution of the worst quantiles does not appear intuitively correct, with some areas around clusters of schools returning the lowest comparable 2SFCA scores. Luo and Qi (2009) also noted the results of 2SFCA tended to show concentric patterns with higher values near population centres and lower values at the periphery, and that 2SFCA does over-rate accessibility in overlapping catchment areas, and issue solved with their enhanced version (E2SFCA) through the inclusion of a distance decay function. The size of threshold also affected the degree of overlap of the catchment areas, and therefore the preponderance of higher values at the centre of populated areas, similar to the pattern shown in Figure 5.14, with some isolated pockets of high or low scores due probably to the combination of demand and supply levels in those areas.

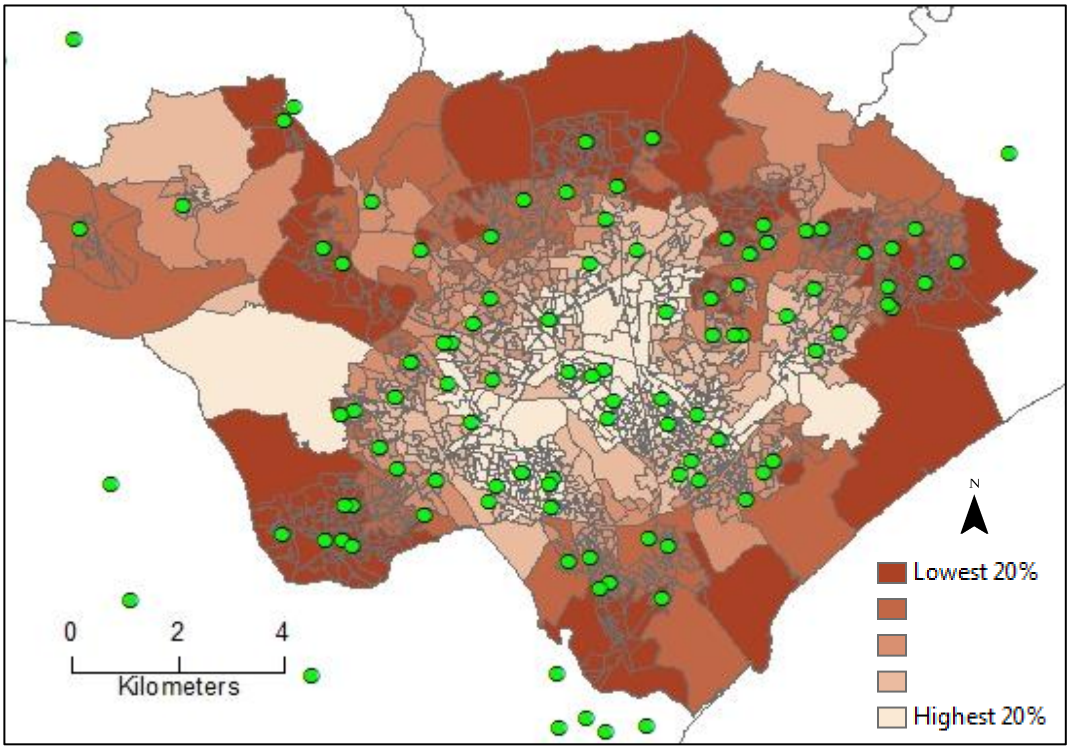


Figure 5.14: Map of 2SFCA accessibility to primary schools (in green) in Cardiff, showing scores measured using ITN to Sites main perimeter points, using quintiles (20% of OAs in each category).

The potential influences of the threshold distance used and on the introduction of a distance decay function were investigated separately, and briefly, using primary school accessibility as a comparator. To reiterate the parameters of the 2SFCA used here in order to investigate the accessibility to primary schools while considering the active travel agenda, a 5km threshold was set (matching a ‘reasonable’ walking or cycling distance to primary school as set by the WAG), using Euclidean distance and available road, cycle and footpath datasets to estimate routes taken using different networks, and using the same networks to obtain 2SFCA scores in order to compare results when supply and demand factors were included (as outlined in Chapter 3), with school roll as supply capacity and the primary school age population (5 to 12 year olds) as the demand level, with population location represented by census OA population-weighted centroids. Figure 5.15 therefore shows the results of applying the same parameters as the map in Figure 5.13, but with a 1500m threshold as opposed to 5000m, with the same 2SFCA splits.

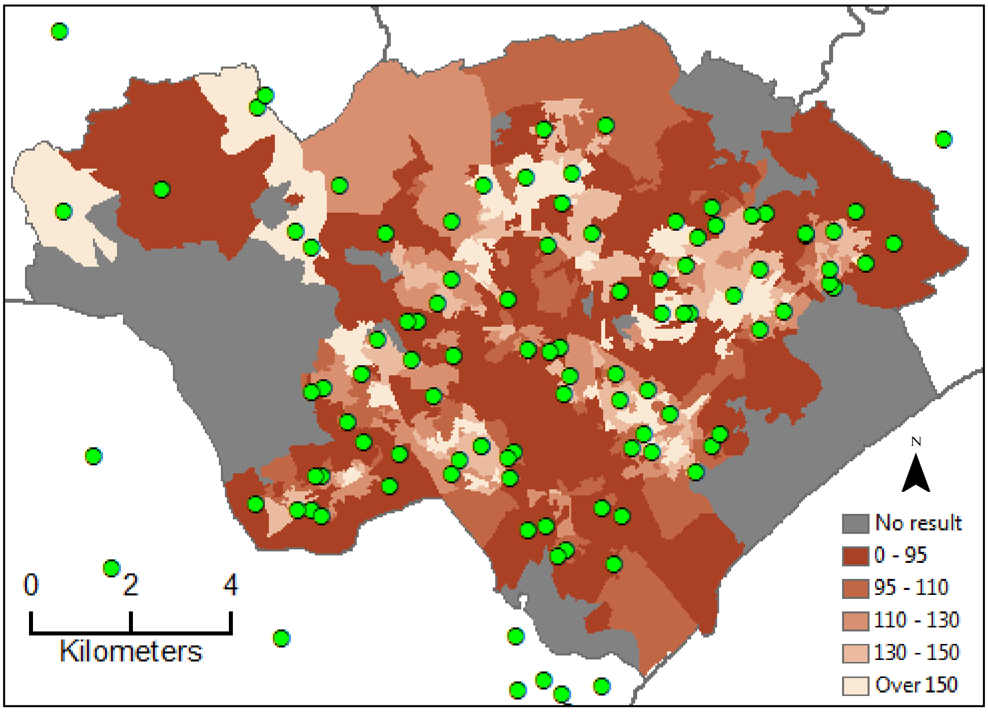


Figure 5.15: Map of 2SFCA accessibility to primary schools (in green) in Cardiff, showing scores measured using ITN to Sites main perimeter points, using a threshold of 1500m, to compare with the maps generated using 5000m threshold. Note that OA boundaries have been removed.

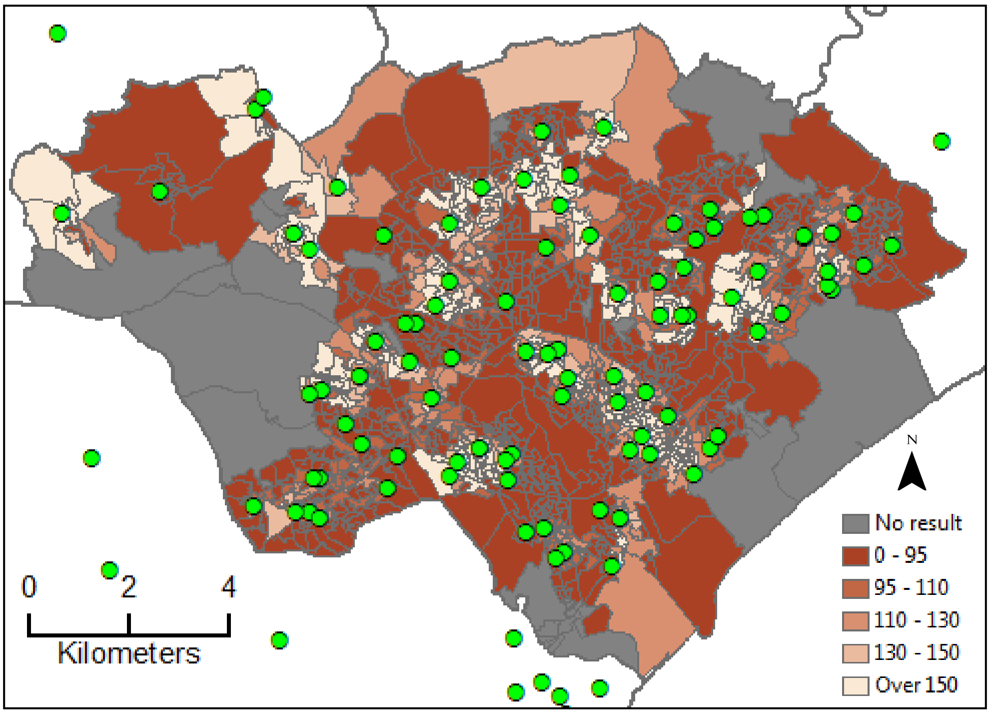


Figure 5.16: As map 5.15, but using a threshold of 5000m and a linear decay function. Note that OA boundaries have been lightened in some areas to aid clarity.

The results of the smaller threshold are much less smoothed, and instead of one central core of high 2SFCA scores, there are several smaller cores. Lowest scores are again evident around the periphery, but also within Cardiff itself, but the most notable issue is the number of areas with no result, despite some of these OAs having schools in the same or adjacent area. The areas to the south-western edge of Cardiff still retail low scores, despite a cluster of six schools in the area.

Figure 5.16 shows a map of using the same parameters as the map in Figure 5.13, but incorporating a linear distance decay function. The scores of the centre of the area have declined using this function, and the peripheral areas still score poorly, with the decay function resulting in those at the furthermost point on the 5000m catchment returning nil results. None of these particular areas have schools close to the OA centroids. In both Figure 5.15 and 5.16 the results are less smoothed than in the other 2SFCA maps, with several distinct areas, mostly central, with higher 2SFCA scores. Strictly speaking, with the inclusion of distance decay the model was the enhanced version, E2SFCA, as outlined by Luo and Qi, 2009). Peripheral areas were still the lowest scoring, but the south-western outskirts of Cardiff have pockets of better scores adjacent to clusters of schools.

The 2SFCA maps produced with the other network datasets followed very similar patterns, with minor changes only. OSM results were an exception with its three unconnected OA centroids, all of which stood out as they were located in areas of otherwise good or medium accessibility.

The results from using the custom-built tool to calculate Euclidean 2SFCA are shown in Figure 5.17 and also exhibits a much less smooth pattern, though with general similarities to the ITN results. The major difference from network results was the considerable improvement in scores for the southernmost polygons. This was due to the primary schools in Penarth, outside the Cardiff county boundary, having been included as the Euclidean measurements ignored the river that flowed along the southwest margin of the county, forming the county border and acting as a barrier to network travel.

The 2SFCA results for the Vale of Glamorgan exhibited a much less concentric pattern. In the Vale, accessibility as assessed by gravity models tended to have the worst levels further south with smaller ‘islands’ of poor accessibility in the centre of the county and on the western periphery. Those southern OAs were on the coast, therefore had no overlapping school catchments from outside the county boundary on the southern side, which was not the case with the north west (which overlapped with Bridgend county schools) and north east (which had overlapping thresholds from several Cardiff schools).

The patterns of best and worst accessibility for the Vale of Glamorgan had little in common with those of distance measures, with the OAs along the coast exhibiting the most noticeable reduction, as shown in Figure 5.18. OSM results for primary school 2SFCA were virtually identical to those of ITN, for all three location methods in the Vale, and those for Open Roads were also very similar.

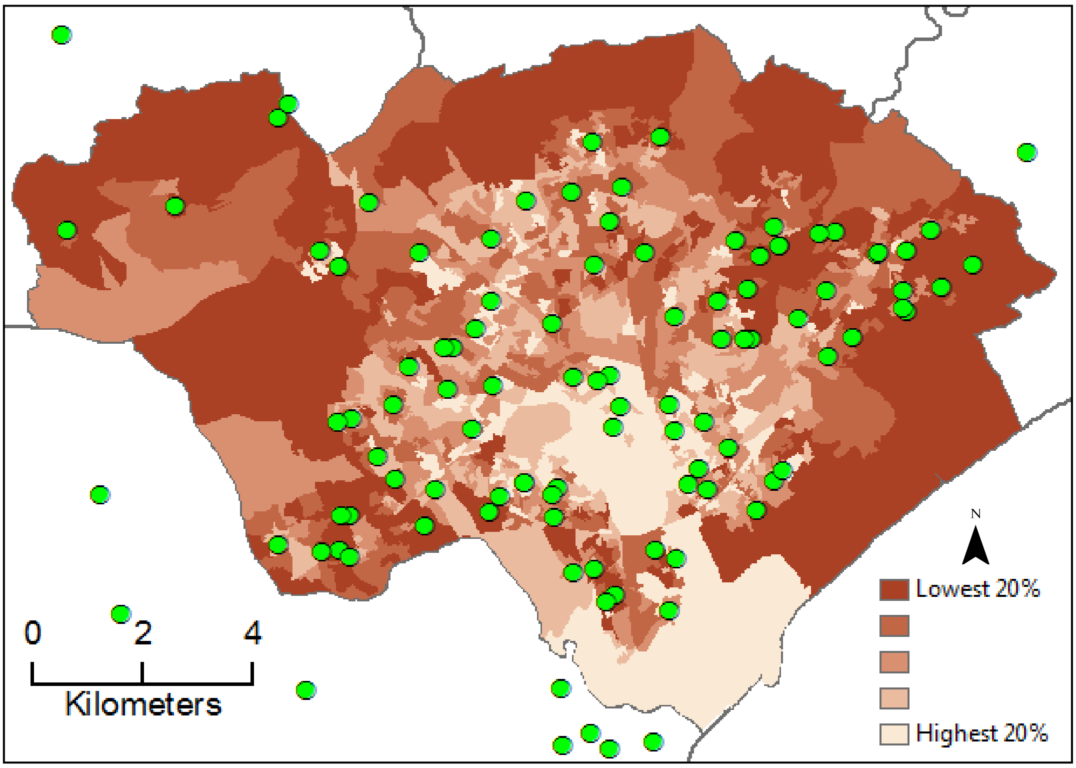


Figure 5.17: Map of accessibility to primary schools (in green) in Cardiff, showing 2SFCA scores calculated using Euclidean 2SFCA tool to Sites centroids, using quintiles (20% of OAs in each category). OA boundaries have been removed to aid clarity.

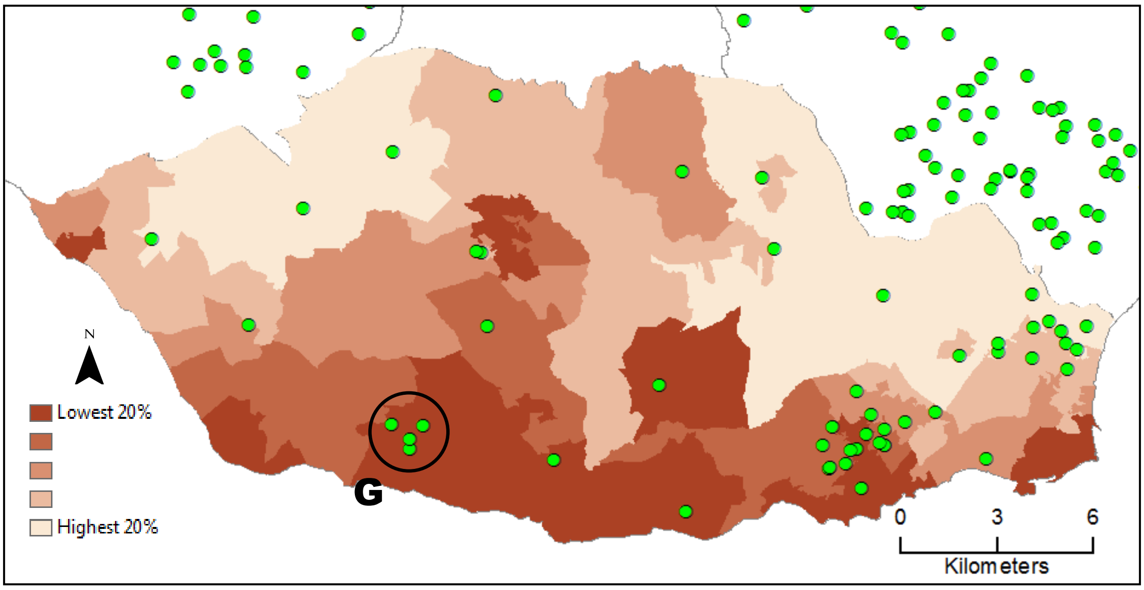


Figure 5.18: Map of accessibility to primary schools (in green) in the Vale of Glamorgan, showing 2SFCA scores measured using ITN to Sites centroids, using quintiles (20% of OAs in each category). The village of Llantwit Major is labelled 'G', for discussion in the text. OA boundaries have been removed to aid clarity.

When the areas of Barry and Penarth were looked at more closely, little similarity with distance accessibility results can be seen (Figure 5.19). There was also a great degree of smoothing, with wider bands (and larger areas) of similar scores accreted into zones of comparable accessibility, as was reported by McGrail and Humphreys (2009). As quintiles were used, any number of OAs which reduce in score in these extracts must be balanced by other OAs having an increase in score. In this instance the OAs in the centre and west of the county showed increases in relative accessibility.

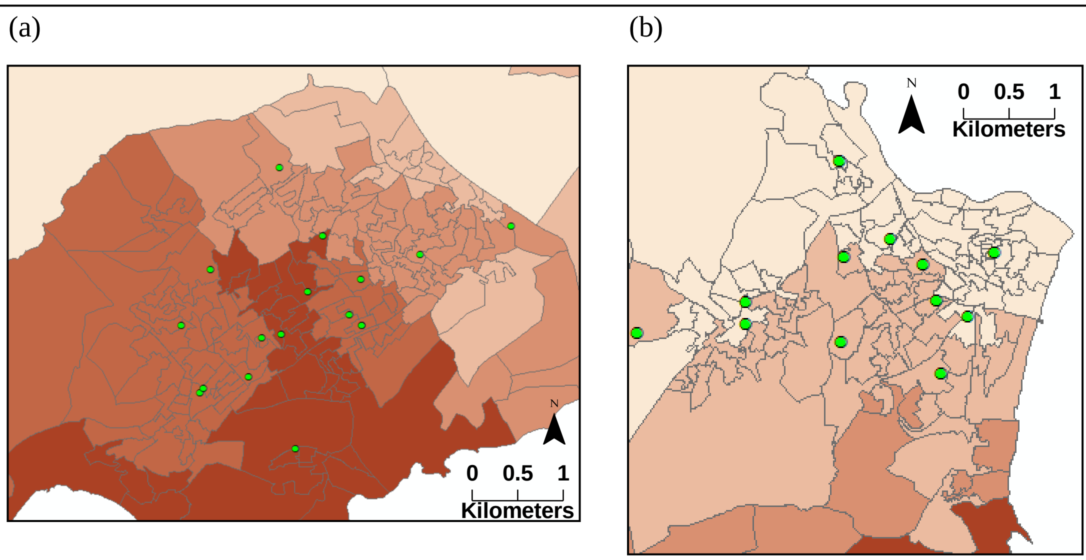
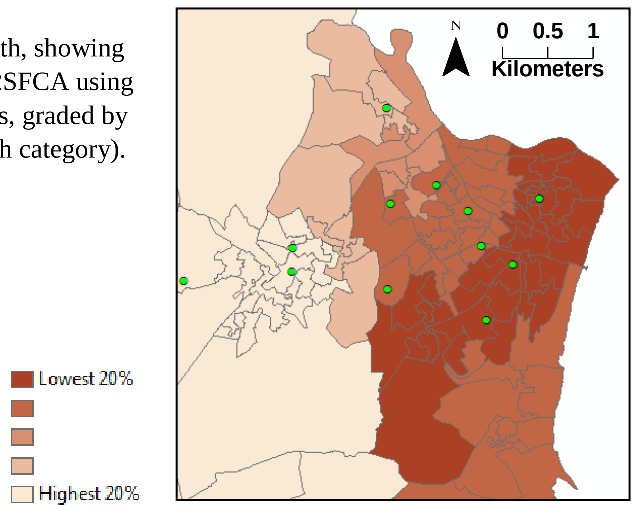


Figure 5.19: Detail of (a) Barry and (b) Penarth, showing accessibility as assessed by 2SFCA, using ITN to Sites centroids, graded by quintile (20% of OAs in each category).

The volatility of the 2SFCA scores when assessed to perimeter points indicated that the use of gravity models was not appropriate in some circumstances with particular data sets. The levels of assumption and generalisation required in the identification of the representative point on the perimeter was too restrictive to produce a reasonable destination point for 2SFCA calculation, illustrated in Figure 5.20 by the high degree of change exhibited around Penarth.

Figure 5.20: Detail of Penarth, showing accessibility as assessed by 2SFCA using ITN to Sites perimeter points, graded by quintile (20% of OAs in each category).



Results from the use of the Euclidean 2SFCA tool were considerably different from those that used network distances. Figure 5.21 shows the maps obtained from using Euclidean travel to school Sites centroids, with categories split into quintiles.

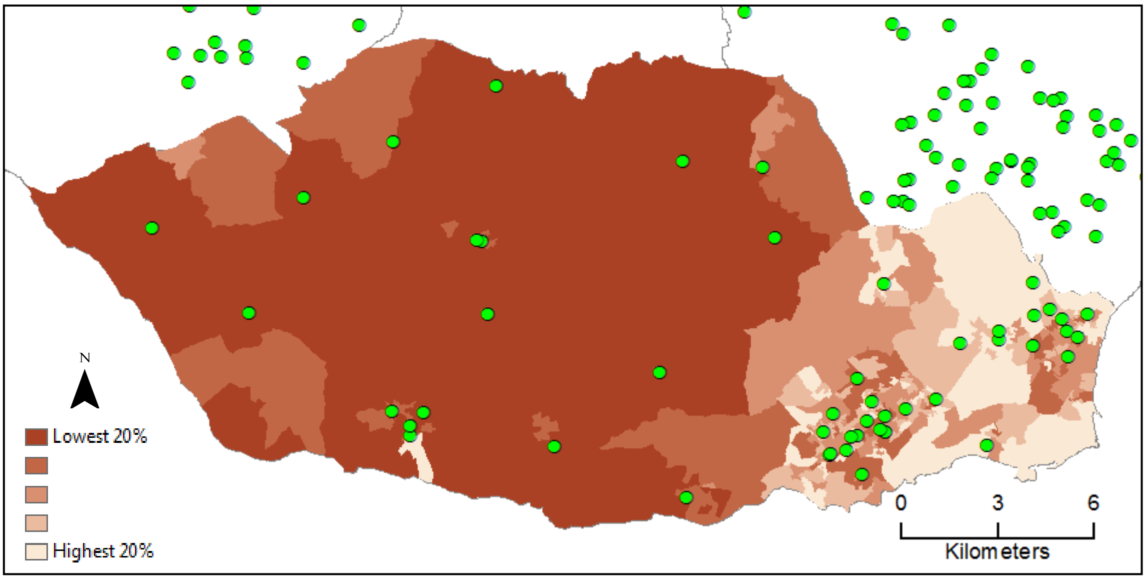


Figure 5.21: Map of accessibility to primary schools (in green) in the Vale of Glamorgan, showing 2SFCA scores measured using Euclidean Distances to Sites centroids, using quintiles (20% of OAs in each category). OA borders have been removed to aid clarity.

At first glance the Euclidean map appears to have a smoother pattern than those using network datasets, but on closer examination this is due to the effect caused by the large, rural OAs dominating the image. The appearance was patchier around Barry and Penarth, and the influence of Cardiff's supply points dominated the eastern part of the county.

5.2.3 Accessibility to secondary schools within Cardiff and the Vale using distance

The maps showing Euclidean distances to the nearest secondary school centroid (Figure 5.22) provided a benchmark from which different networks and location methods could be compared. The Euclidean distance map shows the concentric patterns that would be expected, but with fewer schools and more widely spread, the concentric rings overlap much less than with primary schools. The outlying villages in the north west of the study area have no local secondary schools and were classified in the 'over 2400m' category, as were the OAs around Cardiff Bay. Ten per cent of all OA centroids were within 400m of the nearest secondary school, with 7% in the worst category.

When the maps showing network distances using ITN were compared to those showing Euclidean distances, several OAs fell by three distance categories, indicating the overestimation of accessibility caused by using Euclidean measurements, the simplest distance measure. The biggest changes occurred around the periphery of the study area as there were fewer secondary schools just outside the borders compared to primary schools. Where a school in a neighbouring county was identified as the nearest destination to a Cardiff OA, the distances were still towards the larger end of the range. One school (Mary Immaculate RC High) was located just over the border into the Vale, and had an effect on the accessibility of OAs in the housing estates to the west of Cardiff. When ITN was used with Sites centroids used to locate each school, only 3% of OAs were in the lowest distance category, with 17% in the highest. When access points were used the figures changed to 6% in the best category and 15% the worst, showing improved accessibility. A further improvement was obtained through the use of school Site perimeters, with 10% and 12% in the best and worst categories, respectively. Using Urban Paths had a further, small improvement, and the map showing the results from this network using Sites perimeters is shown in Figure 5.23. Visually, the differences from Euclidean to Urban Paths are most noticeable on the periphery. Differences in the more densely-populated areas were more difficult to identify by eye. The position of the OA centroids also influences results, resulting in some OAs not falling in the lowest distance category despite being adjacent to a school.

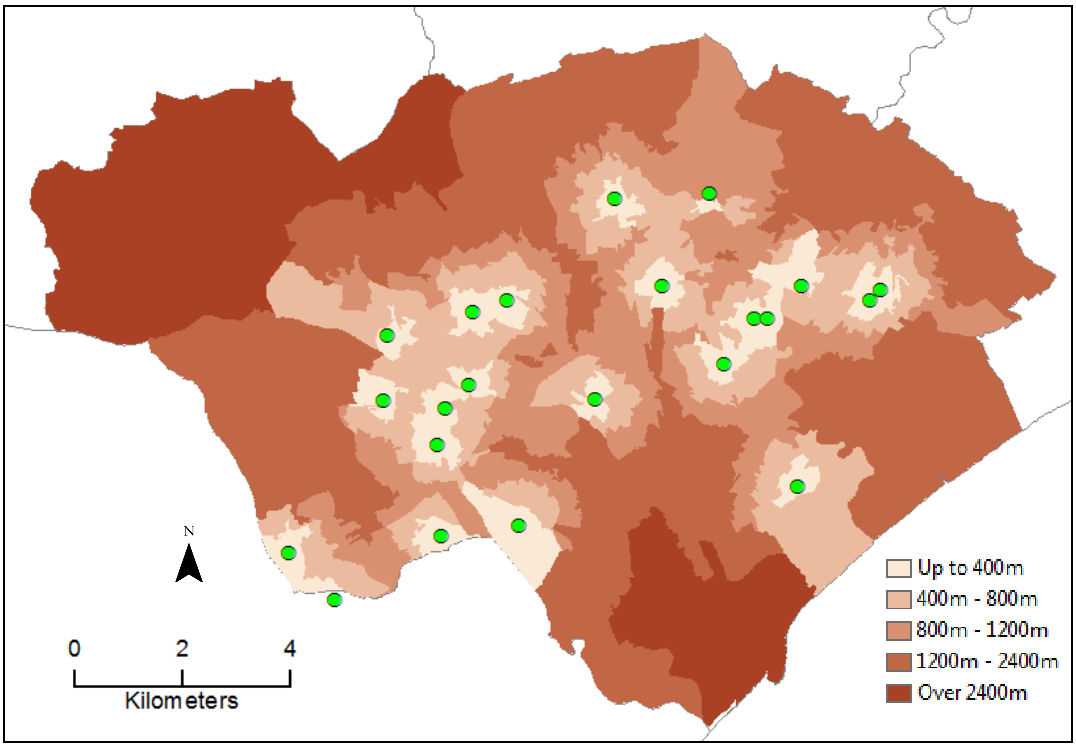


Figure 5.22: Euclidean distance to nearest secondary school (shown in green) Sites centroid, in Cardiff. OA boundaries have been removed to aid clarity.

The maps with the poorest accessibility figures were for OSM network distances to Sites centroids, with 3% of OAs in the lowest distance category and 18% in the worst. The areas around Radyr Comprehensive (Cardiff's most north-westerly secondary school) had the most noticeable drop in distance category, reflecting the OSM network around the school's large site having several side roads and access roads missing (when compared to ITN), and having no footpaths mapped, with Urban Paths having identified paths all around almost the school site, and throughout the woodland and parks lying between the school and the OAs in question. Results such as this, mapped as they were, helped to identify locations and situations where the inclusion of certain network components had a highly positive effect on accessibility, and also where these edges and ways were omitted and therefore had a highly negative effect.

Due to the larger areas involved in the Vale of Glamorgan, maps of walking distances to secondary schools appeared much worse than those for primary schools when viewed at the county scale (see Figure 5.24).

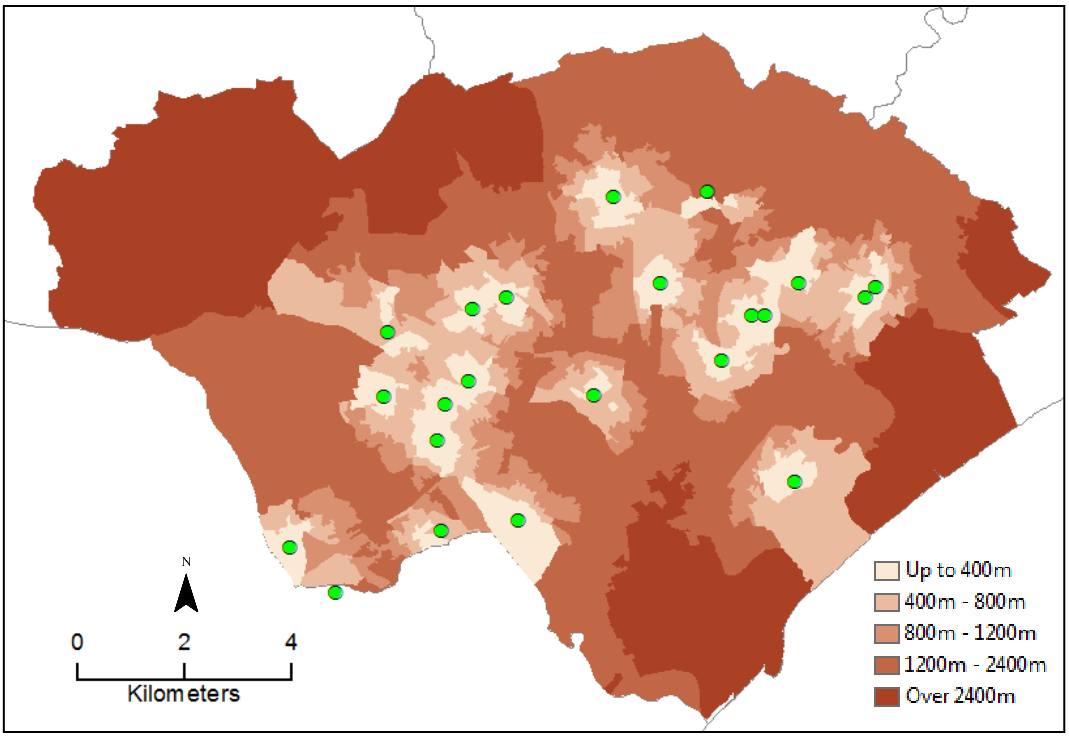


Figure 5.23: Network distance to nearest secondary school (shown in green) in Cardiff, using ITN with Urban Paths to Sites perimeters. OA boundaries have been removed.

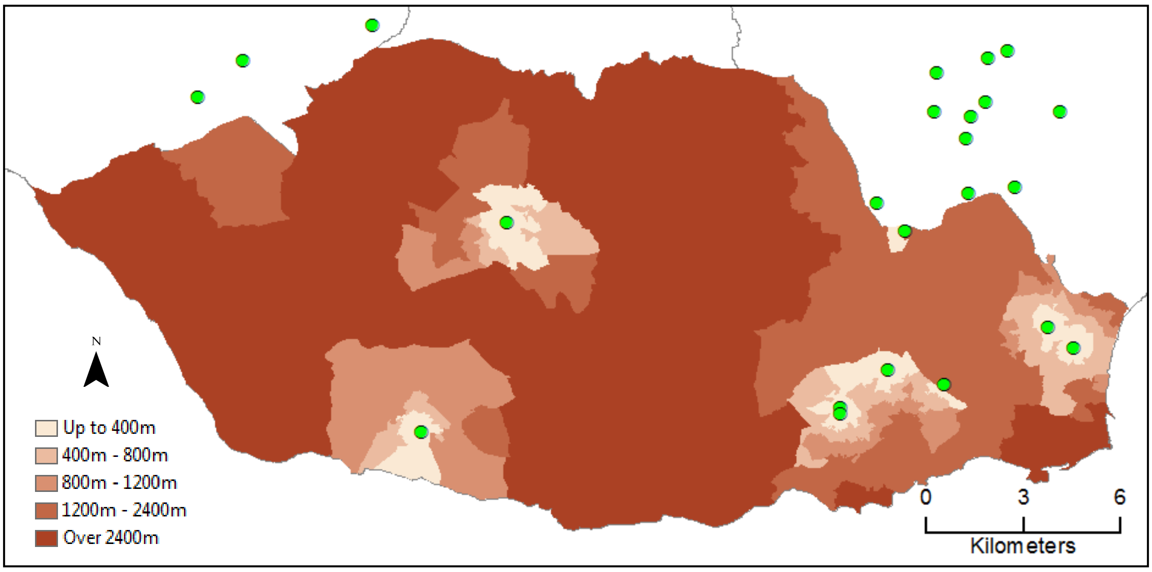


Figure 5.24: Network distance to nearest secondary school (shown in green) in the Vale of Glamorgan, using Euclidean distance to Sites perimeters. OA boundaries have been removed.

The distances to the nearest facility were considerably more than the distances to primary schools due to there being far fewer secondary schools in the county. Large areas of the countryside (18% of Vale OAs) fall into the worst distance category of 'over 2400m' which equates to walking times of over 30 minutes, at an average speed of 4.8kph. Only at town scales were the concentric patterns apparent (see Figure 4.25) but note that the location of the school to the west of Barry compared to the location of the OA centroid in which it was found meant that it fell into the 1200 to 2400m category, illustrating the dangers posed by the ecological fallacy (that is, automatically assuming that the entire school-age population of this OA was within that stated range of the school, with none closer and none further). With the fewer numbers and greater spread of secondary school to that of primary schools, a far smaller area of Barry and Penarth falls into the lowest distance category.

With Euclidean distances returning the shortest distances, the maps showing the results using network distances had much wider swathes of OAs in the lowest accessibility category. ITN had a range of 23 to 36% in the worst category, for distances to perimeter and centroid, respectively, with UP the range was 22 to 32% and for OSM 32 to 38%. Even though the choice of feature had a great effect on the accessibility of the demand points, the choice of network also had a considerable influence on results.

(a) (b)

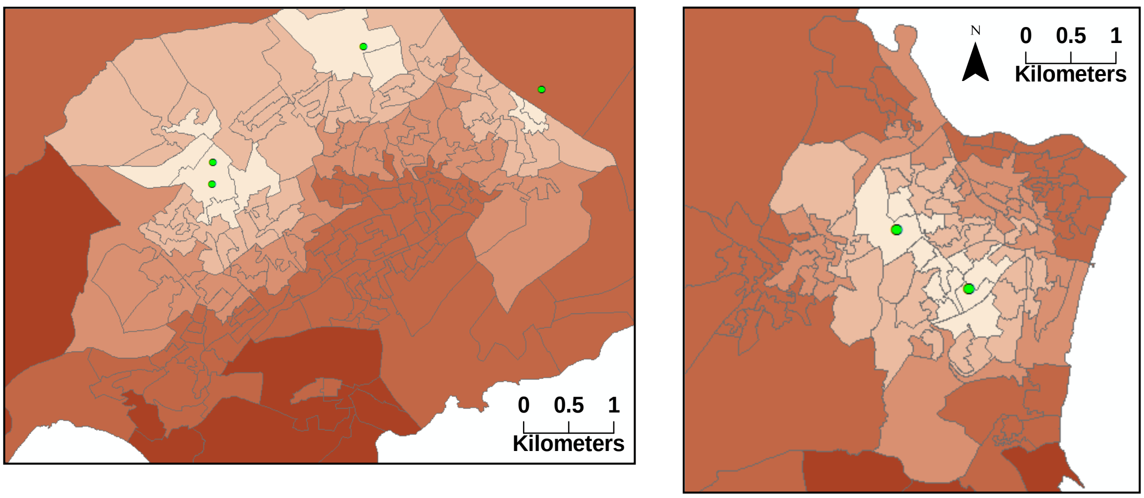


Figure 5.25: Map of accessibility to secondary schools (in green) in the Vale of Glamorgan, measured using Euclidean distance to Sites centroids, showing detail of (a) Barry and (b) Penarth.

The maps showing these Vale results were overwhelmingly 'dark,' with little detail to analyse. One point worth highlighting was the similar number of OAs in the lowest distance category for ITN centroids and OSM centroids (6 and 7, respectively), but with only one OA in common. This indicated that the presentation of results can mask true differences, especially where these differences were not in any of the larger areas within the map. Figure 5.26 shows the two networks compared in Penarth, showing the ‘best’ area in common. These differences were the result of snapping issues, as mentioned earlier, where the less-detailed OSM resulted in a ‘snap’ to a length that was closer to the feature and brought the distance to the destination down, whereas the slightly more detailed ITN snapped to a closer length, but which was further from the destination, and involved a more lengthy route to the same school.

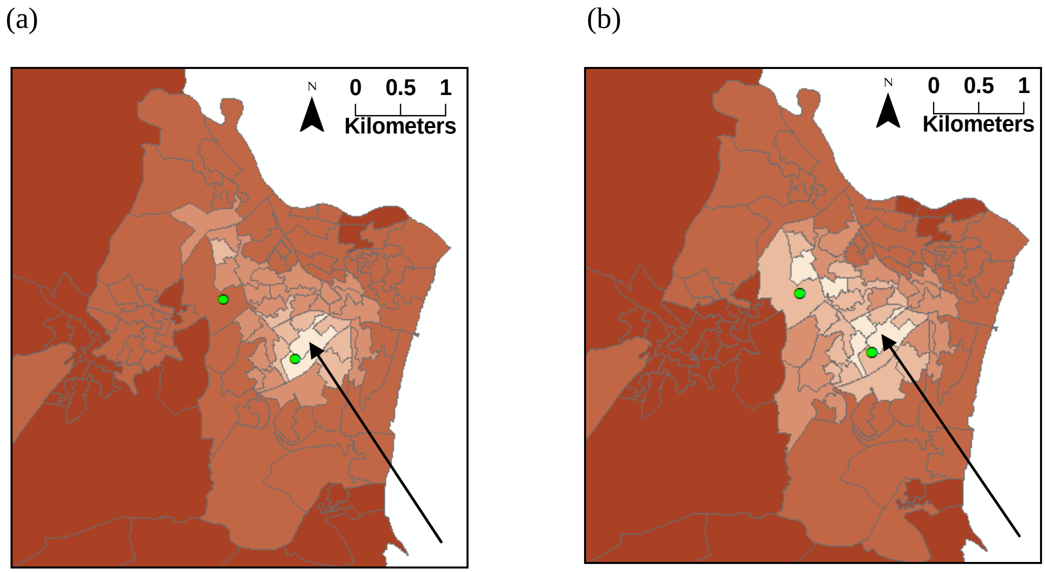


Figure 5.26: Map of distances to nearest secondary school in Penarth for (a) ITN and (b) OSM network, showing only one OA in common (indicated by arrows).

In looking at the maps produced from the 2SFCA model, concentric patterns were again evident, with a high degree of smoothing (see Figure 5.27 which uses ITN with Urban Paths and Sites centroids for each school as a typical example). An area just outside the city centre of Cardiff was the focus, with a nucleus of highly-accessible OAs. The pattern of school locations was a factor, with the majority located in a band around, but outside, the city centre, with many in outlying housing estates. With a larger catchment than primary schools, the array of schools in Rhondda-Cynon-Taff and the single school in Newport county all had an influence on the 2SFCA scores of accessibility of several of the peripheral OAs.

Similar concentric patterns of 2SFCA scores were found for many of the combinations of networks and supply points, though the scores varied. For example, the results for perimeter points were generally noticeably poorer, with no OAs in the highest accessibility category in the centre of Cardiff.

Results from using the OSM network were generally very similar, though three OAs with nil returns (due to being isolated from the main network and no destination feature falling within the ‘islands’ of OSM-ways in each area) were identified, the same three as were found in the primary school study. It cannot be assumed that the same three OAs will have nil returns for all five features, as there may be an instance where a feature was located within the island itself. For example, in the case of Canton, the island was made up of a few small, residential side streets, making it unlikely that any destination feature would be found within it.

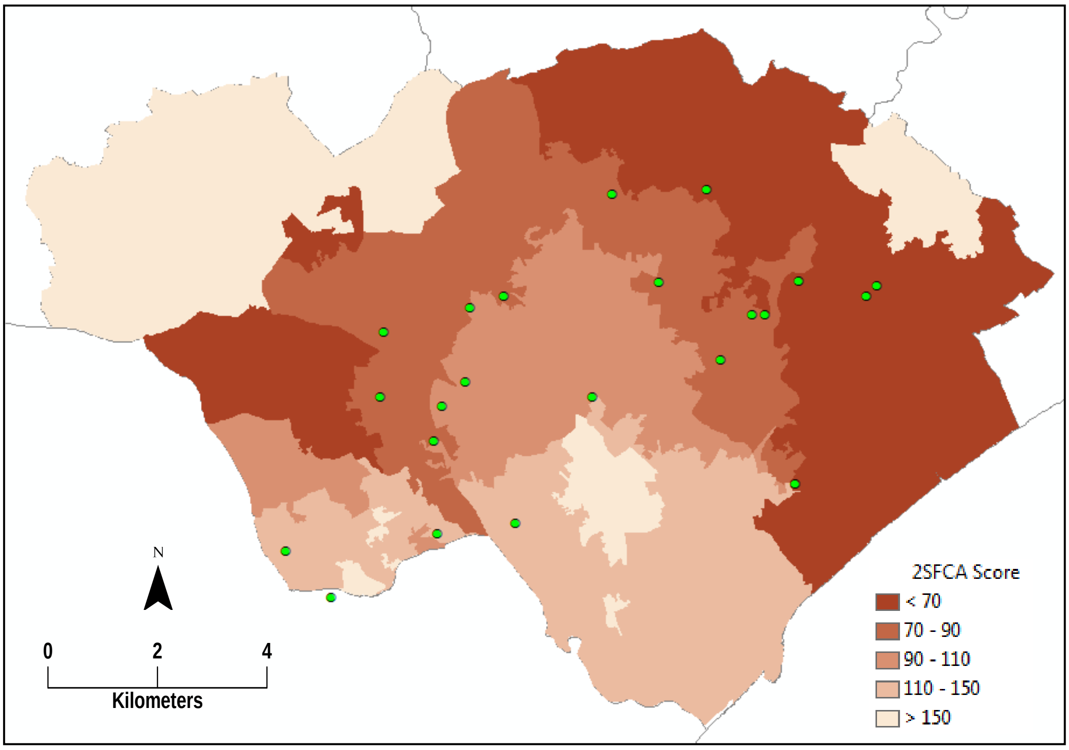


Figure 5.27: 2SFCA scores for Cardiff secondary schools, using ITN with Urban Paths as the network, and Sites centroids as the supply point. Category splits are rounded quintiles. OA boundaries have been removed to aid clarity.

In the Vale of Glamorgan, 2SFCA results when mapped did not display the concentric patterns that may have been expected (see Figure 5.28), but did exhibit a smoothed effect, with agglomerated areas of similarly scored OAs. With this feature, however, the smoothing applied even within the two main towns in the county (as shown in Figure 5.29).

The influence of multiple schools in the neighbouring areas of Cardiff and Bridgend again dominated the map, with the central areas and coast falling outside the catchments of these schools, hence assessed as having the worst accessibility. The schools outside the county raised the figures for the north east and north west Vale OAs and, as 2SFCA is essentially a ratio, the remaining, fewer schools within the Vale, exert much less influence. The details in Figure 5.29 show the relatively small influence of the more isolated schools in Penarth, but particularly in Barry, where even two schools relatively close together did not raise 2SFCA scores into the more highly-accessible ranges, but the towns show the considerable influence of Cardiff schools. The other networks produced very similar 2SFCA results for the Vale, again highly smoothed even in the towns.

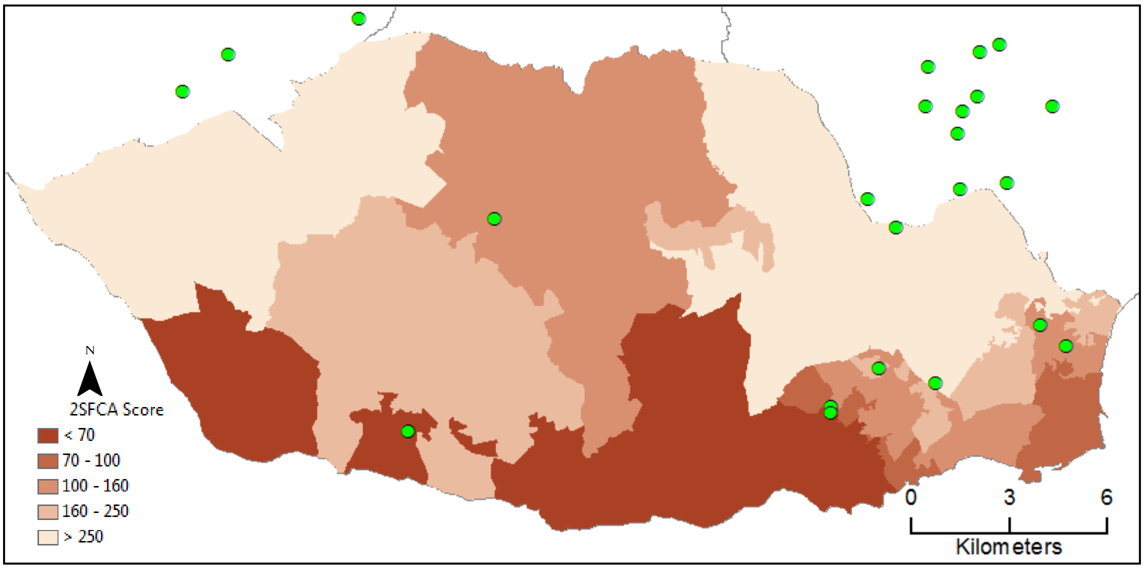


Figure 5.28: 2SFCA scores for Vale secondary schools, using ITN as the network and Sites centroids. OA boundaries have been removed to aid clarity.

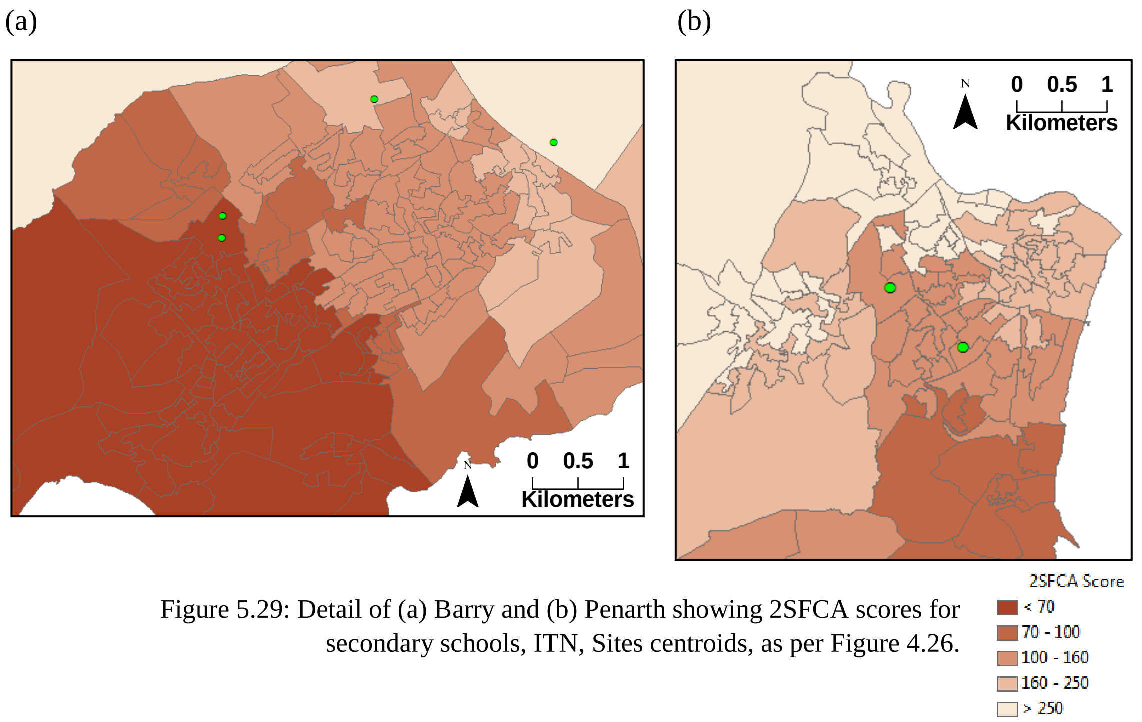


Figure 5.29: Detail of (a) Barry and (b) Penarth showing 2SFCA scores for secondary schools, ITN, Sites centroids, as per Figure 4.26.

5.2.4 OS Code-Point and Code-Point with polygons

The use of post codes as demand points offered the opportunity to undertake accessibility studies at a further level of population disaggregation, with matching polygons supplied (as an optional dataset) able to present visualisations at a finer scale than that offered at Output Area levels. The supplementary information held in the dataset, in addition to the post codes themselves and locational data, also offered (in theory) the possibility of a more accurate population representation, when applied to this type of accessibility study. The use of Code-Point may also serve to highlight issues and errors within network data sets, which is discussed in some detail in the next Chapter 6.

One drawback to the use of postcode-level data at county scales is the issue of visualisation. Code-Point and Code-Point with polygons offers mapping at a finer scale than with OAs, and although the same base population figures are used (OA populations being the finest scale available to be freely downloaded for academic or public use) the more-numerous points enables differences within smaller areas to be identified, and the smaller associated polygons enable a more detailed visual analysis. The distinction made between residential and non-residential post codes also enables more precision, in that night-time population data will not be allocated to non-residential postcodes, thus omitting results from retail parks, industrial and commercial areas.

The results for Euclidean distances to secondary school perimeters using OAs as demand points will be compared to the use of post codes (PCs) as demand points. First, the county-wide results for the Vale of Glamorgan will be compared, as shown in Figure 5.30.

Although the overall pattern looks similar, the areas of ‘best’ accessibility have shrunk somewhat, particularly around Cowbridge in the centre of the county. Two issues are worth noting: the size and shape of the study areas do not match exactly, as the boundaries of post codes do not necessarily follow any other administrative borders due to the business needs of the mail service, for which the boundaries were made; secondly, the white areas apparent in Figure 5.30(b) are postcodes which are entirely non-residential, and so have no night-time population associated with them. This results in an aesthetically less-pleasing map, particularly around the Barry docks area (the south eastern edge of the county) where the lack of data results in a jarring appearance, albeit more accurate, in a strict sense.

Details of the areas around Barry and Penarth are shown in Figure 5.31, again comparing the results from using OA polygons to using those of Code-Point. The general pattern of results is similar, but even at this higher scale level the post-code polygons cover an area so small in the built-up areas as to render the detail indistinct. In a GIS or interactive map (as opposed to a paper or static map) decision makers or researchers would be able to zoom in to particular areas of interest to look at the results down to the level of a few streets, where detail is more apparent.

Again, the differences in the border of the study areas are visible, but the coastline provides a common line of reference for both comparisons. Smaller PCs with no residential population are noticeable at this level, with Barry docks and coastal chemical works responsible for large areas of white, while a country park and retail areas to the north are responsible for those around Penarth. These visualisations do provide a more accurate interpretation of accessibility to the area (errors in the tools notwithstanding), but the confusion and uncertainty caused by the 'gaps' may make the maps less usable to the public or decision makers, and any replication of these maps would have to be accompanied by an explanation of the gaps and justifying the approach taken.

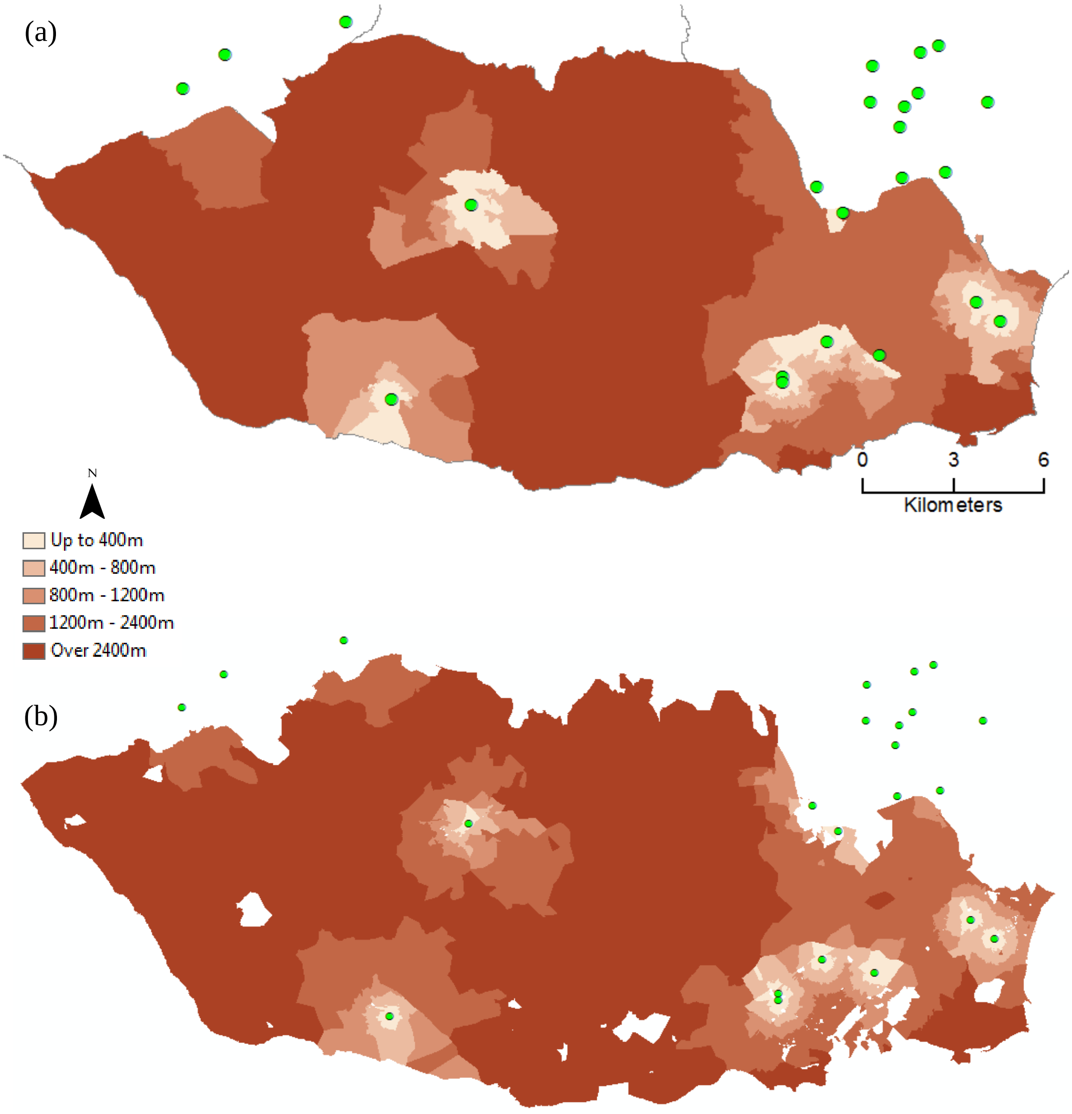


Figure 5.30: Comparison of accessibility levels using OA polygons (a) and post code polygons (b), to secondary school perimeters using Euclidean distances. OA boundaries have been removed to aid clarity.

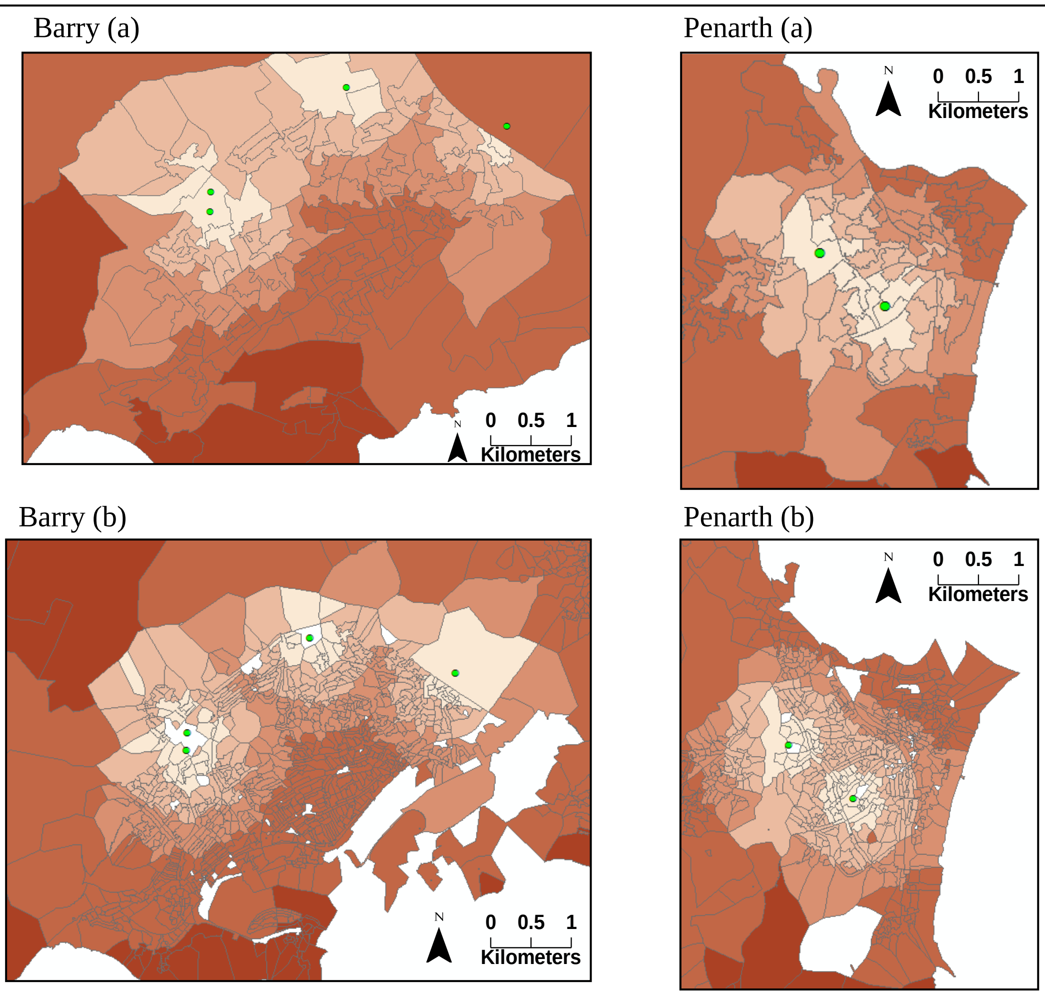


Figure 5.31: Detailed comparison of Barry (on the left) and Penarth (on the right) using OA polygons (a) and post code polygons (b).

5.2.5 Alternative visualisation: cartograms

A potential alternative form of visualisation of the results in Section 5.2.4, which takes into account the wide differences in size of the polygons, is the cartogram. Maps are called cartograms when distortions of size, shape or distance, are made, with the areas on a cartogram drawn so that their size is in proportion to the feature being measures (Dorling, 1996). Generally, mapping with population cartograms changes the perspective from the countryside to the towns, where most people live.

The advantages of cartograms are that areas which are less distinct at a certain scale of analysis can be exaggerated. This could be particularly advantageous when comparing urban and rural areas, where the sizes of (for example) OA and post-code polygons have a large variation in size. Cartograms would reduce the visual impact of the larger, rural areas while making more detail visible from within the urban areas.

In Figure 5.32 the same results as shown in Figure 5.30(b) are presented as a cartogram, using the Newman-Gastner method, via a tool obtained from Esri's support site (http://arcscripts.esri.com/details.asp?dbid=15638, Cartogram Geoprocessing Tool version 2, accessed 23 March 2015). The outcome was not entirely aesthetically pleasing at county level (Figure 5.32), nor for town level (Figure 5.33). Although the cartograms enable smaller areas to be distinguished, the geographical relationship between areas is diminished, thus their use in analysis is limited and such maps are generally used as a visual tool.

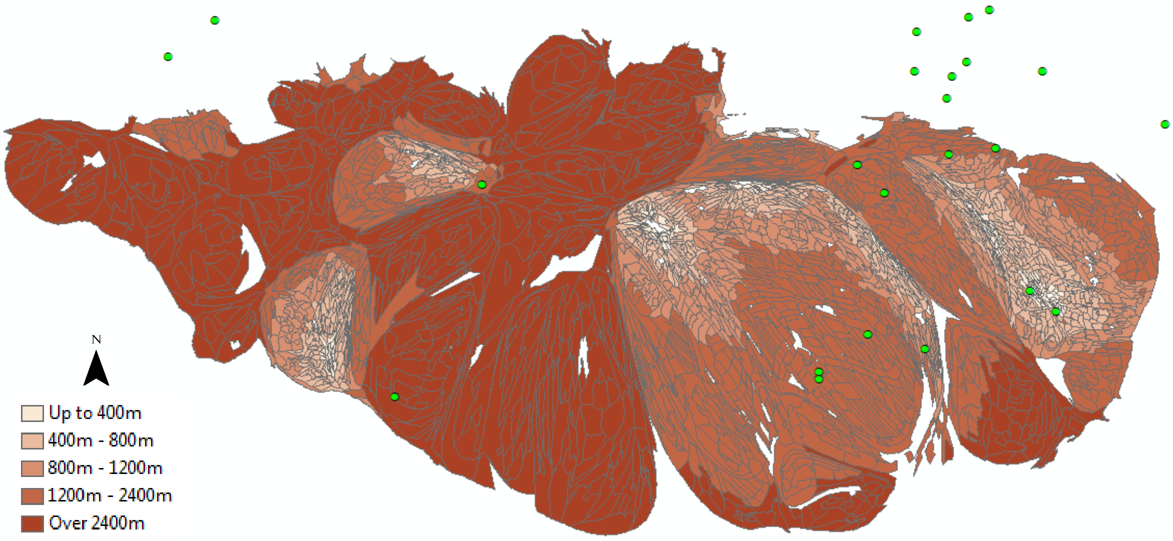


Figure 5.32: Cartogram representation of results shown in Figure 5.30.

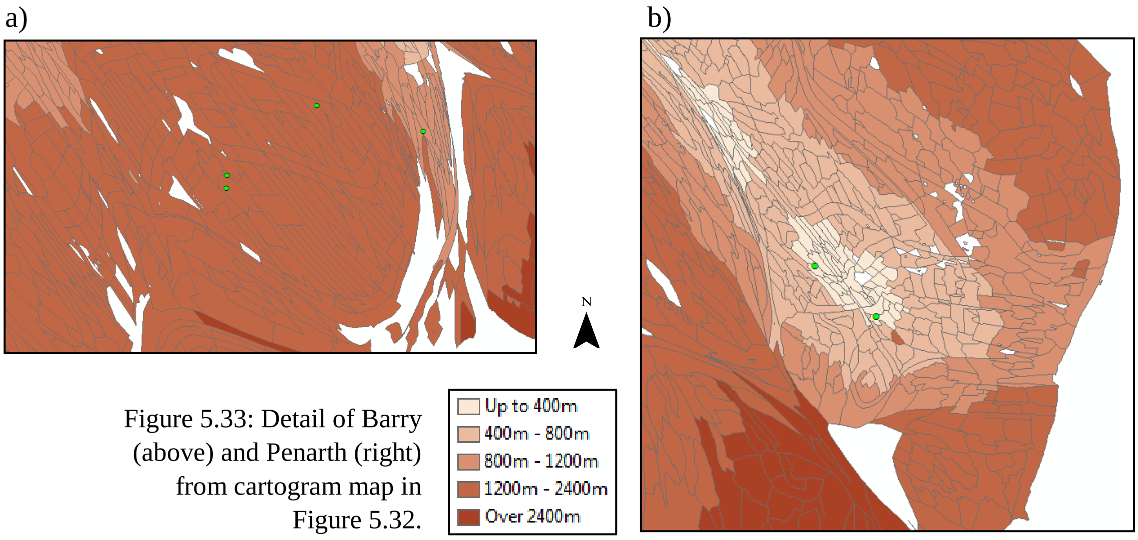


Figure 5.33: Detail of Barry (above) and Penarth (right) from cartogram map in Figure 5.32.

For comparison, Figure 5.34 shows a set of results for Cardiff using OAs in choropleth and cartogram form for 2SFCA scores. In this case the central, highly-populated areas and the suburban and semi-rural locations are given more emphasis, with the peripheral areas with lower accessibility having their emphasis reduced considerably. Care must therefore be taken that the visualisation method does not overly diminish the impact of areas which may already be marginalised in terms of accessibility.

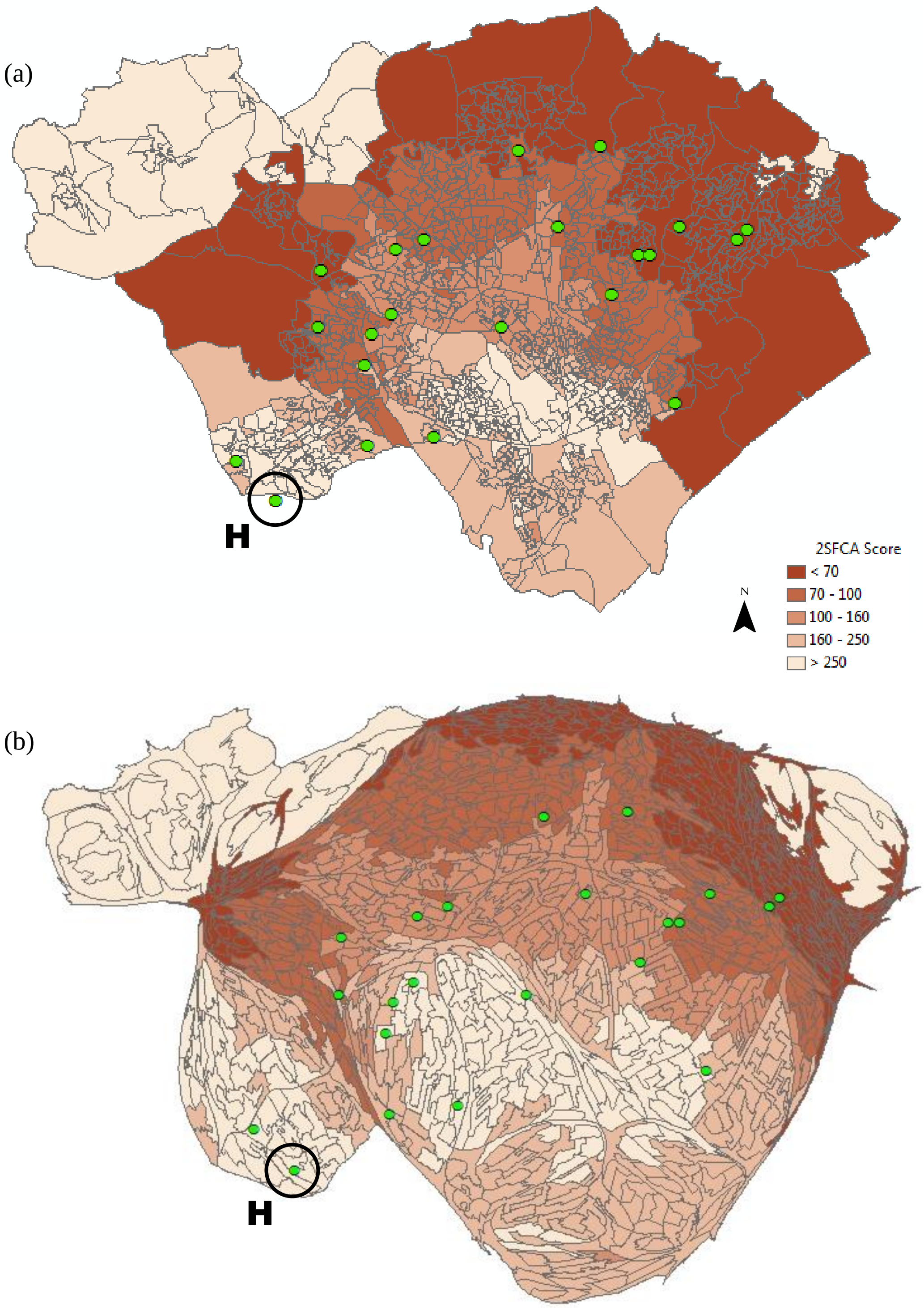


Figure 5.34: Accessibility to Cardiff secondary schools with ITN measured by 2SFCA method, visualised using (a) choropleth map and (b) cartogram. The location of schools is marked in green in both maps in order to aid comparison. Note how the location of Mary Immaculate RC High School (marked 'H') falls within the Cardiff boundary due to the distortions caused by the cartogram creation method, emphasising the unsuitability of this method for geographical analysis.

5.3 Chapter summary

This chapter provides a summary of the results from the sensitivity analyses carried out on the various datasets. Examination of each dataset in isolation produced some usability information, but by considering the results of using the data, by looking at the outputs produced by the various GIS processes, it was hoped to throw some light on the nature of the data itself. Unfortunately, the output was such that the most stringent statistical tests could not be applied, and less fine measures had to be employed, due to the results exhibiting non-normal distribution and the results not being completely independent of each other (as all results had the same OA centroids as origins in common. This had the effect of restricting some assessment to the relative values of the results that were produced, rather than the absolute values. Although evaluating the levels of similarity and difference between the datasets was difficult, given the nature of the data involved, an indication can be given as to the broad similarities or differences achieved through comparing outcomes and also the issues and problems associated with the use and analysis of this geographic data.

5.3.1 Summary of visualisation results

The work in this thesis could be considered as but one strand in the study of data usability. This work utilised sensitivity analysis to test OS data sets representing supply, demand and network. The GIS functionality used to examine the usability of the different sources of data in such contexts was accessibility analysis. This involved the use of 'traditional' measures of accessibility such as shortest distances, and the use of gravity based models (using 2SFCA tools) to compare findings in rural, semi-rural and urban areas. Sensitivity was assessed through a statistical and visual comparison of accessibility scores. Choropleth maps were used in the visualisation of results, with alternative visualisations trialled to improve clarity.

Shortcomings in the use of choropleth maps were discussed in Section 5.1, where the dominance in any maps of geographically-larger areas was noted. An attempt to address this issue was made through the use of cartograms, with mixed results: larger areas were less dominant; smaller areas were more noticeable; but geographic reference points were lost and direct comparisons of results from the same area to choropleth maps or to other cartograms were impossible, due to the deformation of the size and shape of each polygon to reflect the measured value attached to each particular polygon.

Certain assumptions and generalisations were made in (see Chapter 3 for details) which affected the visualisation of results. The main demand-side assumption was the representation of population in each OA by one point: the OA population-weighted centroid. Although OAs were the lowest unit of census area available to researchers, a level of generalising had still occurred. A finer representation of population using postcode locations was applied, and the assumption made that population was spread evenly across each postcode location within each OA. The level of generalisation involved was mitigated somewhat by the removal of non-residential postcodes, meaning that postcodes containing purely commercial and industrial addresses had no night-time population assigned to them.

Analysis and understanding of results arising from distance measures were easier to comprehend when presented in choropleth map form. Visualisation of the results from distance measures for Cardiff showed the areas with poorest accessibility to all features were located on the outskirts of the city, reflecting the green belt at the LA boundary and the barrier of the River Ely to the west. Euclidean measures could ignore the river barrier and utilise the facilities of the neighbouring town, Penarth. Network distances meant most of these facilities were not reachable from Cardiff and therefore some OAs in the south of Cardiff fell into the poorest accessibility category (over 2400m, the equivalent of over 30 minutes walking time). These results highlighted how Euclidean distances could be used inappropriately in usability studies.

Although the different methods used to represent features such as schools made significant differences to distance measures (as shown in Chapter 4), many of these differences were not apparent in the choropleth maps, as many of the changes fell within the same distance splits. However, where distinct changes in distance split did occur, the choropleth maps provide an easily-accessible method of identifying where these considerable changes were located, enabling further investigation into the root cause. In the majority of cases the sharpest differences were not caused by the different methods of location, but by network issues or by errors in the attributes of the feature in question. Errors of both omission and commission were present in several of the datasets. No errors were identified relating to OS ITN dataset, though potential shortcomings in this network for travel other than by motor vehicle were apparent (issues which will be discussed in Chapters 6 and 7).

The visualisation of 2SFCA results was more difficult to interpret than those of distance measures. As a ratio of accessibility, each map showed what areas were rated best and which were rated poorest compared to each other: 2SFCA was not an absolute measure of accessibility. The thresholds used in the calculation of 2SFCA also had a considerable influence on the appearance of the results, with maps showing considerable smoothing of categories, and central areas, which fell within the threshold of multiple destinations, generally exhibiting the highest accessibility scores. The thresholds, which reflected reasonable walking distances, were so great as to dominate an area the size of Cardiff. When reduced, however, some of the outlying demand-side points (OA centroids) fell outside all thresholds, therefore produced nul results. The difficulty of assigning suitable thresholds, especially where there is lack of clear evidence as to what the threshold should be, is a major shortcoming associated with the 2SFCA type of model.

The requirements of the 2SFCA plug-in tool meant that considerable processing and further generalisation of location methods were required for the tool to operate. Specifically, rather than identifying the nearest part of a Site perimeter, the feature in question (a primary or secondary school) had to be assigned one representative point on the perimeter, a point identified as the mode point which was closest (by network distance) to demand-side points. This mode point varied according to network, which meant a considerable amount of processing before the plug-in could be used. A similar situation arose with Sites access points, but as the choice of representative point was much more limited, the processing required was considerably less that that required for perimeters. However, these issues with the operation of the plug-in raised considerable concerns over the accuracy of 2SFCA results for access points, but especially for perimeters.

The visualisation of results using 2SFCA compared to those using distance models had few similarities, confirming the numerical results with their low correlations and high levels of difference. This was particularly striking in the Vale of Glamorgan, where scores reduced from north to south (with areas of low accessibility also down the centre of the county). This reflects the influence of Cardiff facilities, and those in other neighbouring counties, on the overall scores, with the areas along the southern coastal areas of the Vale having few, if any, overlapping thresholds. Even a cluster of facilities (in this case primary schools) in the village of Llantwit Major was insufficient to bring the score for the surrounding OAs up to that of the highest-scoring areas, which had multiple overlapping thresholds.

5.3.2 Summary of overall results

In looking at the results as a whole, certain broad issues were evident:

- No comparisons of any two combinations of dataset produced identical results, despite representing the same features, be those supply-side features, demand-side representations or network datasets;
- The vast majority of comparisons resulted in statistically significant differences being found, despite many having very strong correlations;
- In most cases the choice of dataset used to represent a feature had a statistically significant effect on results;
- Some of the OS network datasets were broadly similar, particularly ITN and Open Roads;
- In several cases, OSM and ITN had very similar results;

- The inclusion of Urban Paths meant that results using UP were considerably different from those using ITN, in both urban and rural contexts (but less marked in the Vale), indicating the importance of key pedestrian facilities (such as footbridges) in assessing pedestrian accessibility;
- In both Cardiff and the Vale, coverage of OSM and updating of OSM data was considerably below that of other areas. On investigation, many footpaths identified using UP were lacking in OSM in the outskirts of Cardiff and throughout the Vale, casting doubt on the ability of OSM to provide a reasonable representation of a travel network for pedestrians, despite indicating that its data includes footpaths and cycleways;
- 2SFCA results showed a considerable urban/rural split, with the Vale returning a higher level of non-significant differences than Cardiff, indicating a higher level of statistical similarity;
- In the Vale (less so in Cardiff) when the method of locating a supply-side feature was constant but the network varied, the outcomes showed little significant difference. When the location method was varied and the network remained the same, generally the differences were significant;
- When nearest destinations were identified by Euclidean measurement to the various location options, only 86.6% of Cardiff demand-side points were mapped to the same destination. The figure for the Vale was 93.6%. This indicated the effects of altering the location method between Point of Interest point, Sites access point, Sites perimeter and Sites polygon centroid;
- The comparison of ITN and Open Roads returned the highest destination overlap figures in both Cardiff and the Vale for GP surgeries, sports centres and community hubs. Despite the
- temporal differences between the ITN and Open Roads dataset, in the practical task of identifying nearest destinations they still returned the highest percentages compared to the other combinations;
- Greater accuracy and precision of data does not necessarily equate to better usability, as the provision of OS Sites shows when used with the 2SFCA plug-in. Available tools are not designed for the greater degree of accuracy and precision offered through the representation of single facilities by multiple points.
- The results obtained from using the custom-built Arc Model to assess 2SFCA using Euclidean distance were not as informative as hoped, though again illustrated the dangers of using Euclidean distances in accessibility analyses, where major barriers such as rivers are effectively ignored.

These issues will be discussed in more detail in the next chapter.

Chapter 6 Discussion

6.1 Introduction

Chapter 1 outlined the background to this research and introduced the main aim and objectives. Chapter 3 explained the methodology which was applied and Chapter 4 outlined the results obtained. An initial presentation of the results was carried out in Chapter 5. This chapter includes a detailed description of the main findings from this thesis, suggests some reasons why such trends emerged and makes some observations on how the results of sensitivity analysis can inform those interested in geospatial data usability.

Both general and specific usability issues which were encountered during the various steps involved in the analysis will also be included in this chapter. For example, as reported in Chapter 4, the ‘distance’ results for schools implied that a rural context increased the levels of similarity between the all the datasets that were considered. It would appear that urban-rural contexts did affect results, however at this stage considerable care would be required before any generalisation were to be made regarding the utility, usefulness or usability of data in rural compared to urban situations. Such generalisations would have to be severely qualified, carrying caveats to inform potential users that the usability of such data is not just affected by the context of the task to be completed, but in the geographical context, too, and that what may apply in an urban context may not apply to the rural, and vice versa. This issue will be further explored during the course of this chapter.

A classification of the issues found in the course of this study is provided in a typology of errors, helping identify patterns and trends of errors and issues with the various datasets in a summary form. A SWOT analysis also provides a more general summary of the main findings along with key characteristics of the datasets. Such SWOT analyses such as this could add to the usability information held as metadata within any set of geospatial data, indicating ways in which established techniques could be applied in a data usability context.

6.2 Supply-side geospatial data representation

The aim of this section is to comment on the use of different supply-side representations within accessibility models. A summary of the data sets used to represent the supply-side representations was provided in Section 4.3, and is reproduced here, as Table 6.1, for convenience. Many of the comments refer to issues or difficulties in the utilisation of the information within the datasets in the context of accessibility analysis. Care must be taken in broadening these comments to a wider context (and this has been done where deemed appropriate) but it must be emphasised that without further evidence such broadening would be speculative, and that any firm comments reported here reflect purely on the empirical results from the specific analysis carried out.

Following the destination overlap results and the statistical analysis of distance and 2SFCA results as outlined in Chapter 4, it was clear that the location method used to map the position of a supply feature had a considerable effect on accessibility levels. Preliminary findings indicate that the distribution patterns of primary schools may have influenced results, as well as the topology of the feature itself. Comparing results from other features, with different distribution patterns, may indicate if the visualisation outcomes from primary schools are representative. Secondary schools, with their much larger-sized sites (with much larger perimeters), could be expected to show that the choice of locational method had a larger effect on these factors than on primary schools.

The presentation of secondary schools results was expected to show some differences to those of primary schools. Accessibility maps for distance would be expected to appear lower (due to fewer features, further apart), though the effect on the patterns of 2SFCA may be less obvious. Secondary schools were also rarely located in the heart of established communities, therefore it was interesting to see what difference this made to the relative accessibility of densely-populated urban areas.

6.2.1 OS Points of Interest (PoI)

There were no specific errors noted with the PoI dataset during the course of this research which found the data to be detailed and comprehensive. General issues and concerns were noted throughout this thesis, particularly those concerning the high levels of generalisation which were required, with some very large locations (such as schools) represented by a single, representative point. In the context of this research PoI was the only viable, comprehensive source of destination features available which had a detailed classification system that permitted a sufficient level of enquiry and selection. Some issues over classification were raised and noted in the course of this thesis, but appeared rooted in an ontological debate as to whether the purpose of the PoI dataset was to map locations as to what was there, or to map and classify according to what activities took place at that location.

Datasets used				
Feature	**Ordnance Survey**	**Non OS**	**Strengths (in relation to accessibility studies)**	**Limitations (in relation to accessibility studies)**
Supply-side	Points of Interest		Detailed, comprehensive.	Heavily generalised. Very large facilities represented by point.
	Sites		Detailed, comprehensive, highly accurate representation of functional polygons. Access points give actual points of entry, with clear classifications.	Access points not fully surveyed. Some errors of omission and commission.
	AddressBase Premium		Fine scale, to address level.	Complex, inconsistencies in classification.
Demand-side		Census OA centroids	Free. Seamless coverage of UK. Stable content (very similar in 2011 to 2001). Population-weighted.	Population 'adjusted' in some cases, to ensure confidentiality. Long updated cycle (10 years).
	Code-Point		Larger scale. Content changes and updated regularly. Distinguishes domestic/non-domestic postcodes.	Boundaries change through time, impractical for studies of long-term change.
	Address Layer 2		Fine scale, to address level. Content changes and updated regularly.	Difficult to distinguish domestic addresses.
	AddressBase Premium		Fine scale, to address level. Content changes and updated regularly. Distinguishes domestic/non-domestic addresses.	Complex. Requires disaggregation. Addresses updated much more frequently than supporting population figures.
Network	ITN		Comprehensive. The 'gold standard' of UK network data. Excellent for travel by motor vehicle.	Not comprehensive for journeys by cycle and on foot.
	ITN with Urban Paths		UP not national. Comprehensive where applied.	Some inconsistency in application.
	Open Roads		Open data. Simplified ITN. Good for travel by motor vehicle.	Limited for journeys by cycle and on foot.
		OSM	VGI. Open data. Updated in real time. Cycle map layer.	VGI. Uncertainty over content quality. Unclear classifications, lack of definitions. Data drop-off with distance from large urban areas.
		Euclidean	Easy to calculate. Simple to understand.	Overestimates accessibility. Not a true reflection of real-world travel. Ignores barriers.

Table 6.1: Summary of datasets compared in this thesis.

Using OS PoI, correlation coefficients for features in the Vale generally had higher correlations than their Cardiff equivalents (and this also applies to Sites features, see the next section). The relatively few destination features and the greater distances involved from the demand points appear to be major influences. However, now that differences have been identified as present a full, designed multi-factor experiment could be designed, and some form of regression analysis conducted, to confirm and quantify the dependent factors and their level of influence.

6.2.2 OS Sites

Full details of the Sites dataset was given in Chapter 3 where the advantages and disadvantages of this relatively-new dataset were outlined, as summarised in Table 6.1. Specific issues with the dataset, and particular problems encountered, will be outlined in this section.

6.2.2.1 Issues with Sites dataset that impacted on results

The use of perimeter data resulted in the lowest travel distances for all networks (as assessed from the map categories): logic dictated that the perimeter would be the part of the feature that would be reached first. Although the access points lay on the perimeter of each feature, it was unlikely (but not impossible) that they would be the closest point to any origin feature. Although this may not be directly relevant to schools (with their typically secure perimeters), the use of perimeter data may be relevant to other, more open, destinations, such as parks and green spaces and public areas such as town squares, etc, which are typically represented by generalised point locations.

Several instances of duplication of secondary schools were noted in the Sites dataset. Clear duplications (where two or more schools were duplicated by both name and exact location) were removed before any calculations were conducted. Where schools with the same name were mapped to different locations, they were retained (it was possible that some schools were split-site, as was the case of Whitchurch High, which had Upper and Lower schools some distance apart from each other. The following schools were duplicated: Richard Gwyn, Archbishop McGrath and Whitchurch High (which was triplicated). Although the duplication of school sites would have no effect on either destination overlaps or distance measures, the 2SFCA results would have seen considerable effects, with each duplicated school doubling (or tripling, in the case of Whitchurch) its influence in terms of supply with respect to the population points within the catchment as set in the 2SFCA calculations.

The duplication of features was identified through examination of the attribute tables in the GIS, which tabulate the information associated with each feature. It is assumed that those more familiar with GI would examine such data as a matter of course (even if only a cursory check was made), and in the case of these supply-side features the numbers of records involved enabled a more detailed examination to be made, and the duplications identified. It may be expected by general users that the data, from a trusted and reputable source, would be accurate and correct and only required loading onto a GIS before analysis began, and this would have serious consequences over the results of any analysis. Depending on the purpose and the market at which this product is aimed, more care should be taken with the data quality, or appropriate caveats stated clearly. For accessibility analysis, the Sites datasets allow a variety of approaches to be taken, and a variety of options made by which to represent the various features, all of which add to the flexibility and usefulness of the dataset (assuming accuracy of content).

Section 3.2 in the Methodology chapter provided the detail of the 2SFCA calculations and described the tools used to calculate the 2SFCA results in this thesis. Attention is drawn once more to the limitations of 2SFCA plug-in, with respect to the assumptions and generalisation required to enable the plug-in and Arc Model Builder tool to operate with the Sites dataset characteristics (particularly multiple access points and the perimeter of features), and the considerable potential effects of these generalisations on the 2SFCA results. This could have been addressed through recoding of the 2SFCA plug-in and is an area for further research discussed in the concluding chapter. The use of a form of accessibility analysis other than an FCA-model may have addressed this issue, and the inclusion of distance measures were intended to provide a suitable alternative. Future research could for example involve developing GIS tools to exploit the greater accuracy and precision offered by this particular dataset.

6.2.2.2 Reporting of specific results

The distance correlations of primary schools were generally higher in the Vale than in Cardiff, indication an urban/rural divide. The greater distances involved in the Vale combined with fewer features within the area may have contributed to this difference. Correlations of 2SFCA scores were reversed, with Vale returning slightly lower results, perhaps due to the fewer number of overlapping catchments applicable to the Vale, when catchments the same size as Cardiff were used. A similar pattern was identified for secondary schools, and the same underlying reasons appear to apply to this feature. Future study could involve examining the possibility of having larger thresholds in rural areas and comparing findings to see if the results of the gravity model become more strongly correlated.

The results of 2SFCA scores when measured to the perimeter of facilities were highly correlated in both Cardiff and the Vale for UP and OSM networks, signifying the similarity between these two particular networks (the only two studied which included footpaths in their data). However, overall results strongly indicate that the use of different models of locational representation (site centroid, access point and perimeter) result in statistically significant differences in results for both distance and 2SFCA methods. The choice of locational method should therefore be taken with care, fully justified with each approach and should be kept consistent in order for accurate comparisons to be made. The findings from such models should be fully detailed to permit transferability to other contexts.

6.2.3 OS Address Base Premium (ABP)

Chapter 4 provided an example of a potential alternative supply-side dataset to PoI and Sites, namely that of AddressBase Premium (although this dataset had included private schools in Cardiff in the general classification for secondary schools). A further issue involving secondary schools was identified in the Vale of Glamorgan which arose from Cowbridge having two secondary schools recorded in ABP, despite PoI and Sites only identifying one. One of the ABP records had full identification attributes for Cowbridge Comprehensive, in the same location as Sites and PoI, but no name or identification for the second. By entering the postcode provided by ABP on Google Maps and Street View (using ITN for road names for fine location within the postcode) this second instance was found to be the derelict site of a previous location for Cowbridge Comprehensive, which closed around 2010. The point representing the disused school was removed from the dataset and the remaining points matched those of the Sites and PoI datasets for the Vale of Glamorgan.

6.2.4 Observations on supply-side representation

Some issues arose in the course of this study following an opportunity to sample a database of sports facilities held by local authorities. In addition to the ‘usual’ types of facility there was a specific category, in only one LA area, of ‘kickabout area.’ The location of several of these areas was noted and investigated further. One such area, Lewis Road kickabout area, is shown in Figure 6.1.

When compared to OS resources, it was found that the nearest Points of Interest point was the adjacent playground and that OS Topographic Layer (Topo) had a TOID (a unique OS identifier) for the playground. There was no record of the kickabout area as a feature. Other areas had layouts similar to that above, with a playground and kickabout area adjacent to each other. Most OS datasets had nothing to distinguish this area, although Bower Street kickabout area in Kenfig had separate TOIDS for a playground and the area around its adjacent kickabout area. In some instances the kickabout areas were in parks or on commons (for example Litchard Common kickabout area) which had no PoI features in the vicinity and the TOID referred to ‘Land, natural environment, rough grassland.’

Figure 6.1: Lewis Road kickabout area (from Google Street View).

This case illustrates several points. Firstly, different organisations have their own separate records of geographical features which were kept privately. They would not appear in any academic research or report into sports or play facilities unless the LA in question volunteered the information. Secondly, not everything that is considered a feature by one person or organisation is treated the same by everyone else. Thirdly, what constitutes a feature? In these cases the LA need, presumably, to record these areas as they have constructed something within them, in this case a set of goalposts, for maintenance and upkeep purposes. If the kickabout area was a junction of back lanes with goals painted on a wall and the suspension of normal 'no ball games' rules, would it still be a feature? Again, the council would presumably keep records for their own operational purposes, but there would probably be nothing similar recorded in any other geographic database. A further point could be lack of consistency across authorities, as it was noted that the term 'kickabout area' was used by one LA but not by others. It was entirely possible that other LA's may have such areas within their boundaries, but refer to them in different or more general terms (for example, as a Recreational Area), drawing attention to instances of feature definition within such models.

On a similar theme, but reflecting the difficulty in mapping actual locations of sporting facilities, is the case of small clubs and societies. In one typical example (chosen from a very small sample of data held by a voluntary organisation) is the case of Bridgend Judo Kwai, which was listed with a postcode and a contact telephone number. However, as in many cases with small clubs, the postcode referred to a private house address, while the actual facility was several streets away, in a back-lane location (as per Figure 6.2, which presumably did not receive any post (therefore will not have a post code itself).

Figure 6.2: Typical back-lane sporting facility, not mapped as such in any data base consulted for this research.

In the case of this case, the Judo Kwai itself has a TOID, as a building, but nothing to identify this as a location of a sporting facility in OS records. As this example is also relevant to boxing gyms, scout huts and the like, it is possible that geographical assessments of the less-formal side of sporting facilities are inherently inaccurate, even if the organisations that hold the 'raw' data are conducting the research.

The issues of the kickabout areas and back-lane sporting facilities are raised to illustrate wider concerns about mapping when related to activities: should maps only represent objects, or should they also represent activities, uses and purposes. If the latter, how can a non-physical thing be mapped, especially if a temporal element is involved? From the point of view of accessibility analysis, measuring potential geographic accessibility to physical features, such as buildings, is relatively straightforward: the buildings will be there. However, identifying some buildings (such as in 6.2 above) may be problematic, and identifying the activity space accurately is also problematic (for example when addresses relate to residential addresses of those involved in running a facility, rather than of the facility itself). In such cases the increasing accuracy and fine tuning of tools, such as those used to calculate E2SFCA, does not seem to match any increase in accuracy in mapping the location of certain classes of destination feature, facility or activity. Such issues are typically reflected in such studies and the research presented here has drawn attention to the potential significance of such matters in 'typical' GIS tasks.

6.3 Demand-side geospatial representation

As noted particularly in Section 6.4.4 (though relevant to all the network datasets), the use of alternative aggregated representations of population (from census OA centroids down to address level) served to 'stress test' the various network datasets and succeeded in highlighting errors and faults with the various network representations. This involved the detection of anomalous results compared to other networks and provided an illustration of the usefulness of sensitivity analysis in this context. The use of different, diverse supply-side features enabled a variety of routes to be identified, examination of which provided the examples in this section.

6.3.1 Census OA centroids

In studies assessing accessibility to health facilities, Apparicio et al (2008) utilised the smallest unit of census population available, and the main demand-side representation used in this thesis was the smallest unit of UK census population. However, when distances of less than 2km were involved Apparicio et al (2008) recommended further population disaggregation be conducted. There may, therefore, be a case for repeating some of the case studies from this thesis and restricting the study area to town or metropolitan areas (where many demand points would be within 2000m of potential destinations) using postal head counts or address level data, to ascertain if the results from various correlations were improvements on those reported here (see concluding chapter).

One issue identified with OA centroids was that it was possible, in theory, for centroids to fall within the perimeter of a Sites feature. Closer examination of the lowest distance results confirmed that in some cases this did happen, particularly amongst primary schools, which were generally located in and amongst their respective communities. Examples included Bryn Deri County Primary and Holy Family RC Primary, both of which had centroids inside their perimeters, and Rumney Junior, Severn Road Primary and Danescourt Primary, all of which had centroids a few metres outside their perimeter. Although unlikely, the possibility would have to be kept in mind that a distance could be recorded from the demand point out to a perimeter, despite the 'true' distance to the featured site being zero. Although such an occurrence was less likely in other, larger featured Sites such as airports (population centres generally being some distance away), it would perhaps be possible with hospitals, especially in large sites adjacent to residential areas, sites which may have a road network mapped within its boundaries. It was noted that OS network lengths which were located within school perimeters were generally categorised as 'Private Road – Restricted Access,' a category which was classified as signifying unusable routes in this network analysis, with St Joseph's RC Primary School in Penarth and Greenway Primary School in Cardiff two examples. Larger sites such as hospitals were observed to contain roads described as 'Private Road – Publicly Accessible,' and as such would be included in any accessibility analysis. The classifications of OSM network lengths were less clear cut, with ways through schools generally not mapped, but with a few exceptions, such as Greenway Primary (as mentioned earlier in this paragraph), which had a road length described as unclassified highway. As such this would be included in any accessibility analysis and in the event of having a demand point within its perimeter would skew results for that area. It was also noted that on large hospital sites, OSM 'ways' (OSM terminology for network lengths or edges) were also registered as unclassified highways. This draws attention to the problem of inconsistent OSM classifications in particular contexts.

6.3.2 OS Code-Point

As reported in Chapter 4, the use of post codes as demand points offered the opportunity to undertake accessibility studies at a further level of population disaggregation, with matching polygons supplied (as an optional dataset) able to present visualisations at a finer scale than that offered at Output Area levels. The supplementary information held in the dataset, in addition to the post codes themselves and locational data, also offered (in theory) the possibility of a more accurate population representation, when applied to this type of accessibility study.

The use of Code-Point also served to highlight issues and errors within network data sets. When OSM was used with OAs as the sources of demand it was noted that three OAs were not connected to the full network. This was due to their location in ‘islands’ of OSM ways, due to one or more unconnected edges, with no alternative routes available to the wider network. The examples referred to later (Figures 6.3 and 6.4) illustrate that such issues are not related to functions within ArcGIS, but are related to the mapping of the networks. With Code-Points, more were found to be unconnected: 6 in the Vale of Glamorgan; 10 in Cardiff. All were investigated and found, again, to be caused by unconnected OSM network edges. With the greater number of demand points offered by Code-Point the increased number of unconnected edges was expected, as wherever one isolated OA was located, several Code-Points were located in the vicinity. It was entirely possible that more OSM ways were unconnected, but they would be unlikely to be noticed if a demand point was not snapped to one of the unconnected edges. Some unconnected edges will no doubt be located in areas with dense road networks, therefore alternative routes could be identified to supply points with an increased distance, but not so extreme that the discrepancy would be noted immediately. The occurrences noted here (and Figure 6.3 provides some illustrations from Cardiff) did not have alternative routes available, therefore were identified easily by returning nil results and paying attention to error messages raised when using the relevant Arc tools. OSM was not the only dataset which had issues highlighted by the finer scales offered by Code-Point. Figure 6.4 shows the one Code-Point origin found in Cardiff which did not have a destination allocated when Open Roads was used. Whether this was a one-off error or indicated a wider usability issue is unknown. The scope of this study restricted the examination of networks to within the study areas.

These four specific examples did not change the actual accessibility findings in any way: they were all recorded as ‘nul’ results and did not contribute to any set of results. They did serve to highlight the issue of unconnected ways, and it is emphasised that these four were easily noticed as no alternative route from those origins were identified. What is not known, however, is how many instances occurred where poor connectivity resulted in a longer distance being recorded when and where alternative routes were available.

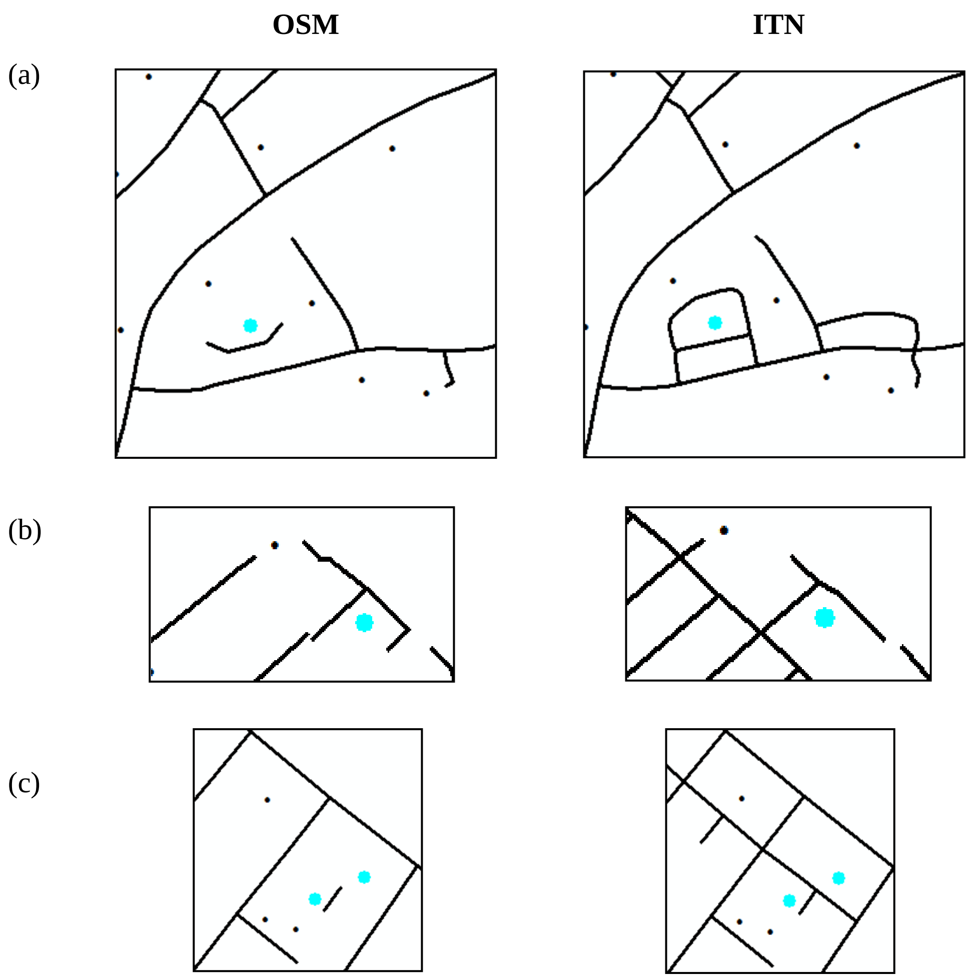


Figure 6.3: Examples of Code-Points (highlighted in blue) snapping to unconnected segments of the OSM network, compared to ITN for same area, in (a) Llanishen, a 1960s housing estate, and (b) and (c) in Roath, a densely-populated inner urban village.

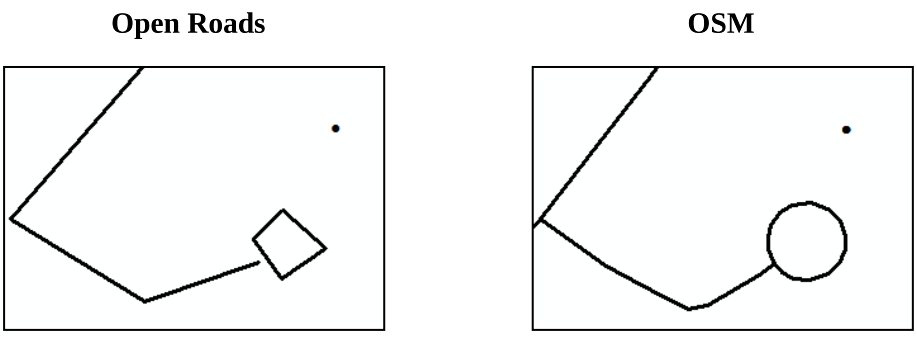


Figure 6.4: Open Roads network issue. The Code-Point for Waverley Square in Cardiff (which actually ends in a circle) was not connected to the wider network in Open Roads, meaning this demand point had no destinations when using Open Roads. The same point was connected to the wider OSM network.

The Code-Point data offered a further level of population disaggregation from OA centroids, without placing excessive computing load. The provision of an accompanying dataset of matching polygons added to the potential uses of the data, with choropleth mapping at postcode level suitable at town and city levels. The lack of readily-available population data to match with these potential demand-side points is a drawback, entailing some further calculations of census OA data with which to estimate population at a postcode level. The identification of non-domestic postcodes enables more accurate accessibility analysis, but accompanied by challenges of how to present results in an aesthetically pleasing and understandably format.

6.3.3 Address Layer 2

This dataset offered demand-side representation to address level, the finest level available. However, it was difficult to distinguish domestic and non-domestic addresses within the dataset, and therefore disaggregation of population to this level would be in danger of being inaccurate. With regular and frequent updates, and being relatively simple to load and use in a GIS, Address Layer 2 has the potential to be a valuable resource. As population studies diverge away from the default 'night-time' population (which was relevant to this thesis) when considering accessibility to destinations that may not be accessed from home, having a geographic representation of every address in a study area could be extremely useful. In the context of the studies carried out for this thesis, Address Layer 2 was not assessed as a viable alternative source of demand-side data.

6.3.4 AddressBase Premium (ABP)

As with Address Layer 2, AddressBase Premium also offered demand-side representation to address level, differed in that its comprehensive classification and coding system did distinguish between domestic and non-domestic addresses within the dataset, therefore disaggregation of population to domestic address level would be more accurate (within the limitations imposed by 10-yearly census updates). ABP data was also updated regularly and frequently. The main drawback to this dataset was its complexity and difficulty to load and use in a GIS. In this study it was admitted that full functionality of the ABP dataset was never achieved, through issues with the interlinking of the various databases that, working together, could have provided seamless information on every address in the study area, whether domestic, residential, commercial or industrial. There was a high computational load associated with the number of points created by this dataset, and the context of any study in which to use such data must be considered carefully. For example, a county-wide study resulted in considerable calculation time relating to assessing accessibility, a lag which rendered the dataset impractical at that level. City-wide, town-wide or analysis for smaller localities would be ideal for this level of data.

6.4 Network geospatial representation

Section 4.5 reported on the results of network comparisons. The road networks, as used for car travel, for example, were generally very similar, but the extra stresses put on the network datasets by investigating pedestrian travel highlighted several issues, many relating to quality, coverage and errors of omission. The use of different supply-side features also helped identify issues with the various networks, some specific and some more general. Examples of such issues will be given here, along with some discussion as to whether the issues were specific errors, or had wider implications.

It has already been mentioned (throughout Chapter 4) that the network used had a considerable effect on destination overlap and on both accessibility measures. In the course of the process, and on investigating anomalies and issues which arose, it was noted that the architecture of the actual road network proved to have a considerable influence, with post-war planned housing developments particularly prone to large differences in measured pedestrian travel distances. Figure 6.5 illustrates one example, showing how a typical development made up of crescents and cul-de-sacs can result in a difference in pedestrian walking distances of over 80% when footpaths are incorporated into the network.

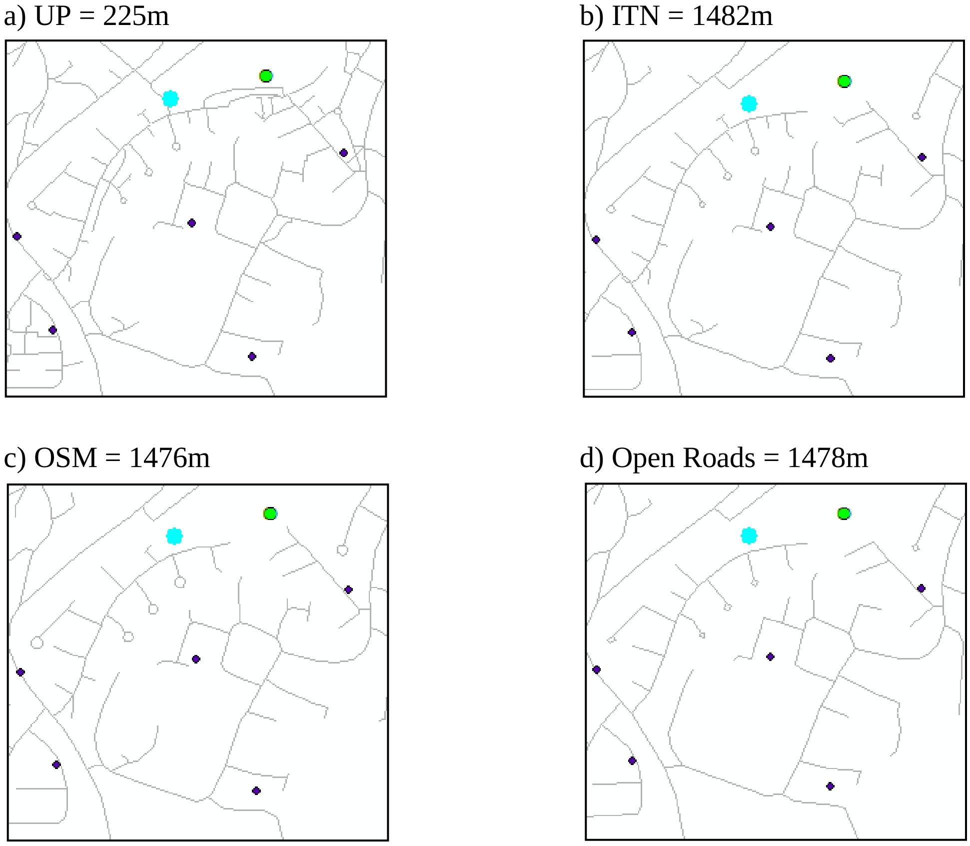


Figure 6.5: Illustration of the impact of incorporating footpaths into travel analysis, showing origin OA centroid (in blue) to destination (Murchfield Community Hall, in green), and the network distances using each of the four networks.

6.4.1 OS ITN

Throughout this thesis there were no specific errors identified with regard to the ITN network dataset. No connectivity errors were noted, all attributes were complete, and road lengths inside Sites boundaries appeared intuitively correct, with roads through hospitals classified as usable, while those within school boundaries were classified as restricted. However, with the introduction of UP (see below), the lack of a network dataset for other modes of transport, particularly bicycle, is apparent, which appears to be a gap in the comprehensive transport coverage provided by Ordnance Survey.

The lack of a full network dataset containing all transport options does apply restrictions to all but the most simple (and simplified) accessibility analyses. Multi-modal travel analysis is restricted when some of the modes require sweeping assumptions to be made (such as that all roads are traversable by pedestrians, all footpaths are suitable for cyclists) or where the information is not available (on, for example, dedicated cycle ways). Effective analysis requires appropriate data, and although ITN is the 'gold standard,' it accurately reflects only travel by motorised transport, with other modes requiring several assumptions (as outlined above).

6.4.2 OS ITN with Urban Paths (UP)

The importance of the additional pedestrian access opportunities offered by Urban Paths was noticeable where footbridges allowed the crossing of physical barriers, such as rivers and railway lines. Both types of barriers were traversed by footbridges from Gwaelod y Garth (north of Cardiff), which shortened pedestrians access to a GP surgery in Taff's Well, allowing UP to return walking distances around 1700m less than ITN, Open Roads or OSM. Again, the OSM urban drop-off seemed to be a factor, with a large, obvious feature missed by the volunteer mappers. The same issues applied to a footbridge over the M4 connecting upper Morganstown (again, north of Cardiff) to Radyr, which returned a figure of 92m from one specific OA to the surgery, with all other networks identifying a different surgery, 2.3km away, as the nearest. Although there was some aspect of geographical difference in the completeness, coverage and quality of the data in the OS datasets, this aspect was particularly marked in OSM data, presumably an issue with VGI in areas other than only Cardiff, but perhaps less visible in areas with a higher number of volunteer mappers and a higher rate of contribution.

These findings did not concur with some of those of Jones (2010), who found that OSM included many footpaths thus returning lower distances and walking times than ITN, albeit in the heavily urbanised area of Birmingham. The urban OSM drop-off (as reported by Zielstra and Zipf, 2010, in Germany) seemed to be a factor in Cardiff, whereby Birmingham had a much more active VGI mapping community (see section 4.3.3 looking specifically at the OSM network). Jones also highlighted the influence that lack of footbridges had when using ITN for pedestrian studies, which was confirmed here. For the area around Cardiff it seemed that the additional data provided by Urban Paths addressed this shortfall.

6.4.3 OS Open Roads

Open Roads became available at a late stage in this research (spring 2015), and in the execution of the various accessibility analyses throughout this study only one error was evident in the empirical study conducted (illustrated in Figure 6.6 and described in Section 6.3.2). This may have resulted from an automatic generalisation or simplification process used to create the dataset, and may be indicative of a systematic error, where circles are simplified into squares and in the circumstances were the circle is at the terminus of one road this may result in the connection to that road being lost or broken. Further work would be required to identify other similar features (in, for example, ITN) and investigate if such an error was repeated elsewhere.

Figure 6.6: Illustration of where mapped pedestrian routes can differ. OSM maps show a through road, therefore navigable by pedestrians in this study. OS ITN correctly shows a road blocked to vehicles. UP incorrectly shows a road blocked to vehicles and pedestrians.

6.4.4 OpenStreetMap (OSM)

An anomaly was noted with OSM in the case study looking at Vale secondary schools, where OSM returned a distance figure considerably less that of all three OS datasets. Approximately 2000m of this difference was due to one occurrence, as shown in Figure 6.6: the picture from Google Street View illustrating the blocked-up Earl Road at Stanwell Road in Penarth (one of the small towns within the Vale), recorded as a through way by OSM (and therefore navigable by pedestrians) but as a cul-de-sac in both ITN and UP. Such detail may be missed when a sample of hundreds or thousands of origin-destination calculations are made, but manual checking of smaller numbers of routes was feasible in this instance, thus identifying this particular example which lay on a direct route between two secondary schools. The blocking-up of some side roads in urban and suburban locations, in order (it is presumed) to prevent ‘ratruns' (regular short cuts taken by drivers to avoid obstructions or obstacles such as traffic lights or queues of traffic), but which are designed to remain passable by pedestrians and cyclists, appears common (judging by personal observation of local areas), therefore obtaining some indication of how these are treated in other circumstances would be useful.

Within Cardiff there was a discrepancy with OSM where one community hub was not connected to the network. This occurred where one connection error isolated an 'island:' a cluster of side roads not connected any other part of the network. This error would not be apparent in any other part of the analysis, there being no other features of interest to this study located within the small area served by the unconnected roads. Similar issues may be found elsewhere where relatively finer scales of mapping supply features or demand representations were used, effectively increasing the sampling rates of OSM connections. As the number of demand points in accessibility analysis would normally be expected to vastly outnumber those of supply (at OA levels and finer representations), it would be expected that the demand points may help highlight other network errors.

A further example illustrates two points made earlier in this thesis, one regarding the layout of modern housing estates (referred to at the start of Section 6.4), and the other regarding OSM coverage in areas of social housing and/or economic deprivation which have been excluded by OSM, to some degree, from the in-depth coverage found in other urban areas. Figure 6.7 shows the large council estate of Llanedeyrn on the eastern outskirts of Cardiff, with (again) a crescent and cul-de-sac road pattern. The OSM network results in a different 'nearest facility' being identified from the ITN network, but the OSM also has roads missing compared to ITN, visible with even a cursory glance. The UP data changes the available pedestrian network considerably.

Quality issues with the various datasets used had an effect on results, and the main data quality issue concerns the OSM dataset. Specifically, with OSM changes over time were likely to have an impact on data quality, as well as the broken links and unconnected ways which were identified in OSM but not noted with either ITN or UP (though there was once instance identified in Open Roads) as used in this study. The advantages of the 'quality by crowd' model have been stated previously (continual updates, almost immediate response to new or altered features in the real world, many 'eyes' examining data looking for errors, etc), but the VGI issue of contributors having insufficient knowledge or technical skill resulted in this study identifying several instances highlighting where this resulted in problems with the OSM network. An example of one type of problem was where a road in Cardiff (Colum Place, in this instance) was not connected to the main road, and was thus an 'island' in OSM terms. One OA centroid beyond this break was 'snapped' to this length, therefore not connected to the greater network and returned a nil result for destination overlap, nearest facility and 2SFCA results.

However, when checked on a later download of OSM data (see section 4.3.3 for an appraisal of OSM network coverage), the error had been corrected and the links connected properly. A similar network quality issue was noted in the Canton area of Cardiff, where one incorrectly connected link created an island of four side streets, causing no distance or 2SFCA scores to be recorded from this particular centroid to any feature. It may be assumed there were many more such instances within the OSM network, however they were most easily identified when non aggregated demand-side features were involved.

Figure 6.7: Further illustration of effects of using different networks on nearest destination identification. Origin OA centroid in blue, destination features in green.
a) Using ITN, nearest feature is Llanedeyrn Community Centre (2492m);
b) Using OSM, nearest feature is Llanedeyrn Library (2486m);
c) Using Urban Paths, nearest feature is Llanedeyrn Community Centre (996m).
All three datasets are noticeably different, with OSM clearly missing some roads.

A further issue connected to poor data quality and lack of quality control over OSM data, and only noticeable when primary school results were compared, was one OSM edge in Pentyrch (once again to the north of Cardiff) classified as Prohibited Access. This was therefore not available to pedestrians accessing the nearby school from one OA in the village, and the distance to the nearest destination (which was the same school) involved a much lengthier route. This particular road was classified as passable in the other networks. It was noted that due to other features being much further away (secondary schools and sports centres) or being located elsewhere in the village that did not involve this edge in route calculations, this anomaly may not have been otherwise noticed. Issues such as this emphasised the problems that may be caused when generalities are made from the study of a limited number of types of feature, or even of one feature, as the anomalies described here were only identified with (in many cases) one type of destination, and therefore could have been missed or avoided if a different supply feature was being examined.

Issues regarding OSM in the rural area of the Vale of Glamorgan were less apparent than may have been expected, given the quality and coverage issues already mentioned here. The greater geographical distances involved in travel in the Vale, and the less dense and less complex main road networks present in the area, meant that differences in destination overlap and in travel distances were not appreciably worse than in the urban context, and in many cases the Vale returned results that indicated better levels of accessibility than in Cardiff. However, some issues were apparent at the more local scales. In some cases OSM produced similar results to ITN and to UP. However, when investigating the reasons for differing results, the inconsistencies of OSM was apparent. In several case studies it was noted that in cul-de-sacs around Sully, UP linked up the ends of these dead-end roads to the main roads, with OSM conspicuous by its absence. In housing estates around Dinas Powys, Rhoose and Barry, again only UP had footpaths acting as short cuts between the estate roads, but around Cadoxton (on the outskirts of Barry) OSM had included some lanes not present in ITN which shortened distances to Palmerston and Cadoxton schools, though only UP had the lanes that connected the parallel roads in this hilly area, thus shortening journeys from some points even more. The probability of there having been few OSM volunteer mappers in Barry, or simply not enough volunteer interest in such areas reveals the potential exclusivity of OSM data, reflecting Haklay's (2010b) concerns regarding OSM coverage outside major urban centres, and echoing the comments of the OSM founder Steve Coast (GISPro, 2007) that if areas were not mapped fully it was of no great concern, as they were probably the type of area no one would want to go to anyway. Whether this description applies or not, the social housing of Cadoxton and the densely-packed terraces of Palmerston did have gaps in their OSM coverage. The instances where OSM included footpaths and some less formal routes which were not included in OS maps shows the potential of using VGI to obtain a fuller representation of travel routes used by pedestrians, but the inconsistencies in coverage and quality meant that the levels of trust and confidence in the data required for accessibility modelling or similar geographical analysis were insufficient, rendering OSM unsuitable for use in this analytical and geographic context.

For OSM to be improved to reach the levels of quality, consistency and trust required for analytical purposes, a philosophical (or policy) change is required. If the stated aim is to map the world, then the marginalisation of rural areas and deprived areas within urban settlements needs to be addressed. If the aim is to represent the world of OSM contributors and users, then perhaps rural coverage will be left to reflect that particular VGI user group, and the areas where 'they' would not want to go can and will remain unmapped to the same levels as other, popular (mostly urban) areas. That the demand from this VGI user group resulted in more layers being added, such as that of a cycling layer, illustrates the potential of VGI to respond to user need. Although not specifically considered as part of this thesis, the provision of the OSM cycling layer within cities looks like a useful resource for urban travel studies, and appears to be one of the few cycling map products widely available. The caveats stated in this section that apply to the OSM road and footpath data would also apply, it is envisaged, to the cycling data, but further research is needed to establish the usability of the data set in that context.

6.4.5 Euclidean measurement

There has been considerable comparison between Euclidean and network travel in the literature, especially regarding accessibility to health facilities. In a study regarding accessibility to health care in rural southwest England, Jordan et al (2004) reported correlations between Euclidean distance and drive times of 0.95, which was at the maximum of correlation found here comparing Euclidean distance to UP network distance to GP surgeries in the Vale of Glamorgan. Phibbs and Luft (1995) also found high correlations (0.987) between travel times and Euclidean distance to medical facilities in upstate New York, but noted that high correlations did not seem to apply in dense urban areas, a finding common to the findings for GP surgeries in Cardiff. Apparicio et al (2008) also noted high correlations (> .95) between Euclidean to network distance with regard to access to health services in Montreal, but with reductions when distances under 2km were considered, and variations notable in suburban areas. Though these correlations were again at the highest levels found in this study, they also found correlations in excess of .9 between gravity models and distance, which were not replicated in the findings of the present study.

6.5 System issues

In addition to unavoidable issues with the ‘snapping’ of features to the network, the use of the GIS in this research also resulted in some unusual results, only noticeable when comparing some features to others. The example of Cowbridge, in the Vale of Glamorgan illustrates one situation, where the demand centroid ‘snapped’ (as it was meant to do) to the nearest part of the network. In this case the nearest road was Cowbridge By-Pass, which had no exits apart from junctions at either end of the town. By snapping to this road, the shortest GIS distance to local features (GP surgery, primary school, but most noticeably the secondary school) took a route along the by-pass to the nearest exit, turning onto local roads and doubling back into town. In the real world, the local secondary school (Cowbridge Comprehensive) was accessible from this centroid via an underpass (under the by-pass). UP had several footpaths connecting bus stops on the by-pass to the town, therefore its results were not initially noticed as unusual. Only when compared to Open Roads (which had some connections which did not actually exist in real life, when checked on Google Earth), ITN (which had results over twice the distance of UP) and OSM, did the problem become apparent. Similarly to ITN, the OSM network had no footpaths mapped from the by-pass to the town’s minor roads. The assumption that the GIS process can be trusted unconditionally to carry out an accurate assessment in such an occasion had to be questioned, and although GIS specialists would expect such anomalies, casual users may not. Of course, Cowbridge by-pass could have been classified along with the M4 and A48(M) as not usable for pedestrians, in setting up the network parameters on ArcGIS. However, until the results of the case study were examined there was no way of identifying that road as 'pedestrians prohibited' without local knowledge.

The assumption that a road network is reflected in its two-dimensional representation may also be incorrect, along with the assumption that pedestrians traversing the network may connect to any network length at end points and any crossing points. Multiple levels in networks means that some lengths may not be accessible from others, and unless this is made explicit then incorrect assumptions may be made. The lack of a level indicator in any of the pedestrian networks (relating, for example, to underpasses and bridges) may be another source of inaccuracy.

These occurrences highlighted a problem when looking at pedestrian accessibility studies in general. In most cases, there is an assumption that the presence of a road also equates to a pedestrian route, except in the obvious cases were the classification of the road makes pedestrian use illegal, such as in the case of motorways in the UK. It would perhaps be a useful addition to road attributes to identify those prohibited to pedestrians, or even those where no provision has been made for pedestrians (for example where no pavements were constructed alongside dual carriageways, by-passes etc). In the case of active travel to school, setting some criteria by which a safe pedestrian route could be identified would enable decision makers (local authorities, etc) to map, mark and measure the most appropriate route for children to walk to school. The addition of further attributes regarding the cycling status of a road or path (for example, whether it is recommended or not by a cycling group) could also prove useful in promoting road safety and active travel amongst school children, as well as providing a resource to the wider community.

The use of a different GIS to run the same base data as used here may produce interesting results. As a commercial product, many of the algorithms used by ArcGIS are proprietary, and confidential to the owner. A different system may calculate things differently, and as yet it is not known whether such differences exist, and if they do, whether or not they are significant.

6.6 Indicators of geospatial dataset usability

All the datasets used in this study had usability issues of one kind or another, and many had problems or errors associated with them which have been discussed throughout this chapter.

How to represent these issues, or how to summarise them in a convenient way to indicate the usability of the data, has not been addressed in the past. This section offers several proposals building on the findings from this thesis, proposals which can be built on with subsequent research into geospatial data usability.

6.6.1 Typology of errors

A typology of the errors found in the course of this thesis is provided at Table 6.2, which serves as a summary of the errors and issues found, using error classifications as listed as sub-elements of the usability element of quality. Such a typology (if included in metadata) could give prospective users of data an indication of the issues encountered by previous users. If completed by users, it could also provide useful feedback for data producers, giving them useful detailed information for amendment in the next data update. It is noted that OS now provides user feedback forms in the user guides for many of their products.

6.6.2 SWOT analysis

A SWOT analysis of the datasets used is provided in Table 6.3 which outlines the strengths, weaknesses, opportunities and threats associated with each of the datasets used in this study. The strengths and weaknesses of each data set have been detailed throughout this thesis, but opportunities and threats may not have been raised specifically, therefore are done so here. None of the points raised should come as a surprise, having been implied through the previous, and current, chapters. Table 6.3(a) emphasises ITN's place (as confirmed by the results of the accessibility exercises) as the 'gold standard' which sets the benchmark for other datasets, a standard which OSM (for example) cannot reach in the context of this study. One aspect implied in the thesis is the perceived threat to proprietary GI datasets posed by FOSS or free-to-use alternatives, however it is specifically mentioned here that the VGI FOSS data provided by OSM may itself be under threat from higher quality Open Data from the same providers as the proprietary data (such as OS and Open Roads).

6.6.3 Utility factor

The results of the Utility Factor calculations (see Section 4.6.1) have a major caveat associated with them, in that the Utility Factor applies to the datasets used in the context of the research for this thesis and for the particular GIS tasks conducted. For use with other tasks it would have to be adapted. However, in any comparison of results it would be expected that indications of correlation would be obtained (Spearman, in this case), and it is suggested here that a statistical indication of difference should also be obtained (Wilcoxon was used in this case), along with some measurement of the practical effect of the use of the different datasets (in this case destination overlap was used). The application of this formula in other contexts would be required for verification purposes, and is suggested as a future direction of potential research.

6.7 Chapter summary

This chapter emphasised that all the datasets used in this study had positive and negative points. Specific issues were discussed more general conclusions drawn from these examples, where appropriate. Quality issues were identified as having a considerable effect on usability, and the finer scales of study (at postcode level and address level) were seen to throw more light on such quality issues, particularly with network datasets, effectively stress-testing the quality of the network data. ITN had no quality errors identified, nor did UP; Open Roads had few, but OSM had many.

Specific issues with the design of the road and housing networks were noted, with 'modern' patterns of crescents with multiple cul-de-sacs emphasising the differences between road network distance and pedestrian network distance, confirming that using the road network for pedestrian travel in some contexts will produce inaccurate results. Shortfalls with the definition and identification of footpaths also serves to restrict the usability of pedestrian networks, were also identified, raising the question as to the purpose of datasets such as UP. Is it simply to show the location of permanent footpaths, or is it produced to indicate the routes actually used by pedestrians. At the moment it falls short of the latter, due to restrictions on what data (ie what paths) is gathered.

Finally, the chapter outlined three possible methods of assessing usability information in a format easily communicated to users: typology of errors; SWOT analysis; and Utility Factor. The first two are established methods, while the third is a novel approach proposed as a way of summarising the information from the various accessibility analyses in an easily comprehended tabular format.

Feature	Dataset	Where identified/exemplified	What	Error classification
Supply-side				
	Points of Interest	Cardiff Steiner and Cardiff Muslim schools	Not included, but appears in Sites	Omission/classification.
		Maindy Pool	Duplicate entry for two separate functions: pool and velodrome	Duplication/classification.
		Maindy Pool	Not classified as sports centre despite classed as such by LA	Omission. Thematic accuracy.
	Sites	Throughout Cardiff	Duplication of secondary schools	Commission.
		Whitchurch and Melin Gruffyth primaries	No access points	Omission.
		Cardiff Steiner and Cardiff Muslim schools	Not on PoI. No separate classification.	Omission/commission. Thematic accuracy.
	AddressBase Premium	Cowbridge	Duplication of secondary school	Commission. Temporal accuracy.
Demand-side				
	OA centroids	Primary schools (Bryn Deri, Holy Family, St Joseph's, Greenway)	Point located within feature	Not, strictly speaking, an error. May result in unusual outcomes.
	AddressBase Premium	Cardiff secondary schools	No use made of NS classification. Private schools included in wider 'Secondary School' classification despite separate category being available.	Thematic accuracy.
		Throughout both study areas	Inconsistency in attribute format	Thematic accuracy.
Network				
	ITN	No errors or issues identified		
	UP	Sec schools, Earl Rd at Stanwell Rd, Penarth	Blocked road, passable to pedestrians, not noted as such in UP, noted as cul-de-sac	Thematic accuracy. Omission. Possibly wider issue. Is it a path? Or a road?
		Throughout both study areas	No record of informal footpaths	Not, strictly speaking, an error. Policy issue.

Feature	Dataset	Where identified/exemplified	What	Error classification
Network				
	Open Roads	Waverley Square, Cardiff Bay	Unconnected length, creating island.	Data quality. Accuracy. Logical consistency.
	OSM	Entire network dataset	Required sourcing from third-party provider	Issues of authority of provider, trust and producer (processor) reputation.
		Throughout both study areas	Large number of roads and/or ways unclassified	Thematic accuracy. Omission. Quality. Completeness.
		Cardiff, community hubs	One missing connection, feature isolated in 'island' of ways.	Quality error, mapping error. Only one instance implies NOT an issue of educating one contributor.
		Colum Place, Cardiff	Unconnected length, creating island.	Data quality. Logical consistency.
		Canton, Cardiff	Unconnected length, creating island.	Data quality. Logical consistency.
		When Code-Point used, identified throughout both study areas	Unconnected lengths, creating islands.	Data quality. Logical consistency.
		Gwaelod, Radyr (north Cardiff)	Footbridges not mapped	Omission.
		Llanedeyrn	Footpaths not mapped	Omission. Issue of coverage in less-prosperous / deprived areas.
		Sully	Footpaths not mapped	Omission. Coverage (NB Sully is a prosperous area, therefore not related to wealth).
		Cadoxton	Footpaths not mapped	Omission.
		Throughout Vale in areas of crescent and cul-de-sac residential street patterns	Footpaths not mapped	Omission.
		Pentyrch, north of Cardiff	Road incorrectly classified as Prohibited Access.	Thematic accuracy. Purposely done?
		Greenway Primary	Restricted road recorded as 'unclassified.'	Thematic accuracy.

Table 6.2: Error and issue typology.

(a)

Networks		
<u>Networks</u> **ITN**	**Strengths** 'Gold standard' against which others are measured. High quality (no quality issues identified in this study).	**Weaknesses** Six-weekly update cycle, theoretically not as current as OSM. Considerable download and conversion time. Requires GIS.
	Opportunities Alternative datasets (eg OSM) reveal the demand for provision of cycle network data, full footpath provision, etc.	**Threats** Target at which alternatives aim. Everyone with a smart phone or sat nav is a potential network mapper. Considerable amount of research into auto-creation of cycle networks. Strong desire for free data.
ITN with Urban Paths	**Strengths** Authoritative data provider. High quality (no quality issues identified in this study). Adds more detail to enable pedestrian route mapping and accessibility analysis.	**Weaknesses** Quarterly update cycle, theoretically not as current as OSM. Considerable download and conversion time. Not national coverage of all footpaths. Requires GIS.
	Opportunities Alternative datasets (eg OSM) reveal the demand for provision of cycle network data, full footpath provision, etc, in addition to car / motorised vehicle travel.	**Threats** Everyone with a smart phone is a potential footpath network mapper. Considerable amount of research into auto-creation of cycle networks. Strong desire for free data.
Open Roads	**Strengths** Authoritative data provider. Derived from 'Gold Standard' ITN dataset. Rapid download, relatively easy conversion process. Uncomplicated; relatively straightforward to understand. Open data – free to use.	**Weaknesses** Cannot update as quickly as OSM. Some errors identified. Requires GIS.
	Opportunities Alternative datasets (eg OSM) reveal the demand for provision of cycle network data, full footpath provision, etc.	**Threats** Everyone with a smart phone or sat nav is a potential network mapper. Considerable amount of research into auto-creation of cycle networks. Some into footpath identification.
OSM	**Strengths** Crowd-sourced. FOSS. Real-time, constant updates. Unconstrained internationally. Online availability of map. Cycle layer available.	**Weaknesses** Crowd-sourced. QC by crowd. Inconsistent quality. Social exclusion issues of coverage. Non-standard and incomplete classifications. Need to search for provider of network data. Requires GIS. Inconsistent geographic coverage, drops off outside major urban settlements.
	Opportunities Potential to map road, cycle, footpath provision. Can use, download, amend, adapt, customise as required. The Crowd may find novel uses for the data.	**Threats** Alternative crowd-sourced maps available (eg Wikimapia, but is not Open). Alternative free-to-use authoritative data available (eg Open Roads).
All the above datasets were used in all case studies.		

Table 6.3: SWOT analysis of datasets used in this study.

(a) Network datasets: all four datasets used in all case studies.

(b)

<u>Demand features</u> **OA population-weighted centroids**	**Strengths** Official, government, robust data. Full coverage of UK. Matches administrative boundaries. Builds into increasingly larger units. Provided cost free.	**Weaknesses** Can be affected by issues of confidentiality. Long, 10-year update cycle with decennial census.
	Opportunities Breadth and depth of detailed data about the population in each OA gives wide potential for varied analysis.	**Threats** Mismatch between census cycles and data from other sources results in increasing population inaccuracy, year on year.
	Used in all case studies	
Code-Point	**Strengths** Finer level of geographic disaggregation than census OA centroids. Defined residential / non-residential split. Frequent updates.	**Weaknesses** Generalised / averaged across OA level, therefore less accurate for ‘slices’ of population. Dependent on census for population data. Does not match LA boundaries.
	Opportunities Residential / non-residential relatively easy to split. Non-res classifications comprehensive.	**Threats** Mismatch between PC updates and 10-yearly census cycles results in increasing population inaccuracy, year on year.
	Used in secondary schools case study	
Address Layer 2 / AddressBase Premium	**Strengths** Highest level of geographic disaggregation available for population. Accurate to property level. Areas without addresses are not allocated population (eg parks, wilderness). Frequent updates.	**Weaknesses** Confidentiality issues - data could (in theory) be traced back to individual, but still reliant on census data. Generalised / averaged across OA level, therefore less accurate for ‘slices’ of population. AddressBase Premium complex and difficult to set up initially.
	Opportunities Address Layer 2 has little beyond address locations. AddressBase Premium has a wealth of classification information. Residential / non-residential relatively easy to split. Non-res classifications comprehensive.	**Threats** Political issues with address-level data (eg police crime maps).
	Not used in the case studies reported here	

Table 6.3: SWOT analysis of datasets used in this study.

(b) Datasets used for demand features (population representations).

(c)

<u>Supply features</u> **Points of Interest**	**Strengths** Authoritative data provider. National coverage. Detailed classification system. Frequent updates.	**Weaknesses** Point dataset, generalised representation of larger features. Commercial, expensive.
	Opportunities Contains wealth of data with potential for further exploitation.	**Threats** Various free-to-use options developing. Alternative commercial datasets available.
	Used in all case studies	
Sites	**Strengths** Authoritative data provider. National coverage. Very detailed. Functional access points included.	**Weaknesses** Limited to certain categories of infrastructure (eg schools, transport). Not fully surveyed. Errors of omission and commission found. No demand for product as yet.
	Opportunities Contains a wealth of unexploited geographical data. Tools not yet developed to use this more precise type of date.	**Threats** Major players (eg Google) developing 3D representations of buildings and structures.
	Used in the following case studies: primary schools; secondary schools	
AddressBase Premium	**Strengths** Authoritative data provider. National coverage. Precise location. Regularly updated.	**Weaknesses** Complex dataset, involving interconnected database files. Difficult to use. Expensive.
	Opportunities Clear division between domestic and non-domestic addresses. Little current exploitation of address-level analysis.	**Threats** Commercial directories.
	Not used in the case studies reported here	

Table 6.3: SWOT analysis of datasets used in this study.

(c) Datasets used for supply features (destination representations).

(d)

<u>**Visualisation**</u> **OA polygons**	**Strengths** Authoritative data provider. Total national coverage, no gaps. Precise location. 10-year update cycle – enables long-term comparisons to be made. Stacks into ever-larger units. Matches administrative boundaries. Free to obtain and use.	**Weaknesses** No residential/non-residential split. Polygons include areas with no population. Some polygons extremely irregular in shape. In urban areas polygons very small, in rural areas very large. Will never reach street-scale due to issues of maintaining anonymity.
	Opportunities Enables 'local-scale' representation.	**Threats** Postcode-based polygons available.
	Used in all case studies	
Code-Point with polygons	**Strengths** Finer level of geographic disaggregation than census OA polygons. Defined residential / non-residential split. Frequent updates.	**Weaknesses** Does not match LA boundaries. Regular updates and business-led changes means long-term comparisons do not compare like for like. Difficult to deal with visualisation of non-res areas in map form. Even at town level, detail can be too fine.
	Opportunities Boundaries sufficiently fine for neighbourhood-scale and local-scale studies.	**Threats** Mismatch between frequent PC updates and 10-yearly census cycles results in increasing inaccuracy, year on year.
	Used in secondary schools case study	

Table 6.3: SWOT analysis of datasets used in this study.

(d) Datasets used for visualisation purposes.

Chapter 7 Conclusions

7.1 Reflecting on the research aim and objectives

The overall aim of this thesis was to investigate the usability of geographic information (GI), as summarised in Table 7.1. More specifically, the main foci of the investigation concerned an investigation of the usability and quality of a range of various Ordnance Survey (OS) datasets and a dataset sourced from VGI (as outlined in Table 4.3); and an examination of usability as a key characteristic of GI. In the context of conducting accessibility analyses on a range of destination features, the GI involved was stress-tested through the use of sensitivity analysis in the context of conducting repeated accessibility analyses to a range of service facilities, in order to illuminate issues of quality and usability in order to identify differences or similarities between the datasets. Where possible, the effects of any variations were quantified. Throughout all stages of the exercises the data was assessed according to usability characteristics and associated elements and sub-elements (as itemised in Table 1.1).

Overall aim	**To investigate the usability of geographic information (GI)**
Objectives	Explore the quality and usability of a range of selected data.
	Defend the assertion that usability is a key characteristic of GI.
Approach taken	Use sensitivity analysis to stress the data and highlight differences and identifying similarities between datasets.
Context	Accessibility analysis.
Outcomes investigated	Quantifying effects of variables on results using three separate assessments of accessibility: nearest distance; a two-step floating catchment area (2SFCA) method; and destination overlap.
Specific outcomes investigated	How usable is OS data in the context of accessibility analysis?
	How interchangeable is GI in this context?
	What is the impact of the ongoing development of OSM?
	Can conversion factors for assessing network travel distance from Euclidean distance be identified?
	Can data be 'stressed' in order to highlight usability aspects?
	Are there themes or patterns regarding usability issues within the GI in this context?
	Is it possible to identify a factor of usability for a dataset in a particular analytical context?

Table 7.1: Summary of aim and objectives, repeated from Chapter 1.

In addition to the specific objectives relating to assessing the usability of OS data, this research also included an investigation into the ongoing development of OSM over time, a topic which had relevance as to its usefulness as an alternative to OS network datasets. OSM points of interest was also investigated as a potential source of supply feature locations. This thesis also investigated reports in the literature of conversion factors for assessing travel distance and accessibility from the measurement of Euclidean distances. If Euclidean distances were deemed a suitable proxy for network distance estimates, this may imply that this measure can be used rather than network distances. Finally, when all the results were obtained and comparisons made, a factor of usability was proposed: a Utility Factor. A summary of the extent to which each objective has been met is presented in this concluding chapter.

In the absence of an agreed methodology for assessing the usability of GI, the novel approach was taken of using sensitivity analysis in order to place the various datasets under stress, and then to investigate differences in outcome. This highlighted the fact that GI and maps are representations of the real world, abstractions of reality and subject to interpretation and bias on many levels. One of the main findings from this research was that no two sets of data were found to be identical in terms of performance as measured in the context of assessments of accessibility. The use of sensitivity analysis provided a multitude of cross-comparisons of results in order to compare how different network datasets performed in the measurement of distance, and how different representations of supply-side and demand-side features also resulted in differences being noted. As well as the differences in distance measurements, no two datasets produced identical results when used with a relatively new approach to measuring accessibility, based on 2SFCA techniques. A third approach, testing destination overlaps, also showed that in no case did two datasets produce identical results when comparing actual destinations identified as closest to an origin. In addition to these numerical differences, visualisation of the results, while similar, again did not produce identical results for any two sets of data. A further output of the sensitivity analyses related to the investigation of sudden changes, erratic results, or outliers to the majority of the data. In several instances (outlined in the Results chapters 4 and 5) the investigations revealed issues of data quality, particularly errors of both omission and commission. Further investigation of these errors and issues suggested a potential geographical component to these errors, as well as definitional issues and issues particular to the method of data collection, which made errors much more likely. Examples of some of these issues will be given later in this chapter. All the specific outcomes were investigated, and a summary of these outcomes will be reported here, before the key findings are outlined and a summing-up made of the key results from this research.

7.1.1 How usable is OS data in this context?

Ordnance Survey data usability varied across products. ITN was rated as highly usable, high quality data, but long conversion times to GIS-compatible network were a drawback (but a drawback shared by other network datasets tested. UP made significant differences to accessibility outcomes, but limitations on what features were included (no informal pathways, for example) meant it fell short of providing a full representation of pedestrian travel networks. Open Roads was of high utility (as defined in Chapter 2) and free to use for all, but had some quality issues. Sites provided more accuracy for certain features than PoI, but quality and consistency varied within and between the datasets. Code-Point and Code-Point with polygons offered a useful option for disaggregating population and presenting results at town, city or neighbourhood scales (with some reservations, as outlined in previous chapters, particularly Chapter 5).

7.1.2 How interchangeable is the GI?

Statistical analysis indicated that the vast majority of results obtained from using the datasets had significant differences, though there were some matches in some very specific circumstances. In some cases OSM results closely matched those of some OS datasets. However, when presented in a visual form the differences, though still present, were less apparent, indicating once again that the context in which the data is used, and the context in which the results from using the data area presented, are vital factors.

7.1.3 Ongoing development of OSM over time

Temporal slices of OSM data revealed considerable variation in the lengths of roads within the study areas and also considerable changes in the attributes of the data, reflecting the ‘open to all’ approach of this crowd-sourced, VGI product. Section 7.4.3 provides more detail on this issue.

7.1.4 Investigating conversion factors for assessing travel distance from Euclidean

Many authors identified conversion factors in the course of their research (Martin and Williams, 1992; Love and Lindquist, 1995; Burkey, 2012), but no consistent factor was identified from this research that could be used to convert Euclidean to network distance. Section 7.5 puts this specific outcome into context.

7.1.5 Assessing issues and errors within the GI for identification of themes or patterns

Details of the case studies carried out were presented in Chapter 6 to illustrate some of the issues resulting from the use of these types of data sources. Some patterns and themes were identified and were also detailed in Chapter 6. Patterns of error differed between datasets, and in some cases within datasets, indicating a possible geographical component of error. The geographical component could be assumed to be due to variations in surveying techniques or in standards from one area to another, and relates to OS data as well as that of OSM.

7.1.6 Is it possible to identify a factor of usability for a dataset in a particular analytical context?

A usability checklist is proposed in Section 7.2 which could form the basis for a decision-support framework from the results of using sample or test data, or using it in one context and recording user experience, to inform future users of potential issues. This did not specifically give a value to the data, but returned a grade, based on the judgement of the user. A more objective methodology for assessing usability was discussed in Chapter 6 whereby statistical measures of similarity (correlation) are tempered by measures of difference (Wilcoxon scores in this case) and also by destination overlap to produce a Utility Factor with a maximum possible score of 100. A number of caveats accompanied this proposal specifically with respect to its use in contexts outside those of this thesis, and with statistical measures other than those used in this particular study.

7.2 Consideration of the underlying research problem

The overall aim of this thesis was to investigate the usability of geographic information. Although international standards on usability have been developed, there has been little application to data, and even less to geographical data. Previous studies related to the term ‘usability’ have concentrated on either data quality or on the usability of ‘things’ such as maps, computers or interfaces, but the literature on assessing GI itself is very sparse. Previous approaches involved interviewing users (Harding, 2012), observing, estimating or calculating the timing of task completion (as in Hunter et al, 2003, and van Elzakker, 2005), or expert evaluation (for example Hengl and Husnjak, 2006). In-depth assessments have involved a complete review of the use of the data, including user feedback and fault logging, interviews, focus groups, etc, each of which are time-consuming and labour-intensive activities which were conducted some time after the data itself was used. Benchmarking against 'gold standard' data has been used in the past (by Zielstra and Zipf, 2010, and by Haklay, 2010a), and one element of the methodology used in the present research (the development of OSM over a period of time) used that particular technique. A problem with these approaches was their retrospective nature. Users had to obtain and use the data before reflecting on its usability aspects. This study aimed to explore a novel way of stressing the data in question in such a way to highlight its usability aspects and characteristics.

The original aim of this thesis was to investigate whether the usability of data could be assessed pre-procurement. What was evident from the findings of the study is that several things need to be in place before any assessment of data usability is considered. Firstly, the context of the task has to be known and has to be clear. Data that is ideal for one task (or type of task) may be completely unsuited to another, but how can this be gauged? From the list of usability characteristics outlined in Chapter 1, the following questions should be posed:

- Is the data in question able to complete the task?
- Is the data in question able to complete the task efficiently?
- Is the data in question able to complete the task in a satisfactory manner?

These questions may be difficult to answer without firm knowledge of the data in question and their context, specifications and quality. This brings to the fore the issue of metadata which, if present and sufficient, can inform potential users of many of the points in question. However, with some data producers perhaps seeing metadata as an additional task to be conducted after their main data creation task has been completed, metadata may not always be part of a dataset and may address only basic issues (though this situation does appear to be improving). Having the opportunity to test some form of sample data maybe a big step forward in users being able to assess the worth of a potential data acquisition, and again more and more producers (OS included) are offering sample data or the equivalent of 'try before you buy.' This is important even for free and/or open data, where the overall total cost of the data is more than the purchase price, with personal or organisational time and effort spent in identifying, ordering, obtaining, downloading and converting data before it is even used for the first time. The sample, which could be a relatively small data package, should be relatively simple to download and convert, enabling a rapid assessment of the data in a realistic simulation (or in an actual case scenario), using the software and systems that would be applied to the full dataset. Difficulties downloading or converting, or in using the data in a particular format, could be identified without hours (or days) of computer conversion time. The full dataset could then be obtained with a high level of confidence that it could complete the task required of it. If found to be ineffective or inefficient in any form, alternative data could be sought. Users may need many samples for the same geographical area in order to complete their tasks, possibly multiple datasets from multiple sources (such as ITN, PoI, OAs, etc) and a single point from which to obtain matching or linked data may prove extremely useful.

A checklist, or equivalent, could be incorporated into a works order (or similar) to be completed whenever there is a requirement for new data, with a potential source checked before data is obtained. The checklist may form a simple decision support tool in the first instance, but if used as a ‘front cover’ for a data set that has been obtained, it would remind future users of the pros and cons of using the data, particularly any caveats that should be kept in mind during use. A user-feedback element should be included, and users encouraged to leave their comments following use (as is, increasingly, the case with some data providers). An example of such a checklist is provided in Appendix A: A - 1 is a blank form; A - 2 is an example completed for ITN, as if for the purposes of these accessibility studies; A - 3 is an example completed for OSM, again in the context of the accessibility analysis carried out for this thesis; and A - 4 is an example completed for Yell, as a potential source of supply-side features in an accessibility analysis. The checklist includes each element of usability as detailed in Chapter 1, although not all may necessarily apply in every context. Such information as contained in the checklist may come in useful for future users in the case of using Yell information to locate supply-side features, as detailed in Chapter 3. It took a considerable effort to extract the information required from Yell, only to find it was not usable in the particular context. A record as such shown in Appendix A - 4 held by an organisation would speed up the time in which such data sources could be downloaded and used in any popular GIS task.

Such a form or tool could be used both for sample data from sources outside an organisation, or used within an organisation in order to assess data obtained for one task for suitability in another. It could also be part-completed by data producers, giving at-a-glance information as to any objective, third party or certified information (such as data format, any independently assessed quality statements, legal certification) or any warnings as to its use, perhaps culled from user comments, in effect broadening metadata records to include warnings and feedback. The checklist lacks Brown’s (2010) suggestion of using heuristics to inform the content. It could be used as stated here, however, but use a heuristic approach to assign weightings or rankings of the various elements using feedback from users, and using post-use follow-ups to confirm the results on the checklist in order to fine-tune any accompanying guidance notes.

Through such a checklist, depending on the task, a user could flag up certain elements as essential in that particular context, with an insufficient or unsatisfactory grading in that category rendering the data ‘unusable in context.’ When supplied in electronic format, such a checklist could incorporate hyperlinks or intranet links to definitions, explanations and guidance, ensuring standards were maintained centrally, so providing evidence that contributes to building up a full picture of potential usability. This would take metadata away from the traditional approach to metadata presentation by having free-text elements, as contributed by users with experience of the data (perhaps moderated as required by the data producer). The well-defined and standardised metadata protocols may have to be adjusted to take into account this user-generated content which effectively adds context to metadata records.

The usability elements that make up the usability characteristics of effectiveness, efficiency and satisfaction were described in Chapters 1 and 2, and as far as possible each element was tested in the course of the case studies carried out for this thesis. Each will be addressed in turn.

7.2.1 Cost

Cost is a constraint on use, particularly by the charity or not-for-profit sectors. The availability of a large amount of free-to-use or open data has opened up GI to previously unavailable uses. Much of the cost element now relates to staff and time costs required to make use of it. However, Parker et al (2012) found that when decisions were high risk, cost was secondary to satisfying requirements. In the case studies undertaken here, the data was provided or sourced free of charge, time was the main cost, and examples of conversion times or time taken to identify the correct data were presented in Chapter 3.

7.2.2 Integration and convenience

Integration and convenience were also addressed in Chapter 3, and included elements of conversion time and effort. The changes to OS data availability, by making data available in proprietary GIS formats have made the data much more convenient to use. Similarly, the changes to OSM network downloads also served to make the data more easily integrated into GIS and more convenient to use.

7.2.3 Searchability

Searchability caused difficulties when third party alternatives were sought to the OS supply-side datasets. Despite having commercial imperatives, many commercial data providers were difficult to find, and their data stores even more so, resulting in (for example) no use being made of satnav data providers' PoI data. Not only did it take a considerable time to track down where the data was being held, it proved very difficult to ascertain what data it contained and in what format, rendering the data unusable, in this context.

7.2.4 Security

Security was an issue with the OSM data, where the time-slice data had wide variations. Roads being classified as ‘Private’ in the outskirts of Cardiff may have been a classification error or purposely changed to an incorrect classification. As Hunter et al (2003) pointed out, users need to know their data was free from tampering, and that security was a more significant issue with VGI compared to ‘official’ data.

7.2.5 Speed of access

Speed of access and speed of conversion were addressed in this thesis. The rendering of the various datasets was such that responses were relatively fast. The only question arose when address-level data was used county-wide, and the screen refresh when using the data in ArcGIS was of an order of 15 seconds or so, which was acceptable in the circumstance. Nivala (2007) suggested some animation be added to GIS interface software to reassure the viewer that something was happening, but with Arc this is not required, as the map image slowly fills up with the datasets that are loaded, layer by layer, and area by area. The speed of conversion, particularly from OS gml-format to Arc-usable shapefiles was considerable, with little indication of progress given to the user. The time taken and lack of information were both usability issues.

7.2.6 Standardisation

Standardisation was not an issue in this case, as all datasets generally conformed to accepted and intuitive symbolism and feature definition. The lack of a set classification and definition schema in OSM, which carried a list of ‘suggested’ descriptions, did cause some discrepancies, particularly when different types of road and pathways were being investigated.

7.2.7 Legal issues

Legal issues were looked at in all stages of this thesis, and mainly related to data licencing. McConchie (2008) noted the erroneous perception of much of the ‘free’ GI available on the web, with users unaware of licencing issues, for example. Google’s Terms of Service (Google, 2012) provides a recent example where new content creation based on its maps is forbidden, which may come as a shock to many mashup creators. The possibility of using Yell data to locate supply-side features may also have posed problems, as their terms forbade bulk downloads, but manual ‘web scraping’ for research use appeared to be permitted (Yell, 2016).

7.2.8 Added value

Assessing the added value of data, particularly GI, was difficult. With many approaches measuring costs against benefits (Dickinson, 1990; Cetl et al, 2008; Brown et al, 2011a) the difficulty of assessing the value of intangibles became clear, yet the benefit of such intangibles (improved customer service, improved brand image) were also known, only not in monetary terms. Parker et al (2010) suggested that knowledge of added value equated to usability (applied to VGI), but encountered difficulties in quantifying these values, which changed depending on the user group's own distinct requirements, and the context in which the data was to be used. A lack of recent, relevant literature suggests the topic has not been a primary concern in recent research initiatives. In this case, the value relates to use, and all the main datasets contributed towards the study. All were procured free of charge, therefore no cost-benefit comparisons could realistically be made. OS pricing structures were varied and complex, and made identification of costs difficult, causing knock-on difficulties in calculating added value.

7.2.9 Content

Content of GI is one of the key elements. Google PoI was a potential alternative source of supply-side data, but when the data was obtained it was unsuitable for use. Both volume (in terms of the number of features mapped in the study areas) and quality of content was considerably lower than that of its potential comparators, but no indication was given of this in advance of procurement of the data. Data fall-off was noted in geographical terms, duplication of features was noted immediately, as was mislocation of features. The content was not suitable for use in the context required.

7.2.10 Purpose and context

Purpose and context are key: what is usable for one purpose may not be for another, therefore usability is a relative term (Brown et al, 2011b), therefore data producers must consider their GI from a user's point of view, and when the pace of change and application development is so rapid, this is difficult. The OS Sites dataset seems to have been introduced without a clear purpose in mind. Perhaps some direction should be given to potential users through the encouragement of a task or research using this dataset. Research into OS 3-D products by Pendlington and Capstick (2012) produced information on what the datasets were used for and what relative importance was placed on particular aspects or content. In this thesis, Sites, PoI, ITN, UP and Open Roads were all fit for purpose, though the tools required to make full use of the Sites information in gravity model analysis were not yet available (as detailed in section 6.2.2.1).

7.2.11 Utility

Utility, or ease of use, is another key usability attribute (ISO, 1998), yet the multi-step, complex method required to download, but particularly to convert, GI data to obtain network datasets points to such products only being used by those with some geographical, GIS or technical training or awareness. Such datasets, whether OS or OSM, did not appear to be designed with ease of use in mind, as ArcGIS took hours to convert and load data. Any mis-step in the process required returning to the beginning, with largely generic error messages and very little guidance provided. Where Bugs et al (2010) assessed utility by completeness and correctness in the user's performance, network datasets would have low utility values, however repeating the download process using alternative GIS (such as QGIS or MapInfo) would clarify whether this was an issue with the data itself or specific to ArcGIS. Other datasets used, such as census OAs and OS PoI and Sites, were relatively simple and intuitive to load and use. OS ABP was far from easy to use (see section 6.3.4 for further details), and the aim of achieving full utility of all parts of this complex dataset was conceded, though functionality of the separate parts was achieved, with some inter-connection.

7.2.12 Novelty

Novelty was seen by Scharl and Tochtermann (2007) as a driver for interest. OS Sites and Open Roads were two relatively new datasets, and have the potential to pique the public (or at least GI users) interest. Sites does not contain a large number of different features, therefore there is the opportunity to publicise each new step taken as new features are added. The novelty of the dataset was such that the plug-in tool to calculate 2SFCA scores was unsuitable without further processing of data (as was explained in section 3.2.4).

7.2.13 Popularity

Popularity often goes hand-in-hand with novelty, but some datasets maintain a high profile. ITN has been reported as the comparator dataset in many studies of VGI quality, completeness or coverage (for example Haklay, 2010a), and in this study no issues or problems were identified. Although OS publishes case study information on its products website, no detail is provided as to their popularity. Although popularity is not a proxy for usability, it indicates that many people are actually using a product, though their perceptions of doing and motivations for doing so may be unknown. However, indications of the popularity of GI are rare.

7.2.14 Authority

The authority conferred upon a dataset enhances usability by promoting trust (also a usability element) amongst users, according to Goodchild (2008), giving advantages over products that do not have official approval (Hunter et al, 2003). In the course of this thesis when researching supply-side data from commercial sources (such as Yell and Google) their agenda loomed large, with over-inclusion a major factor (presumably in order to widen the exposure of businesses, etc) as detailed in section 3.8. Although by no means perfect, OS data did carry the authority of being the country's official map agency, and it is presumed this is why OS ITN was used as the standard with which to compare OSM coverage in London (Haklay, 2010a). The results of this thesis confirmed the justified authority of ITN, noting its high quality and consistent coverage in the context of accessibility modelling.

7.2.15 Trust

Trust, closely allied to authority, is difficult to define due to the emotional component involved and a predilection which varies from person to person, and therefore from user to use. as Hunter et al (2003) pointed out, even a professional interface or design increased perceptions of trust, over-riding any caution regarding the data, resulting in some users putting full trust in a system without any knowledge of the accuracy or quality of either the data or the system being used (Harding et al, 2009). For the purposes of this thesis trust was suspended, and attempts were made to record quantifiable and objective results, with examinations of feelings considered after each exercise, so as not to pre-judge any issue.

7.2.16 Caveats on use

Caveats on use relating to the data used in this study were not identified at any stage, and in reviewing literature and uses of geographical data, one example where a clear caveat was highlighted was found to have been removed when the GI was revisited at a later data (see Figure 2.2). It would be interesting to review a range of GI to identify any specific subject areas or organisations that include useful caveats in their data as a matter of policy.

7.2.17 Certificates and standards

Certificates and standards were, again, not considered as part of this research, but the difficulty foreseen with VGI products achieving any published standards may cause problems when VGI products attempt to break into the same markets as professional data providers, such as OS. The experience with OSM products gained during this thesis indicates the difficulty VGI products have in trying to maintain even their own informal standards, with respect to volunteers submitting data of reasonable quality.

7.2.18 Legal defensibility

The usability element of legal defensibility was not considered as part of this research.

7.2.19 Producer reputation

Producer reputation is also tied in with elements of authority and therefore trust. For this thesis, preconceived ideas of producer reputation were put to one side until after the research was completed, hence the emphasis on numerical, quantifiable results.

7.2.20 Metadata

Addressing the content of metadata was not the primary aim of this thesis. This research was not intended to critique, adapt or extend current metadata protocols or standards, such as Dublin Core, though suggestions as to how to incorporate contextual information with metadata have been made. The aim was to reiterate the importance of metadata to the overall usability of the data. This thesis was therefore not a comprehensive survey of geospatial metadata, concentrating instead on that which accompanied the datasets being studies. Metadata provision, or lack of it, did affect the times taken to assess data for suitability for use. It was found that the lack of metadata for Yell, Google and other third party datasets meant the only practical way of testing the data was to download and assess the data in use. 'Official' data, such as that from OS, census data, schools data from WG, information on GPs from health boards, etc, all carried some form of metadata, describing the contents of the dataset, currency, coverage and provenance, all of which contributed to increased trust and improved efficiency by reducing time spent exploring for such information. Such provision also served to confer some authority on to the data itself. There was considerable overlap in this study between identifying usable data and the provision of metadata, going some way to confirming the suggestion of MacCormack and Eyles (2010) that the existence of full and detailed metadata could act as a proxy of GI data quality, though as was found in this study good quality data was not necessarily highly usable data.

7.2.21 Visual appearance

The three sub-elements of visual appearance (data visualisation, interface design and HCI) have considerable overlap and by concentrating on the content of the data, rather the appearance or the system used, this element was not considered as part of this study. Skarlatidou et al (2011) found that a good looking system promoted trust amongst users, but it was the content of the data that was concentrated on here. However, it was noted during the research that the interface and map designs of Google Maps and OSM were impressive in terms of their appearance and their functionality (click and drag, zoom functions, etc all performed smoothly) but that OSM was identical in appearance in (say) the centre of London as it was in the Vale of Glamorgan, giving an impression of uniform content. This was not borne out when investigated further, with a wide difference in terms of contributions and contributors between those areas, suggesting that appearances can (even if inadvertently) deceive users.

7.2.22 Quality

Quality was one of the main usability elements assessed, and data quality has had considerable coverage in the literature. Quality can be measured, through metrics of error rates, accuracy levels, completion rates, and so on, and some attempt was made to assess the quality of the data used in this thesis, through the logging of errors and inaccuracies. Results found confirmed Jackson et al's (2013) findings regarding official and VGI data on schools, with some schools included in some datasets but not others and some data temporally invalid due to new builds and replacements. That study reported that the VGI data led to errors of commission and omission, both of which were also found in the case studies involving schools in this thesis. Errors were also found in the proprietary datasets relating to schools, though the data from VGI sources fell well short in terms of coverage, with a very low number of features in their PoI datasets.

7.3 Key findings

7.3.1 Supply-side features

The different results gained during this exercise from using a variety of different supply-side feature types (primary schools, secondary schools, GP surgeries, sports centres and community hubs) justified the decision to use such a range, rather than relying on the results from one feature type with which to make generalised observations, both of accessibility and usability. The different densities, distribution and patterns of coverage highlighted varying instances and examples of inconsistencies and errors (errors of both omission and commission) in the datasets, many which could have remained unnoticed if the study relied on just one type of feature. The use of one feature or one particular aspect of a GI dataset to make generalised comments regarding data usability or quality is insufficient.

It was noted, at a relatively late stage in the production of this thesis, that OS Sites data was provided to customers along with OS MasterMap Topographic Layer and not (as originally assumed) on request as an add-on to the Topo Layer. It is therefore NOT a demand-led dataset, and there appears to be little information as yet as to how the Sites data is being used, despite the stated aim of promoting analytical work. The discrepancies between specific features found in Sites and those included in Points of Interest (PoI), specifically regarding schools found in one dataset but not the other, raised some concern regarding update cycles, though there was a temporal shift between the dates of PoI information and Sites information being obtained. The effects of using Sites as opposed to PoI (and vice versa) were detailed in Chapter 4. The inclusion of functional access points provided an opportunity for highly accurate travel distance assessments 'door-to-door,' and so improving proximity and accessibility to supply-side features included in this dataset, though tools have not yet been developed to take advantage of this increased accuracy in the calculation of gravity-type models when using this dataset. However, errors of omission somewhat undermined this potential improvement in accuracy, with some features having no access points associated with them, probably due to the combination of the surveying method used and physical layout and characteristics of the features themselves. If OS assessed the potential use of Sites in accessibility studies as high, they could develop (or sponsor the development) of a reworked 2SFCA tool which took into account the issue of multiple access points and/or used the polygon perimeters in the calculations. With no indication of demand for such a tool, the potential benefits cannot be assessed against the costs incurred for development.

For primary schools, the provenance (the source of data) in PoI was almost entirely the Welsh Assembly Government, based on a collation of LA information, resulting in independent schools being omitted, although some did appear on Sites data. Inconsistencies in classification and inclusion were therefore apparent between and within these datasets.

The use of Sites enabled a variety of alternative feature-location methods to be used. Although the method of locating the feature had a significant effect on distance and 2SFCA accessibility results, when the same results were visualised in choropleth maps, the results were not necessarily so marked. The results from using perimeters of functional polygons as the destinations showed considerable variation compared to the other options. The use of perimeters as destinations in this context was found not to be particularly useful (as the features in question generally had ‘impermeable’ perimeters, across which access to the facility could not be gained), but its use with features which were more open, such as parks and public spaces, would offer a useful alternative to the more-usual options of using polygon centroids. In the course of identifying the main access point of each school (that is, the main entrance) it was found that some access points (as identified on Google Earth and Google Street View) were missing from the Sites dataset, and some that were in the dataset were blocked up, possibly permanently (having been identified on Google Earth with rusted-up padlocks and chains, on overgrown lanes and paths, etc). This questioned the precise purpose of the access point attribute. Was it for accurate, current accessibility? Or was it intended to have the potential to locate all possible or future routes? For instance, the attributes associated with access points included three classifications: Motor Vehicles; Pedestrian; Motor Vehicles, Pedestrian; but no indication of whether they were actually in use. There were other attribute fields present (‘accessDirection’ and ‘accessUseRestriction’), all ‘null,’ implying an intention to include a range of attributes for each access point. Using attributes to identify blocked or unused access points may improve the accuracy of the dataset, while still providing locations for all potential access.

The use of freely-available third party supply-side data was found to be impractical. Completion and coverage issues with OSM meant that any data was sparse in the South Wales study areas. Other commercial sources were overly inclusive (presumably to maximise the reach of advertisers, etc to any potential user), rendering their data limited for these analytical processes. As detailed in section 3.8 a search of Yell data to identify primary schools, for example, resulted in the inclusion of many driving schools and several schools of music. Using these results would result in accessibility to primary schools being overestimated due to the considerable increase in the number of features spread throughout the study areas.

The use of OS address-based datasets for supply-side identification and location was found to pose difficulties. Address Layer 2 lacked a suitable classification scheme, whereas ABP’s detailed classifications suggested it had potential to locate destinations, but several inconsistencies (the inclusion of private schools in the ‘secondary school’ classification in Cardiff, for example, with none in the specific ‘non-state secondary’ classification) served to reduce levels of trust in this dataset, with classifications remaining unused in some geographical areas. Errors of commission not due to attributes or classification were also found with ABP. Address-based OS products were therefore not considered as a viable alternative to the Points of Interest dataset, nor as an alternative to identification of the types of feature found in Sites. However, a user or customer with the full AddressBase Premium package, with all the separate files working together as OS intended (but as conceded earlier, full utility of ABP was not achieved for this thesis) could exploit the information within what amounts to a database of all addresses in the UK to conduct a range of feature identification related tasks.

Spatial inconsistencies were evident in OS PoI with the classification of some features. For example, with the selection of sports centres it was found that classification criteria were much tighter in the Vale of Glamorgan than in Cardiff. With sports and leisure centres selected, the Vale had a consistent result of LA run facilities. The same selection for Cardiff resulted in a recreation ground being selected (a possible case of misclassification). Penylan Library and Community Centre was also in the selection for Cardiff, presumably as the community centre has a hall used for sporting activities. However, the Cardiff classification seemed somewhat looser than that of the Vale. Classification of buildings with multiple uses appeared to have issues of omission. For example, Maindy Pool in Cardiff had two adjacent PoI points: Maindy Swimming Pool; and Maindy Swimming Pool and Cycle Track. This facility also has a fitness suite (gym) and dance studio, and is classified by the local authority as a sports centre, but no reference is given for this in PoI, and it was not included in the Sports Centre assessment due to this. This brings up the issue of features and their uses, issues of how to classify features that have more than one purpose in the PoI classification scheme, and issues of consistency as to how such features are treated.

7.3.2 Demand-side features

The use of OA centroids, and their associated, detailed population information from the UK census, proved a satisfactory representation of population. OA polygons were a convenient and easy-to-use dataset, but their variations in size meant that visual interpretation in a typical choropleth map format meant that small urban OAs were difficult to distinguish, and large rural OAs tended to dominated the maps.

Post code-level population representation (as provided in the Code-Point datasets) was found not to exert an unacceptable computational load in the context of this study. The identification of domestic and non-domestic post codes helped improve the precision of population allocation at town and city level, though presented challenges of visualisation and interpretation, particularly regarding the ‘gaps’ caused by the removal of post codes with only commercial and industrial premises when used in conjunction with the associated Code-Point polygons.

The issue of stacked postcodes in the Code-Point dataset (and the resulting mismatch between number of points and number of postcode polygons) required some investigation in this research in order to clarify the mismatch. Consideration could be given to symbolising or highlighting the stacked postcodes in such a way as to distinguish them from ‘normal’ postcodes.

The fine scales offered by Address Layer 2 and AddressBase Premium (ABP) offered a potential alternative to other demand-side resources, though internal inconsistencies in the ABP attributes made the distinction between residential and non-residential addresses more difficult. It is understood that these types of classifications are taken directly from OS Topo descriptions and are therefore reliant on that separate dataset.

OS address-level data would be ideal for fine-scale accessibility analysis when used as a demand parameter at scales up to the county level. Translation to choropleth-type maps would not be straightforward as there are no associated polygon dataset with which to present results. Post code level data does, however, have associated polygons in the Code-Point dataset. Potential issues of confidentiality and (perhaps) spurious accuracy may arise: spurious in that for census-level analysis the lowest census data area (OAs) would have to be disaggregated to address level, with data estimated as appropriate. This estimation was carried out for this thesis on a pro rata basis, but with the points provided at such a scale, users may assume the data itself is accurate to this level.

Address level data contains sufficient information for each address point to be located to a postcode point or postcode polygon. A GIS process was required to allocate the address points to the relevant OA polygon, with a view to disaggregating the OA population to each point. With the OAs having effectively a 10-year life span, it may be possible to incorporate the relevant census OA reference to each address point (and post code point) into the attributes of the OS data. This would provide a further step in the linking of data between two government agencies, and may facilitate inter-use of the two datasets.

7.3.3 Network features

As reported in Chapter 4, inconsistencies in OSM coverage resulted in uncertainty and a lack of confidence in the dataset. Several instances of ‘islands’ of unconnected OSM ways were identified. There may be have been more through Cardiff and the Vale which were not identified with the combinations of supply and demand points used here, but the use of post code level data for the origins was sufficient to reveal many more instances of broken networks. However, these were only tested for residential areas, and a similar stress on the network data in commercial and industrial areas may have revealed more, but this was not required for the accessibility analyses conducted at this time. For this type of data, a similar number of points, distributed throughout an area, could be used to identify broken network links through identification of nil returns and of erratic or outlier results and their subsequent investigation. It is understood there are tools and exercises which OSM use to 'flag-up' such issues for their volunteers to correct, but from the downloaded data used in this thesis, errors were not unusual.

Material provided in Chapter 3 highlighted issues regarding the time and effort required in identifying sources of OSM network data, only for them to withdraw the product, highlighting some of the problems that arose (and could occur again), with procedures for obtaining usable network data. The lack of obvious guidance on the OSM website put the onus on the user to search and find the information required to successfully obtain and download the data required. The implication throughout these occurrences was that any steps beyond the use of OSM as a simple, visual general-purpose (or route-finding) map was aimed at GIS professionals or those within the geospatial community.

The use of Urban Paths had a marked effect on results, particularly on those of Cardiff primary schools, on both distance and 2SFCA, illustrated by the highlighting of UP amongst the lowest correlations. UP generally did not produce very similar results to ITN. The UP dataset did not contain a large amount of data (in terms of network lengths, for example) but these small lengths had a significant effect on accessibility, giving some indication of its importance to pedestrian travel. With the ever-increasing emphasis on active travel, this could become a very important part of the ITN dataset. However, inconsistencies in how certain street layouts are treated must be addressed to reflect the true journey paths of pedestrians, and potentially of cyclists. This is one area in which an aspect of VGI could be utilised. With the prevalence of location-enabled smartphones, the actual paths of pedestrians could be sampled. Where these paths do not match UP data, further investigation could be initiated. In this way the quick-response of VGI is matched to the survey potential of the official map agency, without relying on volunteers to make amendments to maps which are held in high regard and considerable trust. Permitting uploads to a specific user website, similar to the community efforts set up by the BBC Weather Watchers (http://www.bbc.co.uk/weatherwatchers), could be an option, harnessing the interested public as citizen sensors while retaining control of the final map products.

In several instances more detail in the network (and therefore higher expected accuracy) did not necessarily result in higher accessibility results. With less detailed networks (such as OSM in some locations, or Open Roads) the constraints of the GIS meant that origin or destination points could 'snap' a considerable distance, in some cases reducing distances considerably. In accessibility analysis this should be recognised as a potential issue, as identification of specific occurrences would not be easy. Only a wide discrepancy in the distances returned would draw attention to this and in the more sophisticated accessibility assessments, such as 2SFCA, the discrepancy may not be noticed at all. Again, context is key, and where very precise measurements are required then all aspects of the origin, destination and network dataset must be looked at closely to understand the potential sources of error and inaccuracy that may occur.

7.3.4 Data loading and management

Although the data was the focus of this study, factors relating to GIS and to ArcGIS in particular did impact upon the usability of the data. The time required for ITN and UP data (but particularly the ITN data required as part of the OSM longitudinal study) to be converted into an Arc-compatible format was considerable. It also revealed the fragility of ArcGIS, with its tendency to crash should any other activity be attempted on the computer during the conversion process. This issue was not confined to OS data, as OSM data supplied by Geofabric (the third-party supplier of OSM network data) required a further tool, which needed to be searched for and sourced from elsewhere, which required hours of run time to convert the data, leading to considerable inconvenience. Again these processes could not run in background while other work was being done without crashing ArcGIS, therefore the best practical solution was to run the process overnight.

It is noted that OS data from Digimap (for academic and research use) and some data from the OS website itself (though not ITN or UP) was available in Esri Shapefile format (ArcGIS compatible) as well as in gml format, providing a practical example of data providers considering the use of their data rather than simply releasing it in whatever format they see fit, and leaving the user to convert it as required. Despite enquiries being made to OS, it is not known whether this is provided as a service, whether OS pay Esri a fee to provide the data in Shapefile format or whether Esri pay OS to pre-prepare their data thus making it more easily usable to ArcGIS users.

7.4 Implications

The implications arising from the results of this research are provided separately in subsections aimed at each relevant audience or sector in turn.

7.4.1 For Ordnance Survey

As the official government mapping agency, OS products remain the benchmark for comparison in academic research, as the results from this thesis shows. ITN was the only dataset to have no errors highlighted by the use of sensitivity analysis or by the extra stress imposed by the use of post code level and address level data. However, not all their products performed to the same level, as evidence provided in Chapters 4 and 5 demonstrate. Cost-free availability for academic use is a major factor in increasing the usability of ITN and related products.

Of more concern were the instances of spatial inconsistency, particularly in the classification of features, as outlined in some detail in Section 7.3.1. These indicate the potential of a wider issue: that usability of data may not just vary from dataset to dataset, but also geographically within datasets. Although closely tied to data quality, this issue could have a considerable effect on the results of an accessibility analysis, and hence affect the usability of the dataset at a fundamental level.

7.4.2 For OSM

OSM PoI data was characterised by severe drop-off in completeness outside the main urban area of Cardiff, with features extremely sparse in suburban settings 3 miles from Cardiff city centre and virtually non-existent in more rural areas. OSM data exhibited much higher error levels in its network dataset compared to the other data examined. Data on main roads for regional study appeared acceptable, but the quality and detail required for more local accessibility study meant that OSM performed poorly in some contexts. Examination over time revealed large swings in the quantity of OSM data, caused by errors of classification and apparent lack of understanding of mapping practice relating to OSM data. The errors were subsequently corrected, but the nature of crowdsourced contributions to OSM meant they could occur again at any time.

7.4.3 For VGI in general

The context and location of any VGI project appears key to its success or otherwise. Guidance, training and skill levels of contributors all impact on the quality of the data and upon its usability, as do the number of volunteers both mapping and checking the data submitted. The low volumes of OSM activity in Cardiff, but especially in the Vale, do not seem sufficient to maintain a comprehensive map of a combined road, cycle and pedestrian network. With that in mind, Yovcheva et al (2010) found in their VGI study that not all contributors had unlimited access to data creation or amendment. Although the OSM model permits anyone to contribute to their map (and relies on ‘the crowd’ to quality check as appropriate), without a means to check the ‘credentials’ of contributors the use of non-urban OSM data in research outside major cities must be questioned. In contexts where more than a map of main roads is required, users will have little confidence in the content, quality, searchability and consistency of the OSM data, at least for the types of GIS tasks addressed in this thesis.

7.5 Advantages and limitations

In looking back over the approach taken in this thesis, the overall objectives were achieved, in most aspects. In retrospect, the use of sensitivity analysis did expose some shortcomings with the data under examination. However the majority of issues found could be described as data quality issues, which comprise one aspect of usability. The use of sensitivity analysis certainly provided sufficient stress to reveal those issues. The use of accessibility modelling helped put the use of the data into context, and provide a convenient way of making use of many different aspects of the data provided, enabling a searching look to be made of location data, attribute data, classifications and coverage, with comparative study of the results enabling 'outliers' and inconsistencies to be investigated further. Certainly the use of fine-scale origin locations to a variety of destinations enabled issues and faults to be identified that may otherwise have gone unnoticed in the study of only one type of feature. Such fine-scale origin-destination techniques could be used to design standardised data stress tests for the purposes of fault or anomaly detection in network datasets.

The use of the 2SFCA measure caused some concerns. The influence of supply and demand levels, and of the overlapping catchment areas, greatly influenced results. This was interesting in terms of the accessibility analysis, but less so in terms of assessing the usability of the geographic data. From the results obtained here, no consistent correlation or conversion factor between distance and 2SFCA outcomes was identified. Such a conversion factor would have enabled inferences regarding accessibility to be achieved with basic geographic data and simple GIS functions rather than ever-more-complex and finely-tuned gravity models. However, this was not the case.

There are several advantages of the approach taken here. Time is one factor, with a methodology outlined and explored, using a similar approach with different data could be completed relatively quickly, compared to the other approaches outlined in this thesis. One main advantage is that these tests could be run pre-release to gain some impression of usability. Traditional usability approaches using questionnaires, interviews or focus groups to ascertain user experiences certainly have their uses, but are time consuming and expensive, while using the data in specific contexts and using it accordingly could identify issues well before customers or real-life users were involved. This approach meant there were no matters of personal confidentiality or ethics involved, with their respective issues of time and bureaucracy (justified, of course, but again time consuming and costly). This approach also provided metrics with which to compare other datasets, to gauge relative performance.

However, there were some issues to be aware of, some relating to this specific study, but also many relevant to research in general, which will be considered here. There were, for example, several sources of potential bias in the results from the exercises carried out for this thesis. They have been identified as:

- Data issues
- Geographical issues
- Methodological issues
- Overall

Each of these concerns will be addressed in turn.

7.5.1 Data issues

The possibility of data bias with regard to using only OS datasets was addressed through the inclusion of OSM network data, which should not, legally, have used any OS data in the creation of its maps. It should be noted that the possibility of bias does not necessarily demonstrate the presence of bias, though this possibility should be addressed.

The OS Open Roads dataset was not obtained at the same time as the other three network datasets, only being available recently. The temporal differences between the Open Road data and the others must be kept in mind when considering the differences between the results, as the road network may have changed in the time between obtaining ITN, UP and OSM (which were all sampled at the same time) and having the first OR release. As one of the intentions of this exercise was to examine the use of free-to-use OS data in a network, OR was included in the exercise, despite this caveat. Despite these temporal differences, comparing ITN and Open Roads consistently produced high destination overlap figures, the highest of all network combinations in several cases, indicating the differences were not that considerable.

The cautions issued in using the Sites dataset were stated several times, in terms of the steps required for the dataset's access points and perimeter to be generalised in order to work successfully with the 2SFCA plug-in. 2SFCA results for access points and perimeter points should therefore be treated with caution.

OSM road data had a very high number of roads which had no classification in the respective attribute tables. Where possible, these unclassified roads were included in the networks that were created, as without them the network were clearly (on visible examination) far less complete than those from the other sources. A greater level of attribute completion would have given more confidence when using OSM as a network dataset.

7.5.2 Geographical issues

Geographical bias was addressed through the choice two different study areas, Cardiff and the Vale of Glamorgan. Although both had different characteristics (in terms of urban/rural geography) both were located in South Wales, and were adjacent counties. Results from other areas could differ. However, large urban areas such as London have been subject to much study, with good reason, as a large percentage of the national population live there and may find the results important. Some inferences which agree with such studies have been made in this thesis (for example regarding OSM coverage drop-off), but validation through replicating the study in other areas would be useful. Likewise, a more remote rural area could also have been chosen, and extending this investigation to another area would be a logical direction in which to take further research.

7.5.3 Methodological issues

Methodological bias was possible due to one type of study being conducted: that of accessibility. Attempts were made to ameliorate this through taking three different approaches: distance to nearest destination feature; 2SFCA; and destination overlap. The researcher was aware of the need to address this potential bias by conducting completely different sets of analyses on these or similar datasets before any wider generalisation could be made with confidence. With this caveat in mind, it is the contention of this thesis that the results reported here reflect a reasonable view of the data sets used in the context of this study. Although this research focussed on data usability in the context of accessibility analysis, the question must be asked as to whether such an accessibility investigation is the most appropriate framework with which to assess geospatial data usability or, within this, whether pedestrian travel was the most important accessibility approach to take. Possible alternative types of analysis are outlined in section 7.5.4, and could form the basis of a further study.

Pedestrian accessibility in a rural context was a concern, due to the increased distances involved. Walking distances to primary schools and community hubs appear logical, but as to secondary schools, sports centres and GP surgeries the picture is much less clear as to how many of such journeys actually are made on foot. However, by maintaining the ‘pedestrian’ approach the results from using each dataset could be compared directly. This would not have been the case if, say, journeys on foot were assessed for two features and by car for three, making the measures incapable of being compared on a like-for-like basis.

The use of the gravity-type model, in this case 2SFCA, was found to be extremely useful for illustrating the influence of supply capacities and demand levels (as was noted in Section 3.2.4), especially where levels of demand and supply have an influence on the service (for example if there is a finite supply such as a primary school with a low capacity in an area of high demand, or one GP in a surgery in a highly-populated area). Distance or proximity models would be more suitable where opportunity was being examined (for example Reimers et al's 2014 study into proximity to sporting facilities, where no limits were set on the capacity of the destination and all were considered to have equal pull, as simply the opportunity to partake in sport at a facility was being assessed). The performance of Sites in the 2SFCA models indicated some severe usability issues. The amount of processing required to enable access points and perimeters to work with the 2SFCA plug-in was considerable, and the assumptions and generalisations used, questioned the suitability and usability of Sites data in this particular context. This was due to the requirements of the 2SFCA calculations (which required each destination to be represented by one single point), and new tools may be required to make full use of the additional accuracy and precision offered by Sites.

The limitations of choropleth maps were outlined in Chapter 3 and again in Chapter 5, and the same chapters provided details regarding, and explaining, MAUP and the Ecological Fallacy. Those preparing and presenting such maps should be aware of these issues, but decision makers and users of the maps must also be aware. Alternative forms of visualisation should be considered, and one such alternative approach, using cartograms, was illustrated in Chapter 5. With visualisation a developing area of geography and informatics, novel forms of visualisation should be explored to ascertain if they have the potential to inform users and decision makers.

Although analysis of the choropleth maps identified issues similar to those found by Jones (2010) in Birmingham, where the inclusion in a network of footbridges over barriers to travel (rivers, canals and railway lines, for example) were found to have a considerable reduction in pedestrian travel distances to medical facilities. That study used isochrone maps which clearly identified the locations of the footbridges with areas of lower travel times. With hindsight, or if comparing network datasets which include footpaths such as UP or OSM to those without (such as ITN), a similar approach could have specifically identified similar crossing points and their effects on accessibility. The ArcGIS Network Analysis tool 'New Service Area' produces service area polygons which are effectively isochrones when used with constant walking speeds.

7.5.4 GIS framework issues

With the knowledge gained throughout the study, the question had to be asked as to whether types of GIS functionality, other than accessibility using proximity and 2SFCA, would be more appropriate with which to investigate usability. Such different types of GIS functionality involving the same or similar datasets could include spatial overlay analysis, buffer analysis, line-in-polygon analysis or locational optimisation. Other datasets, containing terrain or elevation data, could be used to undertake 3D modelling or line-of-sight analysis. The functionality of modern GIS would enable a wide variety of tasks to be completed. The performance of ArcGIS was not gauged or assessed as part of this thesis, but its algorithms may operate differently to those of other systems. A repetition of some of the work in this thesis, but completed with another GIS (such as QGIS, a FOSS GIS option) would confirm these results or indicate (as suggested by Crosetto and Tarantola, 2001) that the usability and performance of data varies with the GIS and models used to conduct the analysis. However, this research was targeted at accessibility analysis. If considering data usability for a different type of analysis then different methods and functionality would be appropriate.

7.5.5 Overall

Some of the constraints placed upon this thesis were the result of the requirements of the original remit of the sponsoring agency and the agreed approach to the study from the outset. Ordnance Survey provided a variety of its datasets with which to compare usability to other geospatial data both within and outside the organisation. Their sponsorship of this research and the supply of data from them provided an opportunity to test the data using a variety of approaches, some of which (see Literature Review) were relatively mainstream in GIS circles, others novel. Whatever the data used, or specific analysis chosen, the principles outlined here still apply: aspects of usability can be identified or inferred by placing the data under stress, comparing results between datasets, and investigating unusual, outlier, or extreme results. The comparisons show relative performance and the subsequent investigations reveal more detail about issues with the datasets. This approach provides wider lessons that could be applied to other datasets and for GIS tasks other than accessibility modelling.

7.6 Future direction of research

Many questions were raised during the completion of this thesis, not all of which could be addressed here. Some were wider than the scope of this study, and some arose from the assessment of results and outcomes. The suggestions outlined here are both general and specific, some relating to the research and some to the GI that was subject to testing.

7.6.1 Suggestions for dataset-specific future research

As a recommendation specific to OS, it is suggested they investigate how 'blocked-up' side roads are treated. There are many unanswered questions about such features (as detailed in

Section 6.4). Are they surveyed as a specific feature and recorded as such? Are all instances mapped as closed to all traffic? Does OS know when they are blocked? Do councils notify OS when ‘stopping-up’ these roads? In addition, this feature illustrates the difficulty in representing networks for different modes of travel, with cars blocked but cycles and pedestrians permitted to pass.

The ‘no access point’ issue could have been checked in a GIS by conducting a Select by Location exercise using polygons intersected by access points, and matching the number of polygons intersected with the number of features. This relatively simple process could ensure that every functional polygon had at least one access point and could be applied to any new range of polygonal feature added to the OS Sites dataset. It would not, however, identify any further access points that had been omitted from polygons that already had at least one access point mapped. Also mentioned previously was that all or part of this exercise be repeated using another GIS (such as QGIS, but several others are available), to confirm the results here or to quantify differences with other GIS’s used.

7.6.2 Suggestions for further context-specific research

Arising directly out of the research for this thesis and as mentioned previously in this chapter, it would be useful to extend a similar study to this to other areas, to confirm (or otherwise) that results have a wider geographic application. More densely populated urban areas as well as more deeply rural locations should be considered.

With datasets such as OS Sites offering new functionality and higher levels of accuracy, the tools available to utilise such data for accessibility analysis (for example the 2SFCA plug-in used in this study) are unable to make full use of the new datasets, as outlined in Section 3.2. A new tool should be produced, or the current plug-in recoded, in order for full advantage to be taken of the provision of multiple points belonging to one feature, particularly features with multiple access points.

Having shown in this study that using different representations of the same physical features, whether they were travel networks or supply-side destinations, does have an effect on accessibility outcomes, a useful continuation to this study would be to conduct a properly-designed experiment involving several factor changes at a time and applying regression analysis to investigate the interactions between these factors. With so little research having been conducted on what contributes to the usability of data used in GIS applications, and with this thesis as a starting point, casting some light on aspects of this underlying data and assessing the relative effects of the contributing factors may further illuminate the issue. Relating to this point is the opinion that there is little attempt at understanding map user requirements (Meng, 2005). A future study could investigate if this is the case, and if so, why. Is it because it is difficult to investigate? Is it because data producers believe it does not really matter? Or that only those proficient in geography-related skills are the preferred audience for their products? The rapid expansion of all types of GI indicate that users of such information are a wider, more diverse group than ever before, with the plethora of mapping products on a variety of different platforms, and with usability having such emphasis on context, it does seem contrary that users and potential users of GI have not had their requirements ascertained. There seems to be a distinct lack of research examining user preferences into the acceptability, adaptability and usability of these new mapping products and formats. The results may be uncomfortable for mapping professionals as relatively low-quality products come and go, becoming more then less popular in an ever-increasing frequency cycle, yet their popularity implies high usability levels. It could be the case that the pace of change outstrips that of the possible research, rendering research purely (in the colloquial sense) academic. More research into usability issues should be encouraged.

As more knowledge of usability issues is found, a typology of usability could be developed, similar to the typology of errors as shown in Table 6.2, so exploring and expanding on the usability elements used throughout this thesis. The Utility Factor discussed in the Chapter 6 may be a useful first step in this wide field. It was produced using results from the analyses conducted here. Other results from different types of usability study should be used to verify the approach, expand the formula to incorporate different ‘similarity and difference’ results, or take it in a different direction. Development of such a metric would be a useful tool with which to measure and compare usability, where a user may, ultimately, have a methodology with which to decide if a dataset is (or is not) usable in a certain context.

7.6.3 Suggestions for wider geospatial data research

Various errors and issues were identified with the attributes of geospatial features, and one particular observation was the (sometimes) contradictory classification definitions for the same feature represented in different datasets (such as PoI, Sites and ABP). Though the higher level definitions matched (for example primary schools were generally identified as such in all datasets) information below this first level was not necessarily present, complete or accurate, depending (presumably) on the provenance of the information and on the temporal scale used for updates. A consistent dictionary or ontology should be supplied across all datasets. OS is in a good position to set the agenda for such a consistent ontology, not only for its internal products but taking the lead in for all organisations to follow in striving for national consistency. How this is achieved is beyond the remit of this study, but is suggested for future consideration.

The potential of the Web could be further exploited the datasets used for supply-side features, through the use of more links to other data sources. For example, the provenance for each OS PoI feature is given, therefore would a link to the data source within that source be of help to users? As an example from a case study used in this thesis, the WG were the main source for school features, therefore could the point (selected in a GIS or on a map on a phone or computer) lead to that webpage, or to information on the school itself? Linked data is becoming more prevalent, and the Internet of Things is connecting new features and devices. The potential seems to exist into linking information inherent in datasets to the wider web.

The rapid expansion of Web 2.0 indicates a potential resource for many Citizen Science and VGI projects, and making use of the various online communities, or setting one up, is becoming more common, as seen by the explosion of manufacturers, suppliers and retailers with a presence (often an active presence) in social media. Incorporating some form of crowd-sourced or VGI involvement in 'official' map products would be difficult, but Web 2.0 resources may be too important to ignore, particularly with the potential to point out errors, or identifying update requirements in relatively short time scales. This would make an interesting area for further research.

7.7 Final thoughts

One of the final questions relates to one of the first that should be asked when dealing with geographic data: what is the context? It became clear from this research that organisations have developed their own geospatial data holdings with specific purposes in mind. The question has to be asked, therefore, as to what purposes exist for the various datasets featured in this thesis. OS Sites seems to be an example of a dataset waiting for a purpose and sent into the market to see what use is made of it. The use of case studies in the data product web pages of Ordnance Survey point the way to those already engaged with OS products, but whether the potential of new developments are brought to the attention to the relevant groups of users in a timely and effective manner is another matter.

In reflecting on the work and research undertaken for the duration of this thesis, the perspective appears different. Looking back, most of the quantitative, objective results relate to the quality of the data, but it is realised that simply regarding the quality as a proxy for usability would not be sufficient. The relationship between data usability and quality is definitely strong, but usability is still significantly affected by other issues, as outlined in this chapter. Rather than usability being a stand-alone measurable 'thing', it is suggested here that is more akin to an ecosystem, with complex inter-dependencies contributing to the overall whole, with balances which can change depending on context and inputs. The implication is, therefore, that although data usability is made up of many dimensions, which may have to be assessed with a combination of quantitative and qualitative techniques, involving both objective and subjective measures, it may be possible to distil these into a single figure representing usability in a specific context. However, the approach taken in this study, with the sensitivity analysis and subsequent investigations, need not be followed exactly. A form of analysis which acted as a stress test on the data, combined with expert evaluation (using the term from Table 3.1) may be sufficient to highlight any major areas of concern.

Although not the entire answer to usability assessment this thesis makes a contribution to the knowledge on data usability, and provides information on a variety of techniques as well as a useful tool, which can be added to for use with other techniques to assess overall usability. One technique will not address all the elements of usability. A wide approach is required, and the approach taken will depend on the context involved. This thesis outlines methods with which to examine some aspects of the usability of geographic data and of its performance, whilst drawing attention to the areas of research in order to expand knowledge of this subject even further.

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Appendix A - Usability checklist

Dataset:			**Sample data/trial dataset/full dataset**
	Requirement: H/M/L/NA*	Assessment: H/M/L/NA*	Comments
Purpose	H		
Content			
Utility			
Novelty			
Popularity			
Added value			
Cost			
Standard data			
Integration			
Standardisation			
Searchability			
Licence/legal			
Security			
Speed of access			
Caveats on use			
Authority			
Producer reputation			
Trust			
Certification			
Legal defensibility			
Metadata			
Completeness			
Logical consistency			
Accuracy			
Visualisation			
Overall assessment			
Verdict	Usable / Not Usable* for purpose		

*Delete as appropriate.
H = High; M = Medium/Moderate; L = Low; NA = Not Applicable/Not Required.
Enter one into each field, supported by comments.
NB. A High requirement with a Low assessment in any category will normally render the dataset as Not Usable for purpose.

Usability checklist

Dataset: OS ITN			~~Sample data/trial dataset~~/full dataset
	Requirement: H/M/L/NA*	Assessment: H/M/L/NA*	Comments
Purpose	H	H	Accessibility and proximity analysis
Content	H	H	All roads included, options for UP
Utility	H	H	Complex functionality, guidance provided
Novelty	NA	---	Long established
Popularity	L	H	Gold standard
Added value	L	L	Enables completion of research project
Cost	NA	---	Avail from Digimap, free for academic use
Standard data	H	H	No surprises
Integration	H	M	Long conversion times into ArcGIS
Standardisation	M	H	Set classification scheme
Searchability	L	H	Well documented and all items easy to find
Licence/legal	L	H	Free for research use
Security	H	H	High standards. No vandalism found
Speed of access	M	H	Complex dataset. Response times ok for county level analysis
Caveats on use	H	M	No warnings provided
Authority	M	H	Govt mapping agency flagship product
Producer reputation	M	H	Govt mapping agency
Trust	H	H	No issues
Certification	NA	---	Not required for this use
Legal defensibility	NA	---	Not required for this use
Metadata	M	H	Detail provided
Completeness	H	H	Full coverage and all attributes completed
Logical consistency	H	H	No issues
Accuracy	H	H	Flagship product
Visualisation	L	L	Functionality required, not visual
Overall assessment		H	High quality product from highly regarded producer
Verdict	Usable / ~~Not Usable~~* for purpose		

*Delete as appropriate.
H = High; M = Medium/Moderate; L = Low; NA = Not Applicable/Not Required.
Enter one into each field, supported by comments.
NB. A High requirement with a Low assessment in any category will normally render the dataset as Not Usable for purpose.

Usability checklist

Dataset: OSM road network			**Sample ~~data/trial dataset~~/full dataset**
	Requirement: H/M/L/NA*	Assessment: H/M/L/NA*	Comments
Purpose	H	H	To be used for acc'y and proximity analysis
Content	H	H	All roads included
Utility	H	M	Little guidance
Novelty	NA	M	Relatively unknown in this context
Popularity	L	M	Little literature in research
Added value	L	L	Enables completion of research project
Cost	NA	---	FOSS, but time consuming
Standard data	H	H	Commonly used
Integration	H	M	Long conversion times into ArcGIS
Standardisation	M	L	Loose ontology
Searchability	L	L	Not well documented. Items difficult to find.
Licence/legal	L	H	FOSS
Security	H	L	Frequent changes. Possibility of vandalism
Speed of access	M	H	Response times ok for county level analysis
Caveats on use	H	M	No warnings provided
Authority	M	M	Not a govt product, but becoming accepted
Producer reputation	M	M	Brand receives positive press and reports
Trust	H	M	Query over some contributor standards
Certification	NA	---	Not required for this use
Legal defensibility	NA	---	Not required for this use
Metadata	M	M	Some provided (time-slice, etc)
Completeness	H	L	High rate of incomplete attributes
Logical consistency	H	L	Several unconnected links and 'islands'
Accuracy	H	M	Unknown. No set standards or targets
Visualisation	L	L	Functionality required, not visual
Overall assessment		M	Satisfactory basic functionality, but some quality issues at fine scale.
Verdict	Usable / ~~Not Usable~~* for purpose		

*Delete as appropriate.
H = High; M = Medium/Moderate; L = Low; NA = Not Applicable/Not Required.
Enter one into each field, supported by comments.
NB. A High requirement with a Low assessment in any category will normally render the dataset as Not Usable for purpose.

Usability checklist

Dataset: Yell			**Sample data/~~trial dataset/full dataset~~**
	Requirement: H/M/L/NA*	Assessment: H/M/L/NA*	Comments
Purpose	H	M	Supply-side PoI for schools accessibility study
Content	H	M	Overly inclusive
Utility	H	M	No clear guidance on how to obtain data
Novelty	NA	H	Web scraping fairly recent development
Popularity	L	L	Trying out previously neglected source
Added value	L		
Cost	NA	H	Free to obtain, time consuming to do so
Standard data	H	H	Postcode and lat/lon detail available
Integration	H	M	Requires filtering and processing
Standardisation	M	L	Uses organisation’s layout, but lat/lon universal
Searchability	M	M	Front-facing data easy, detail less so.
Licence/legal	L	H	Free for non-commercial use
Security	H	H	Detail from company secure website
Speed of access	M	L	Obtaining data a repetitive, manual process
Caveats on use	H	H	Only warning regarding commercial use
Authority	M	M	Entries paid for.
Producer reputation	M	M	Large commercial concern.
Trust	H	M	Worries commercialism overshadows accuracy
Certification	NA	---	Not required for this purpose
Legal defensibility	NA	---	Not required for this purpose
Metadata	M	L	None whatsoever
Completeness	H	M	All fields filled, but over inclusive classification
Logical consistency	H	H	All entries match location, no duplicates
Accuracy	H	M	Seems accurate to postcode level. Lat/lon reflects postcode rather than feature location
Visualisation	L	L	Point locations required, low visual requirement
Overall assessment		M	Will do if nothing better available, but over inclusivity means considerable double checking
Verdict	Usable / ~~Not Usable~~* for purpose		

*Delete as appropriate.
H = High; M = Medium/Moderate; L = Low; NA = Not Applicable/Not Required.
Enter one into each field, supported by comments.
NB. A High requirement with a Low assessment in any category will normally render the dataset as Not Usable for purpose.

Appendix B - GISRUK14 extended abstract

Data usability from an end-user perspective: assessing contextual quality through geospatial analysis

R. Frew, G. Higgs, M. Langford, J. Harding

This extended abstract was presented at GISRUK14, Glasgow 2014

1. Introduction

The availability of geographical data has increased hugely in recent years, partly due to web-based developments (such as Google Earth) and crowdsourced mapping products (such as OpenStreetMap). Although there has been considerable research in the field of GIS-based usability, the majority of studies to date approach usability from the perspective of software development in areas such as computer interface design and testing, visualisation and cognition, and in aspects of device design (Hunter et al, 2003). Much of the literature on the usability of spatial data has been concerned with conceptual or theoretical frameworks in relation to concepts such as 'fitness for purpose' (Josselin, 2003 and Wachowicz and Hunter, 2003). There has been some recent research concerned with applying usability concepts to real-life applications (e.g. Brown et al, 2012) and with examining the implications of data quality in relation to the application of crowd sourced data (Haklay, 2010). However, very few studies to date have been concerned with evaluating the use and quality of different sources of spatially referenced data in relation to specific GIS-based tasks. With the ongoing trend towards the use of open source GIS, and with the increasing amounts of freely available data through initiatives such as data.gov.uk, there is an urgent need to examine the usability of data sources in different contexts which draw on their application in a range of GIS-based analytical tasks.

This presentation will explore the type of factors that impact on the appropriateness and suitability of spatially referenced datasets in 'typical' GIS-based tasks. In particular the focus here is on their application in accessibility studies (using the example of access to primary schools) as a precursor to developing usability metrics which can be used to gauge the usefulness of spatial data in different contexts.

2. Study Approach and Findings

Three contrasting areas in south Wales were chosen study areas: the city and county of Cardiff; the town of Pontypridd in the South Wales Valleys; and a rural sample area in the Vale of Glamorgan (Figure 1). The study draws on five sources of spatial data which have been used to represent network based presentations in UK-based studies that have focused on accessibility analysis, namely:

Ordnance Survey's OS MasterMap® Integrated Transport Network™ (ITN) Layer and Urban Path layer; OS VectorMap® Local; OS VectorMap® District; and OpenStreetMap (OSM). The ITN products were designed by Ordnance Survey (OS) specifically for use as network products. Standard VectorMap products were obtained and subsequently built into networks for the purpose of this study, using standard Arc network-building tools, with no attempt to amend or quality-check prior to their use in measuring different facets of accessibility. The OSM data for

South Wales was obtained from a third-party provider, Metro Extracts (http://metro.teczno.com/ (accessed 12 November 2013)). The network was built in ArcGIS through a free, open-source add-on for ArcGIS[1].

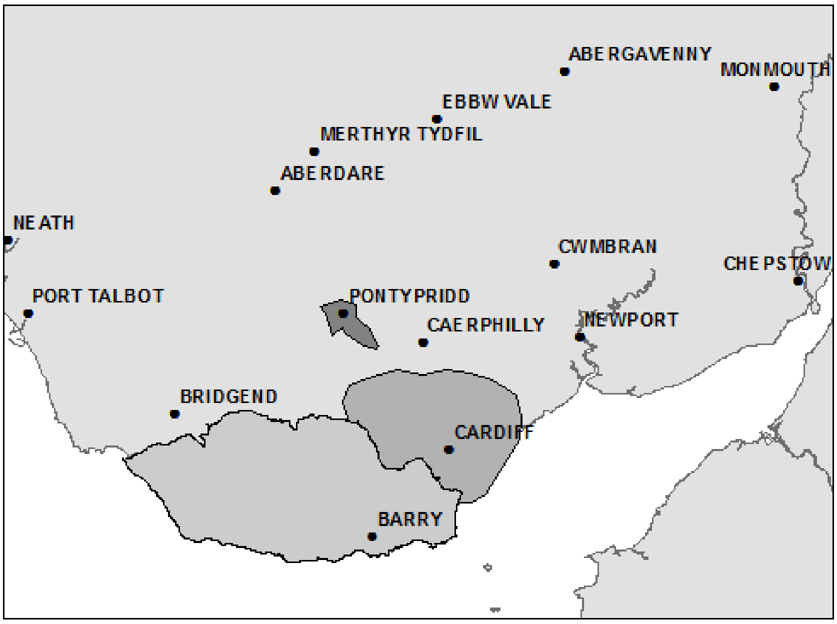

Figure 1. South Wales, showing the three study areas.

For all exercises, 2011 Census Output Area (OA) population-weighted centroids were used to represent the location of population demand in each sample area, and destination locations were taken from Point of Interest (PoI) data, provided by PointX.

Analysis was carried out in Esri ArcMap 10.2 using the Network Analyst extension.

Methods used to measure completeness drew on the work of Haklay (2010) and Zielstra and Zipf (2010). The total network of roads within each sample area was measured, and when assessed against that of ITN with Urban Paths (see Figure 2) was found to differ by up to 34% in Cardiff (VectorMap District returning the lowest figure), 30% in the Vale of Glamorgan (VectorMap District being lowest, by a small margin), and by 27% in Pontypridd (with OSM marginally lower than the VectorMap District figure).

UK Government figures (Dept of Transport, 2012) stated the average trip length to a primary school was 1.8 miles (2.9km) in 2012; and that only 9% of households did not have a primary school within a 15 minute walk. Figures from the Welsh Government suggest that 3 miles (5km) was considered as a reasonable distance for a child to cycle to primary school (Statistics for Wales, 2012). These averages were compared with the situation in Pontypridd, Cardiff, and the Vale of Glamorgan using these different sources of spatial data. Various methods were used to assess travel distance and travel time to the nearest primary schools to examine whether policies promoting walking or cycling for pupils were starting from a disadvantageous position, on the basis that areas with better than average accessibility had a greater opportunity to reduce car use and increase walking and cycling, whereas those with worse than average accessibility may require identification in order to target further initiatives or resources.

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1 http://esriosmeditor.codeplex.com/wikipage?title=Create%20a%20Network%20Dataset%20from%20OSM%20Data

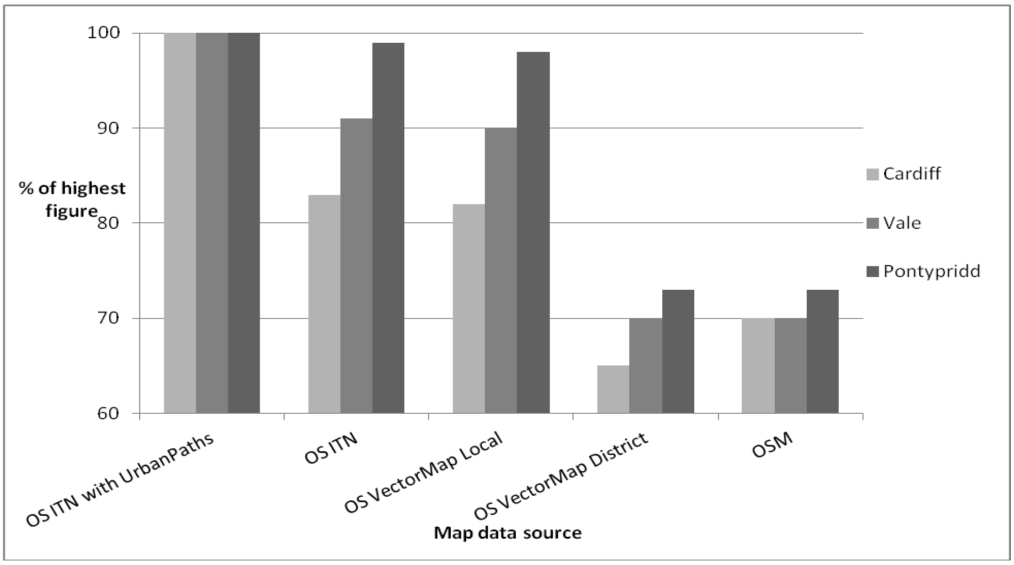

Figure 2. Comparison of total network lengths.

ArcMap Network Analyst OD Cost Matrix maps and Service Area maps were produced for the primary schools within the three study areas. In the absence of school roll data the assumption here is that parents send their children to the nearest primary school, regardless of religious denomination or language (in Wales there are three different state school options: standard, Welsh language, or church).

Figure 3 shows an OD Cost Matrix output for Pontypridd with the shortest walking distance to each destination (the nearest primary school) represented by the black lines from each origin (OA centroid) with the results calculated as network distances or travel times.

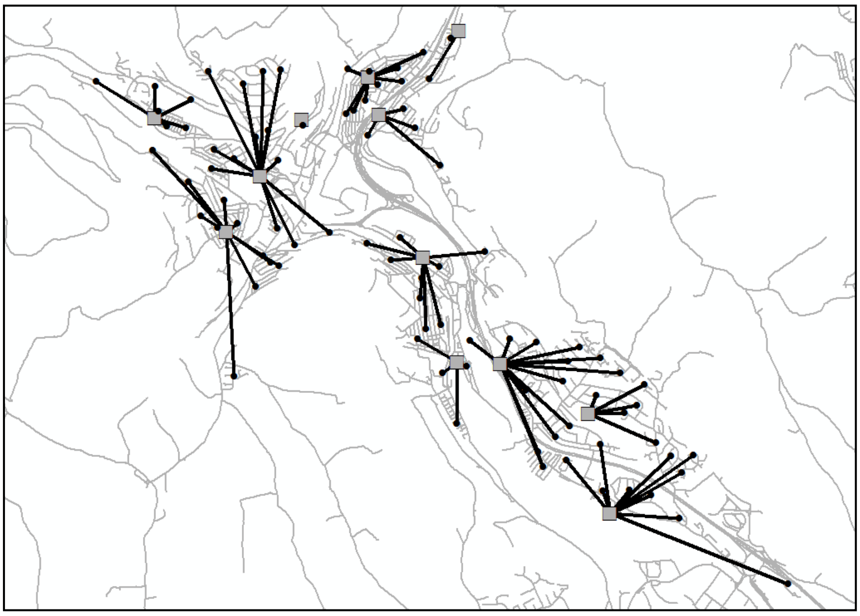

Figure 3. Typical OD Cost Matrix output showing Pontypridd OA centroids (black dots) and their nearest primary schools (grey squares).

The average distance to the nearest primary school ranged from 565m to 690m in Pontypridd (depending on network data set), from 627m to 740m in Cardiff, and from 838m to 970m in the Vale of Glamorgan (against a national average of 2.9km).

Figure 4 illustrates the result for Pontypridd, as an example, showing the mean distance to the nearest primary school for each of the five datasets. The data in each set of results was not normally distributed (following Shapiro-Wilk tests), and the Friedman test indicated there significant differences were present, depending on the map data used. Wilcoxon tests found that ITN with Urban Paths was significantly shorter (at the 1% significance level) than ITN, OSM and VectorMap Local and, at the 5% significance level, shorter than VectorMap District. The difference between VectorMap District and VectorMap Local was also found to be significant at the 1% level, while OSM was found to differ from VectorMap Local at the 5% significance level. The differences between the other possible combinations of these datasets were found to be not statistically significant.

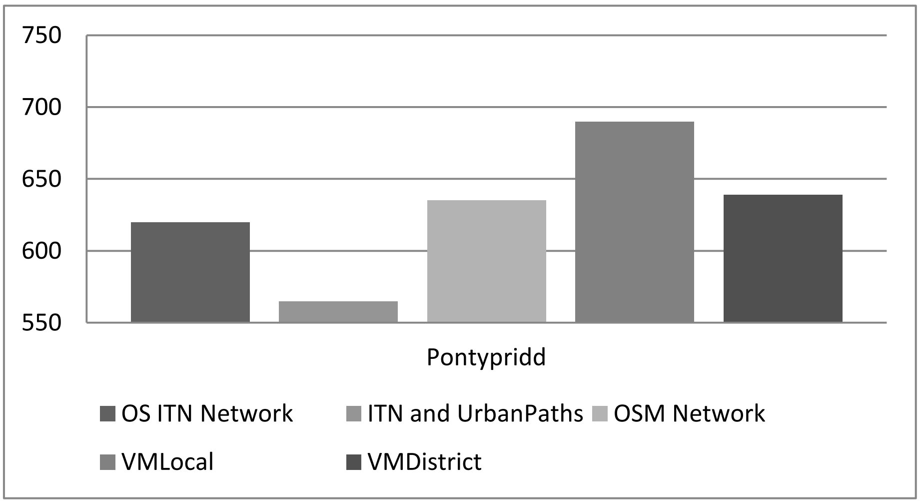

Figure 4. Mean distance (m) from population-weighted OA centroids to primary schools in Pontypridd.

Further statistical tests will be carried out on the equivalent data for urban and rural contexts, using data from Cardiff and the Vale of Glamorgan, respectively.

The choice of network dataset not only influences the magnitude of the journey, but also the feature designated as the ‘nearest’ school (as Figure 5 illustrates). Around 19 to 23% of origins in Pontypridd had alternative choice of designations, depending on the network dataset used. Variations in Cardiff ranged from 15% to 20%, while those in the Vale of Glamorgan varied from 12 to 17% (as shown in Figure 6). A wider disparity may have been expected between the results for urban and rural location, but was not apparent from these results.

Service Areas were produced, using Arc Network Analyst, to calculate walking times to primary schools, once again using census OA population-weighted centroids to represent population. The results for Pontypridd (Figure 7) show a typical output, with the largest polygon representing the 30-minute walking time from primary schools, and including all OA centroids from this study area within its range.

Figure 5. Example from Vale of Glamorgan of different destinations chosen depending on network used (in this case comparing the OD lines produced from ITN and ITN with Urban Paths, overlaid on the ITN network).

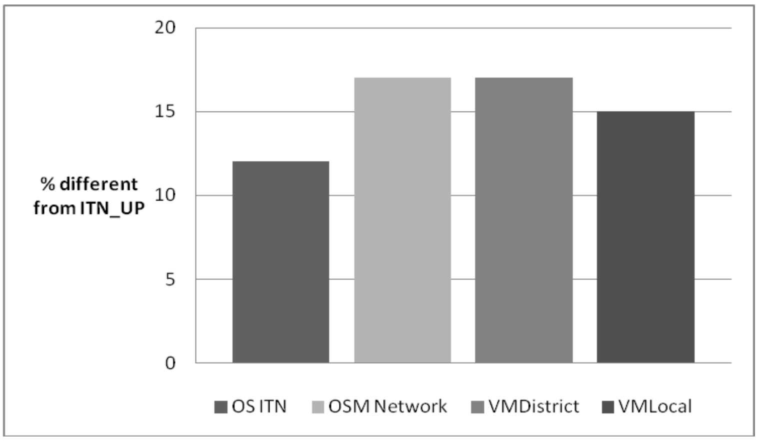

Figure 6. Variation in destination – Vale of Glamorgan. The pattern of results is similar to that of the other study areas.

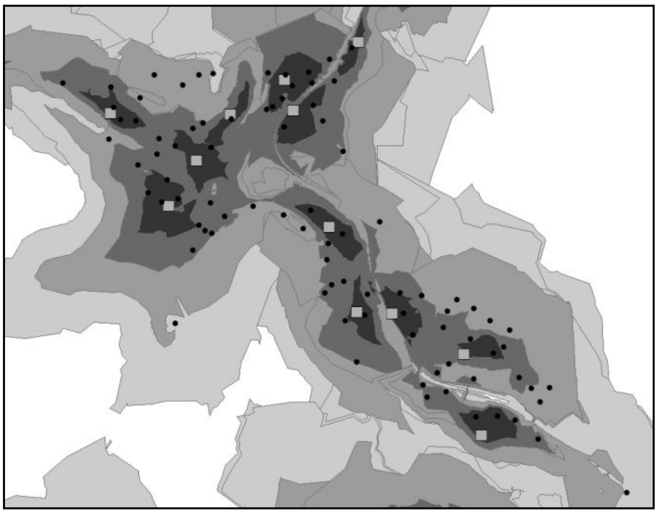

Figure 7. Service Area polygons for Pontypridd, with schools (grey squares) and OAs (black dots), showing walking times, up to 30 minutes, on ITN.

Service Area polygons were used to identify the population within a 15-minute walk of their nearest primary school in each of the three areas being studied. Note that if a constant walking time is assumed, then walking time can equate to distance, providing topographical factors (grade, etc) and mobility factors (age, disability, etc) are ignored. Figure 8 shows the results.

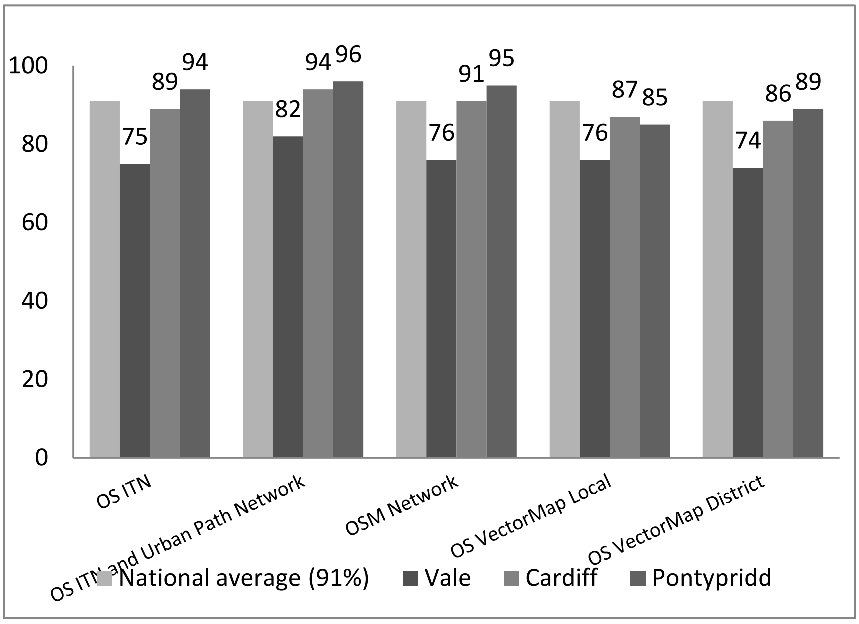

Figure 8. Percentage of population in the study areas within a 15-minute walk of their nearest primary school, compared to the national average.

When walking times are compared, the similarities are striking, though there are differences, an example of which is shown in Figure 9. Note that the OSM data is hidden by the ITN_UP line.

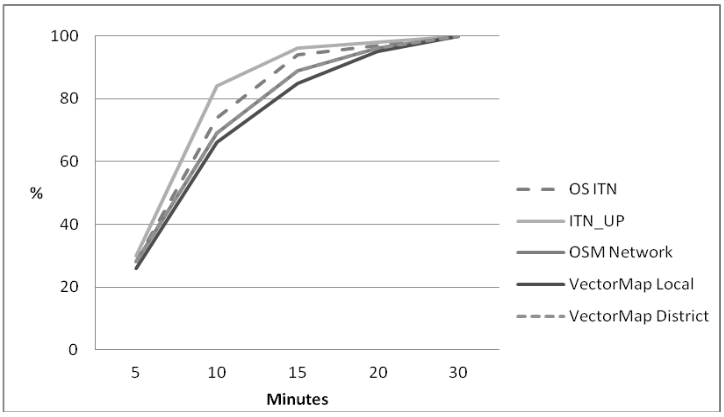

Figure 9. Walking times to nearest primary school – Pontypridd.

3. Discussion

The use of alternative network data sets demonstrate considerable differences in findings from the GIS-based accessibility conducted to date, which will be expanded on in the presentation and which will impact on the usability of these data sets. The aim here has been to apply these datasets in three different geographical settings, and these differences will be explored in the presentation. The two OS VectorMap products (one currently open, one available for purchase), produce similar results to OSM despite not being specifically designed for network analysis.

This, similarly, applies to OSM, though networking for travel directions and full network ability seems to be seen as one of its aims OpenStreetMap, 2014).

Both Haklay (2010) and Zielstra and Zipf (2010) noted how OpenStreetMap coverage drops in terms of quality and quantity outside major urban areas (such as the 'big 5' cities of the UK, or around the larger cities of Germany), with many other areas simply "not covered very well," (Haklay, 2010, Section 4.3). With Cardiff being the largest city in Wales it may have been thought that coverage would be higher than the 70% calculated here. Haklay found OSM's road length was 69% of OS Meridian. As Meridian is a generalised data set, perhaps OSM having 70% of the more detailed network of ITN with Urban Path shows a relatively high coverage, though research into OSM progress over the UK is lacking. Further, more detailed, findings will be presented during the course of the presentation including a statistical comparison of variations for the three study areas.

4. Future work

This study forms part of an Ordnance Survey-sponsored PhD research project which is examining the factors that impact on the appropriateness and suitability of various spatially referenced data for a range of typical GIS-based tasks. A comparison of spatial datasets is provided for a range of Ordnance Survey data products plus some broadly-equivalent third party datasets (including a crowd-sourced dataset). Processes involve a range of typical spatial-analytical operations such as the computation of straight-line and network distances, the evaluation of spatial intersection and containment and adjacency between features. These processes are applied at a variety of spatial scales from amongst the input datasets, and stored in various elemental object types (points, lines, polygons, grids, etc.) to enable contrasts and comparisons to be made. To date the project has compared the use of these spatial data sets in accessibility-based analysis using a range of supply-side features in various geographic contexts.

In future work, features and analytical methods will be chosen in order to compare the 'performance' of different databases in a variety of GIS-based tasks. In addition, different representations of population will also be assessed, with the computational load of OA centroids being considered against less detailed representations (such as Lower or Super OAs). On the other hand, the advantages of using more locally-precise representations will also be considered against the disadvantage of greater processing times.

Comparison of the data when used with commercial GIS such as ArcGIS, with open source GIS such as QGIS, could also produce interesting results, perhaps indicating the usefulness of data depends not only on what is done with it in which context, but also on the tools used to analyse them.

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6. Acknowledgements

The study reported here forms part of an Ordnance Survey-sponsored PhD research programme. However, any views expressed herein do not necessarily represent those of Ordnance Survey.

Appendix C - Ordnance Survey Research Workshop poster presentation, March 2015

Ordnance Survey

Geographic accessibility

and the usability of data

Part of a project examining data usability from an end-user perspective

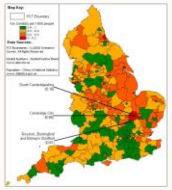
University of South Wales
Prifysgol De Cymru

This study looked at the usability of a range of geographical data when applied to network-based accessibility modelling. By conducting sensitivity analysis on a range of demand-side representations, supply-side features, network datasets and GIS processes (see below), assessments will be made on their usefulness in such tasks, using both basic and more sophisticated methods of measuring accessibility.

How should potential accessibility be measured?

Coverage?

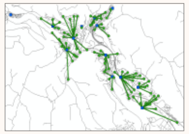
Eg. Population per GP; schools per 1000 of population.
Good for large areas (county, city, etc)
Blunt – no detail
MAUP and Ecological Fallacy issues
Cannot identify areas of good / poor accessibility within the larger area
Data readily available
Data generally free or cheap



Boulos and Phillipps (2004)

Distance / travel times?

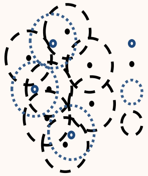
Eg. Average distance to nearest;
Maximum walk time to nearest; facilities within 10-minute walk, etc.
Good for smaller areas.
Can drill down to (and beyond) neighbourhood scales.
BUT
What distance measure to use?
Euclidean? Network?
What network to use?
Car? Pedestrian? Cycle?
Euclidean distance ignores obstructions.
Network data can be expensive and requires GIS skills



Euclidean distance from census OAs to primary schools in Pontypridd

Gravity models?

Methods such as the Two-Step Floating Catchment Area model (2SFCA) utilises levels of supply and demand within user-set catchments..
Level of detail constrained only by computational load.
BUT
Still requires choice of network
Data requires considerable pre-calculation preparation.



Demand (population data)

Represented by 2011 UK census population-weighted centroids, and by OS Code-Point postcode points, with population allocated.

Network (map data)

As well as Euclidean distance measurements, network distances were calculated using OS ITN, ITN with Urban Paths, OpenStreetMap and a network created from OS VectorMap District OpenData.

Supply (feature of interest)

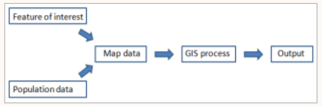
Represented by OS Point of Interest data, OS Sites layer and Address Base Premium.
Sites data can utilise access points (as supplied), centroid and perimeter data (as derived from Sites data).

GIS process

Calculate geographic accessibility to a variety of features in South Wales, using distance and 2SFCA gravity models.

Sensitivity analysis

As per the diagram below, change one factor at a time and see how output is affected.



Analysis of output

Statistical analysis
Similarity and differences in distances to nearest facility from each population location, and in 2SFCA scores.
Similarity: Spearman's Rank Correlation
Difference: Friedman test and Wilcoxon (paired difference) signed-rank test

Graphical analysis
Quintile maps (using Census OA polygons), highlighting the "worst" areas, in terms of distance to nearest facility, and in 2SFCA scores (see maps on right).

Key data usability issues

The usability of data will be influenced by these factors:

What exactly is being measured? What is the scale?
What is the context of the study? Is cost a factor?
What are the skill levels of the users?
Are the levels of accuracy and precision appropriate?
Is the cost of data appropriate to the value of results?
What are the knowledge levels of the audience?

Initial findings

Supply

Alternative third-party data (eg Google maps, Yell) were poor in terms of selection and classification criteria, and were particularly overly inclusive.

The high-precision and detail offered by Sites was not matched by compatibility with common FCA tools.

The Sites data was not always complete (eg in terms of every location having access points).

Demand

More detailed population representations were more geographically accurate, but challenging in terms of visualisation, presentation and interpretation.

Less aggregation meant less error due to MAUP, etc, but resulted in a high computational load and more issues with visualisation.

Network

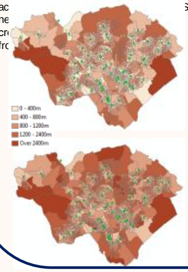
In most cases the choice of network made insignificant differences to the ac ne cr fr

Where differences were found (and when geography is discounted, eg motorways, rivers and other barriers), most variation in accessibility results can be ascribed to differences in the networks.

Note
All distance and 2SFCA results were significantly correlated (but Spearman is a "blunt" statistical tool).

When differences were tested (using Wilcoxon), some were identified, but no consistency or patterns were apparent.

Example maps



The maps show distances from OA centroids to GP surgeries in Cardiff, measured using Euclidean distance (top) and network distance using a network built from OS VectorMap District data (bottom).

Network distances generally look similar to Euclidean distances and were highly correlated. Some, however, had significant differences both to Euclidean distances and to other network distances.

Quintile maps of 2SFCA results were much more varied, exhibiting different patterns to that of distance results, showing the influence on accessibility of supply and demand levels.

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Poster created for Ordnance Survey PhD Workshop, March 2015

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Appendix D - GISRUK15 extended abstract

Assessing geographic data usability in analytical contexts: Undertaking sensitivity analysis of geospatial processes

R. Frew[1], G. Higgs[1], M. Langford[1], J. Harding[2]

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April 6, 2015

This extended abstract was presented at GISRUK15, Leeds 2015

Summary

This paper addresses the comparative dearth of research on spatial data usability by employing sensitivity analyses to the findings from applying GIS-based accessibility models. Comparisons were made using approaches based on Euclidean distances and more sophisticated accessibility measures that utilise network travel distances: the latter incorporating measures of supply and demand by using innovative extensions to the Two-Step Floating Catchment Area method (2SFCA). To illustrate the sensitivity of findings from applying such models with a range of data sources, geographic accessibility to secondary schools was calculated for Output Areas in South Wales using a 2SFCA plug-in to ArcGIS™. By using different permutations of spatial data, for both the supply- and demand-side parameters in such models, differences in walking distances and FCA scores were sought in order to comment on the usability of such data sources. Preliminary conclusions are made on the appropriateness of such data sets in relation to different types of network-based accessibility modelling tasks.

KEYWORDS: Usability; GIS-based accessibility models; spatial data; sensitivity analysis; E2SFCA.

1. Introduction

Sources of spatial data continue to expand with inevitable debates surrounding the provenance of such data and their usability for GIS-based tasks. There is therefore an increased scrutiny as to the quality and usability of such data and the respective advantages and limitations of both proprietary and crowd-sourced data.

Although the highest quality data often remains expensive to obtain for some users (for example high resolution LiDAR data, or Ordnance Survey MasterMap products), other data sets are becoming available without the need for expensive capital or revenue outlay. Recent reports (for example, Avery and Gittings, 2014) on the use of unmanned aerial vehicles to produce a variety of remotely-sensed data as well as the availability of various software solutions, both at low costs relative to traditionally-sourced equivalents are enabling new data-producers to emerge. Such trends are paralleled by the opportunity for data users to generate their own data for their own purposes. At the same time the quality of such data is being questioned in some quarters, reinforcing earlier debates surrounding the use of VGI (volunteer geographic information) and previous work in the field of data quality theory and assessment (Haklay, 2010; Zielstra and Zipf, 2010). However, there is still very little research into the usability of such data in relation to different types of GIS-based tasks, although Higgs et al (2012) did investigate the impacts of different approaches to measuring accessibility to green space using comparable sources of data. Few studies to date incorporate sensitivity analysis that involve the use of different sources of spatial data applied to different stages of a 'typical' GIS project (although see Jones (2010) for a notable exception).

This paper will report on the usability of a range of geographical data in one such application area: namely their use in network-based accessibility modelling. Based on these findings preliminary assessments will be made on their usefulness in such tasks, using both relatively routine and more sophisticated methods of measuring accessibility.

Accessibility studies using GIS have become a well-established component of geographical studies concerned with measuring potential inequalities in provision of both public and private services and are beginning to be used by policy makers to inform decision making processes. Related fields include studies of the spatial distribution and optimisation of services in areas such as public health, welfare provision and environmental justice. Recent examples of such research include those concerned with examining the geographical distribution of alcohol outlets in Glasgow in relation to deprivation (Ellaway et al, 2010) and disparities in locations of sports facilities in Wales (Higgs et al, 2015).

2. Study approach

2.1 Study area

Two areas in South Wales were chosen for study: the city and county of Cardiff; and the neighbouring Vale of Glamorgan County. Cardiff is the largest city in Wales, although within its county boundary are villages located in the green belt that separates Cardiff from Newport (to the east) and the densely-populated Rhondda valleys to the north. The Vale of Glamorgan has several smaller population centres, with much of the area having rural characteristics despite proximity to major transport links (the M4 motorway) and to large towns and cities (such as Bridgend and Cardiff).

2.2 Geographic data

The spatial data products chosen were typical of those commonly used in UK-based accessibility analysis studies, including Ordnance Survey MasterMap Integrated Transport Network™ (ITN) Layer and the additional Ordnance Survey Urban Path layer. OpenStreetMap (OSM) network data for South Wales was obtained from a third-party provider, as an example of the crowdsourced/VGI data that is now routinely available to GIS researchers. One further dataset was used to examine whether a product not designed for use as a network could approximate the results of the specifically-designed datasets. VectorMap District, available free-to-use from Ordnance Survey OpenData, was built into a network using standard, readily-available GIS tools (using Arc GIS). At the time there was no free-to-use network dataset using

Ordnance Survey data, though in March 2015 Ordnance Survey launched the Open Road network dataset, also under their OpenData programme, and this will be subject to later analysis.
The accessibility assessment tasks were also conducted using Euclidean (straight line) distances.

The relative accessibility of different locations within the study areas were assessed using different methods, with the processes subjected to sensitivity analysis in order to identify areas of similarity and difference. Several iterations of each analytical task were therefore performed, using permutations of the different datasets.

2.3 Location of supply features

Accessibility studies use various methods to assess the accessibility (or inaccessibility) of demand to supply. In this study, the supply features were secondary schools (with travel-to-school journeys being the focus of many studies relating to active travel and children's health, child road safety, catchment areas, parental choice, etc). The location of such facilities is also subject to a degree of choice by the researcher. Accordingly, as part of the sensitivity analysis, different methods of locating these features were compared. Many studies use points to represent locations, and as secondary schools often occupy large sites, they are ideal for use in comparing different methods of representing polygons by points. The Ordnance Survey Points of Interest dataset was used as the initial point locations of the schools, and Ordnance Survey Sites dataset was used to extract the "footprint" of entire school sites, including playing fields, etc. From the Sites dataset, three different location methods were compared: centroid (the geometric centroid of the entire site); access point (one or more way in to the school site for pedestrians); and boundary (any point on the perimeter of the site). Figure 1 illustrates how this choice may impact on travel distances, using a typical school site as an example, and Figure 2 shows how network distances may vary using the same variety of location methods.

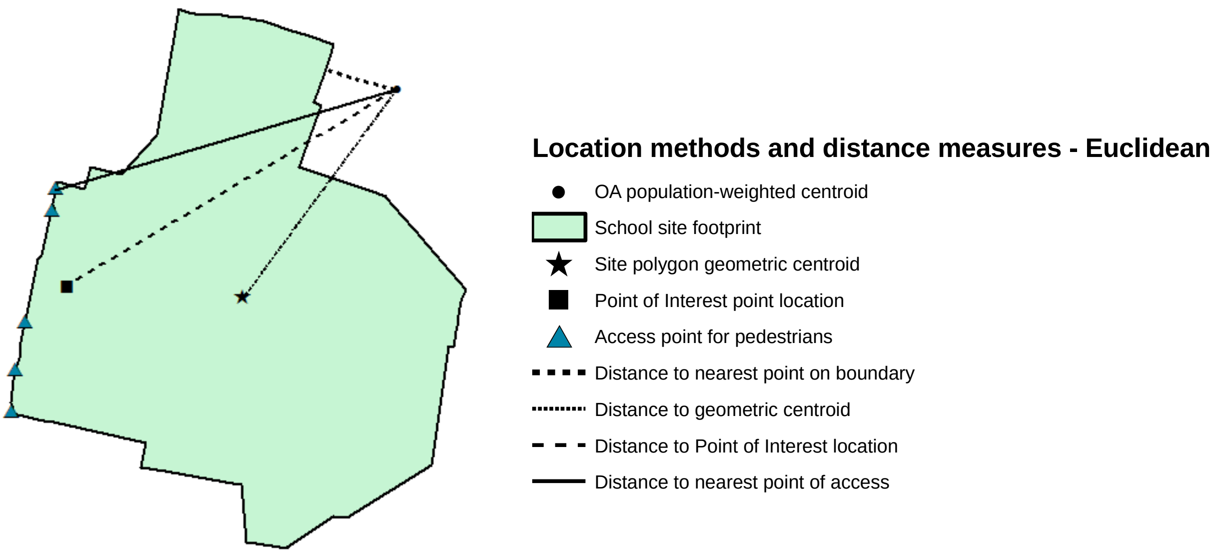


Figure 1 Four different approaches to measuring Euclidean distance from a location to a facility.

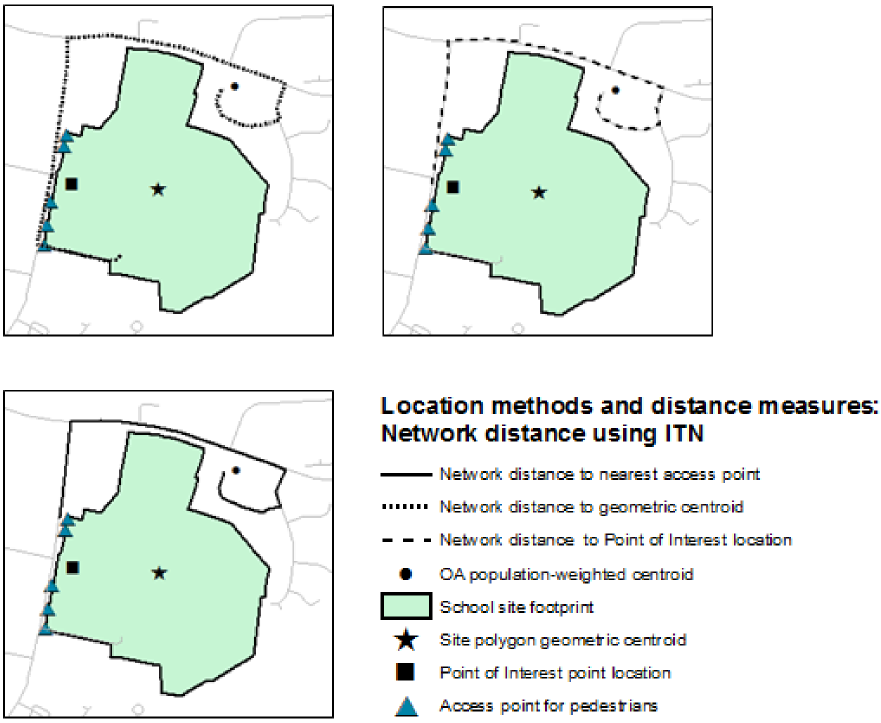


Figure 2 Examples of network distance variations, from a point location to a local facility.

2.4 Location of demand

Various demand (population) representations are available to researchers. In this study, the method of locating the population included the use of 2011 UK Census Output Area (OA) population-weighted centroids. Other methods are available, both more detailed (at post code or address level, for example) or more generalised (for example, either of the census Super Output Area layers, both of which are aggregations of OAs). The method chosen uses readily-available and free-to-use data that is sufficiently detailed to allow differences to be identified between smaller areas while avoiding the increased computational loads and visualisation challenges resulting from the use of more detailed representations.

2.5 Methodology

This study calculated Euclidean and network distances with different permutations surrounding supply-side options. Comparisons were then made between the results of the various iterations of the accessibility models, both visually and statistically. One indication of similarity was achieved through comparison of Destination Overlap, where the identities of the supply facility nearest to each demand centre was compared for each network option (see Table 1).

Euclidean distance ignores the actual travel route taken, and as with network distances takes no account of the capacity of the supply facility (in this case the number of school places available), nor the level of demand (in this case the secondary school-age population). Accordingly, a more sophisticated measure of accessibility was used based on the enhanced two-step floating catchment area method (E2SFCA). A tool developed by researchers at the University of South Wales was used in ArcGIS^{TM} (Figure 3 shows the user interface of the plug-in). In order for the tool to be used effectively, data on pupil numbers/school roll was obtained from information published by the relevant local authority, and an estimate of the school-age population of each OA made from age categories contained in published 2011 census data. Although there was no convenient category of "secondary school age" in the census, there was information on 12 to 16 year olds, and an estimate was made of the numbers of students at school outside these age categories.

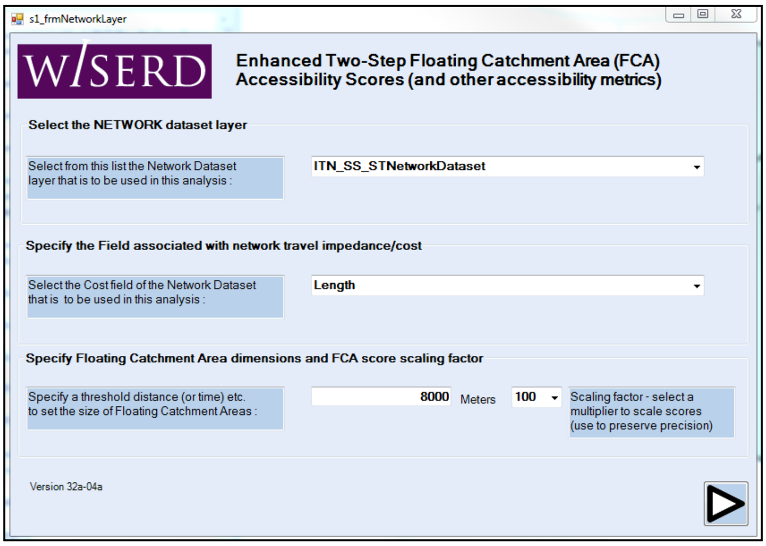
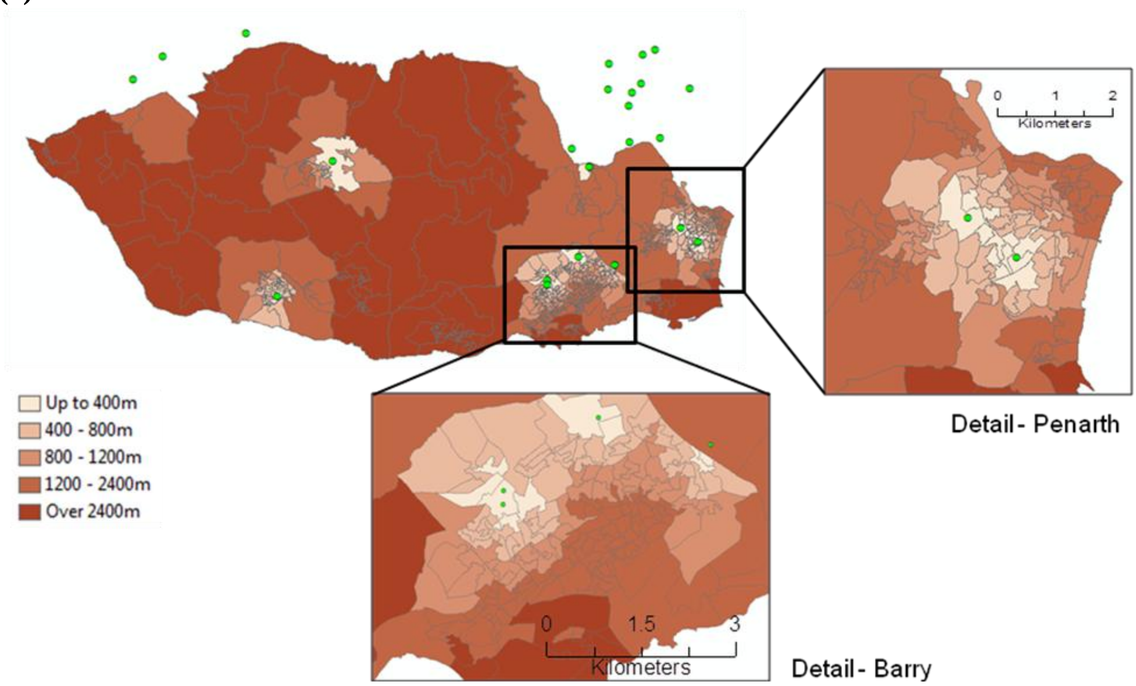


Figure 3 Illustration of the E2SFCA plug-in tool first screen. Further screens offer the options of incorporating levels of supply and demand.

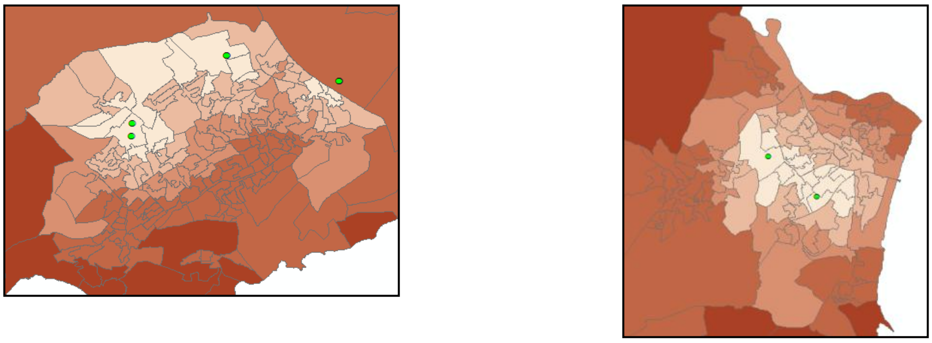
3. Preliminary Findings

Patterns of "worst" and "best" accessibility were broadly similar, but with differences stemming from the method of locating the supply feature (as in Figure 4) and the choice of network dataset.

(a)



(b)



(c)

Figure 4 Examples of variations in distances from OAs to their nearest facility, depending on the method used to locate that facility (in this case, secondary schools in the Vale of Glamorgan).

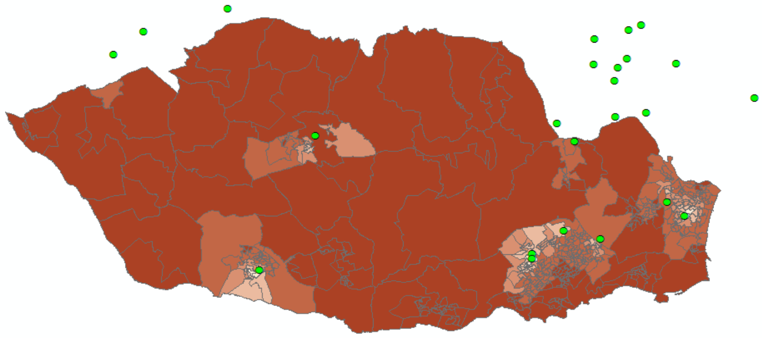
(a) OS Sites dataset, OA to polygon centroid, Euclidean distance;
(b) OS Sites dataset, OA to nearest access point, Euclidean distance;
(c) OS Sites dataset, OA to nearest point on site boundary, Euclidean distance.

Differences in findings when applying alternative methods of measurement (i.e. between distance measures and the results of E2SFCA calculations, examples of which are shown in Figure 5) were evident, highlighting the impacts of using different approaches on the results from GIS-based models. Figure 5(b) illustrates the effect of supply and demand on accessibility, and the influence of the size of catchment area used in E2SFCA calculations. Preliminary findings also indicate urban/rural differences which also merit further investigation, an example of such differences is shown in the Distance Overlap figures of Table 1.

In contrast, other findings suggest that the use of different datasets or different network products may make no statistical difference to outcomes either in terms of distance or E2SFCA scores. All distance results and all E2SFCA results were significantly correlated (using Spearman's rank correlation) and Table 2 shows Wilcoxon Z scores for E2SFCA results from the Vale. Several paired comparisons (18%) have no significant differences between their scores at the 5% level, though the majority of comparisons (76%) have differences that are significant at the < .001 level.

(a) Distance measures for OAs to school centroids, ITN network.

In rural areas such as the Vale, with relatively few facilities, a large number of OAs (150 out of 412) are in the "worst" distance category.



(b) 2SFCA for OAs to school centroids, ITN network.

Direct comparison with Distance measures are difficult, due to the different scales used. Results here use rounded quintile splits, with lowest E2SFCA score equating to "worst" accessibility.

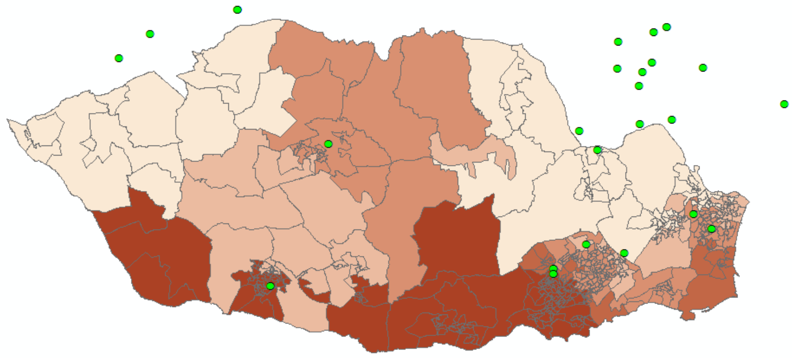


Figure 5 Example of differences in accessibility visualisations obtained when using ITN, comparing distance and E2SFCA measures: (a) Distance; (b) E2SFCA.

As part of this PhD research, further analysis of the results will be conducted with the intention of isolating the factors within the underlying data that contributed to the differences in accessibility scores within the same output areas. However, the extent of differences identified in this preliminary analysis leads us to suggest that researchers need to be made more aware of the implications of using different sources of data in 'typical' GIS tasks.

Practical issues with different datasets (for example cost, ease of download, availability, etc) along with their currency and update patterns, are also worthy of further study. Identifying methods whereby the usability of these spatial data sources can be made more transparent to researchers prior to their implementation in GIS analytical tasks is one of the ultimate aims of this research.

	Euclidean			ITN			UP			OSM			VMD		
	Cent	AccPt	Per	Cent	AccPt	Per	Cent	AccPt	Per	Cent	AccPt	Per	Cent	AccPt	Per
Euclid															
Cents		*87.6*	*96.6*	*83.3*	*84.5*	*93.2*	*86.4*	*89.6*	*94.7*	*81.6*	*78.6*	*78.4*	*83.5*	*81.1*	*80.8*
AccPts	86.9		*86.2*	*80.8*	*87.9*	*83.0*	*84.0*	*92.0*	*83.0*	*85.7*	*89.3*	*85.0*	*85.9*	*89.3*	*84.0*
Perim	84.9	92.7		*80.6*	*83.3*	*92.7*	*83.7*	*87.4*	*93.2*	*93.5*	*82.8*	*92.2*	*92.7*	*82.5*	*92.7*
ITN															
Cents	82.0	76.6	74.8		*84.0*	*84.0*	*94.9*	*87.9*	*84.0*	*93.5*	*81.1*	*80.6*	*99.5*	*84.5*	*84.0*
AccPts	76.5	81.2	76.0	92.9		*87.4*	*87.4*	*93.2*	*86.6*	*84.0*	*97.6*	*87.6*	*83.5*	*95.1*	*87.4*
Perim	72.8	73.0	75.5	92.5	88.2		*86.9*	*87.9*	*97.1*	*83.3*	*86.7*	*96.4*	*82.5*	*86.4*	*98.1*
UP															
Cents	89.2	87.7	87.5	90.0	85.7	83.2		*90.3*	*87.9*	*90.0*	*82.8*	*80.6*	*94.9*	*87.4*	*84.0*
AccPts	88.6	87.9	88.0	89.3	89.1	85.5	93.7		*89.1*	*87.1*	*93.7*	*86.7*	*86.9*	*92.7*	*87.1*
Perim	89.0	86.5	90.2	89.0	86.4	85.1	91.6	93.2		*85.0*	*86.4*	*94.4*	*85.4*	*85.9*	*95.6*
OSM															
Cents	71.1	80.3	80.1	88.8	85.0	84.8	84.2	84.0	84.8		*80.8*	*80.7*	*93.7*	*84.2*	*83.5*
AccPts	81.1	76.2	74.5	90.1	96.9	85.7	81.5	84.9	82.2	74.9		*87.4*	*83.5*	*95.1*	*85.2*
Perim	74.9	79.6	81.3	82.0	80.7	80.6	75.7	74.7	77.2	82.0	80.9		*81.1*	*86.7*	*94.9*
VMD															
Cents	57.0	62.7	61.8	71.4	68.7	65.6	64.9	64.3	66.3	66.8	60.3	60.4		*84.0*	*83.0*
AccPts	55.7	64.0	63.0	70.4	71.3	67.3	66.9	68.4	66.6	66.7	58.8	61.7	78.7		*89.3*
Perim	59.1	65.9	67.5	71.3	67.6	66.5	68.4	68.5	70.1	66.9	57.1	69.8	67.7	72.1	

Table 1 Destination overlap (using distances), comparing Cardiff and Vale Secondary Schools. Out of 105 comparisons, Vale had higher figures in 86 (82%). The 19 comparisons in which Cardiff figures were higher are highlighted for ease of identification.

Below diagonal - Overlap (%) for Cardiff schools. Above diagonal - Overlap (%) for Vale schools.

	Euclidean			ITN			UP			OSM			VMD		
	Cents	AccPt	Perim	Cents	AccPt	Perim	Cents	AccPt	Perim	Cents	AccPt	Perim	Cents	AccPt	Perim
Euclid															
Cents		*.148*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*
AccPts	-1.445		*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*
Perim	-13.084	-12.683		*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*
ITN															
Cents	-13.358	-13.342	-11.001		*.874*	*<.001*	*<.001*	*.020*	*<.001*	*.452*	*.167*	*<.001*	*.266*	*.189*	*<.001*
AccPts	-13.331	-13.292	-10.872	-.159		*<.001*	*.154*	*<.001*	*<.001*	*.041*	*.974*	*<.001*	*.122*	*.522*	*<.001*
Perim	-15.158	-15.140	-14.682	-9.272	-7.610		*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*.935*	*<.001*	*<.001*	*<.001*
UP															
Cents	-13.564	-13.529	-11.134	-4.202	-1.426	-8.613		*.009*	*<.001*	*.070*	*.138*	*<.001*	*<.001*	*<.001*	*<.001*
AccPts	-13.189	-13.130	-11.082	-2.333	-3.615	-9.355	-2.611		*<.001*	*.003*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*
Perim	-15.083	-15.063	-14.656	-8.004	-7.659	-3.871	-10.661	-12.052		*<.001*	*<.001*	*.581*	*<.001*	*<.001*	*.491*
OSM															
Cents	-13.131	-13.083	-11.097	-.752	-2.046	-8.272	-1.814	-2.955	-6.980		*.027*	*<.001*	*.945*	*.573*	*<.001*
AccPts	-13.252	-13.207	-11.040	-1.383	-.033	-8.786	-1.481	-.050	-7.871	-2.213		*<.001*	*.785*	*.002*	*<.001*
Perim	-15.126	-15.111	-14.690	-10.387	-9.698	-.082	-10.225	-11.140	-.551	-12.051	-11.169		*<.001*	*<.001*	*.089*
VMD															
Cents	-14.803	-14.762	-13.962	-1.113	-1.546	-7.766	-4.907	-5.197	-6.264	-.069	-.273	-8.590		*<.001*	*<.001*
AccPts	-14.731	-14.712	-14.083	-1.312	-.595	-8.108	-4.115	-4.158	-7.266	-.564	-3.100	-9.338	-5.138		*<.001*
Perim	-15.547	-15.529	-15.318	-10.528	-9.935	-8.111	-10.312	-10.995	-.689	-8.956	-10.796	-1.702	-6.486	-7.448	

Table 2 Differences in E2SFCA scores between networks and location method for Vale Secondary Schools. Wilcoxon Z scores are shown below diagonal, statistical significance above diagonal (black = sig at <.001 level; green = sig at .01 level; amber = sig at .05 level; red = not significant at .05 level).

4. Acknowledgements

The study reported here forms part of an Ordnance Survey-sponsored PhD research programme. The plug-in to ArcGIS™ was developed during Phase 1 of the WISERD project funded by the ESRC and HEFCW (ESRC Grant Reference: RES-576-25-0021). However any views expressed herein do not necessarily represent those of these organisations.

Appendix E - AGILE workshop paper

Assessing geographic data usability in analytical contexts by using sensitivity analyses of geospatial processes

Robin Frew
University of South Wales

This paper was presented at the AGILE 2015 PhD Workshop, Paris 2015

The number and variety of sources of spatial data continues to expand, as do the debates regarding the quality and usability of such data, particularly those which are Free and Open Source (FOS) or free-to-use. The highest quality data is often expensive to obtain and the option of cost-free data sets is tempting for many users.

With the existence of the huge hinterland of data *quality* research acknowledged, and a great number of studies investigating the usability of devices and interfaces, little attention has been paid to the *usability* of data, and even less into the usability of geographical data in typical GIS research situations. There has been some research into the use of volunteered geographic information (VGI) in the field of data quality theory and assessment (see for example Haklay, 2010; Zielstra and Zipf, 2010), but relatively few studies have incorporated sensitivity analysis involving the application of different sources of spatial data to a range of GIS tasks. Jones's (2010) study into the use of open data in presenting and visualising public health information is one notable exception, with another being that of Higgs et al's (2012) examination of the impact of alternative approaches to measuring accessibility to green space.

This study set out to address cross-cutting themes that are topical in GIS and geographical analysis given trends towards the use of open source data, namely:

- Do different methods of representing real-world features have an effect on the findings from GIS analyses?
- To what extent does choice of data sources affect network analysis?
- In considering network accessibility, are results affected by the representation of supply and demand considerations?

There is little evidence to date on which to quantify the effects of these issues on final results. This research is intended to take a step in redressing gaps that exist in the knowledge, understanding and perception of such data.

This study argues that even the best quality data may not be appropriate in certain contexts. To highlight the type of scenarios where this may indeed be the case several commercial and free-to-use data sources were used in sensitivity analyses of the application of well-established GIS network analysis tasks. The aim is to assess whether findings vary according to the application of alternate data sets used to represent the same features within such models.

The research took the form of various case studies, all tied around a similar theme, that of accessibility. Some of the studies assessed accessibility to features that have been the subject of much research in the past (such as GP surgeries), while some looked at less commonly assessed features (such as primary schools, secondary schools and sports facilities). All were linked by an interest in various health and fitness initiatives and investigations that have taken place in South Wales (UK), such as those looking at active travel to schools, equitable access to health care and reasonable geographical access to sport and leisure facilities.

The part of the study relating to accessibility to primary schools will be used as an example.

The supply feature (primary schools) were represented in four different ways by the two datasets examined: a Point of Interest[2] point (nominally the centroid of the main school building); the pedestrian access points of each school; the geometric centroid of the entire school site (including play areas, sports fields and car parks); and the site perimeter. The Ordnance Survey Sites dataset[3], by providing the footprint of each school as well as the access points, offered more detail and precision to measurements of access, raising another interesting question as to whether any increase in precision automatically resulted in an increased accuracy of results.

The places of origin for journeys to the schools were kept constant, and were UK census Output Area population-weighted centroids (the smallest unit of published UK census data).

Distances from each population centroid were measured to the nearest school, looking at each representation in turn, using the various network datasets. The network datasets included commercial data (Ordnance Survey ITN and ITN with Urban Paths[4]), free-to-use data (Ordnance Survey OpenRoads[5]) and FOS data (OpenStreetMap[6]). Sensitivity analysis was conducted through repetitions of the distance calculations, ensuring every combination of network (plus Euclidean measurement) was used for every feature representation. The process was then repeated in its entirety using a Two-Step Floating Catchment Area (2SFCA) measurement. As described by Luo and Wang (2003), 2SFCA incorporates levels of supply and demand by calculating population-to-provider ratios for each supply centre within a defined threshold distance, then identifying all those supply centres within the same threshold distance of each demand centre, and summing all their ratios for each population. Supply was represented by the student capacity of each school (the school 'roll', from figures published by the local authority). Demand was represented by the number of primary school-age children in each census area (as extracted from published 2011 census data).

The large number of results generated were cross-compared. The comparison revealed that for primary schools the vast majority of results (over 80% of all comparisons) were statistically significantly different from the others at the < .001 level, for both distance and 2SFCA measures. This indicated that the different datasets used were not interchangeable and therefore not equally usable in this type of study.

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[2] https://www.ordnancesurvey.co.uk/business-and-government/products/points-of-interest.html
[3] https://www.ordnancesurvey.co.uk/business-and-government/products/topography-layer.html
[4] https://www.ordnancesurvey.co.uk/business-and-government/products/itn-layer.html
[5] https://www.ordnancesurvey.co.uk/business-and-government/products/os-open-roads.html
[6] http://www.openstreetmap.org/

At this early stage of analysis initial indications were that differences between the network datasets had the greater effect on results. Differences due to method of demand- or supply-side feature representation were less important.

Initial findings suggest that more attention needs to be given to the nature of data sets used to represent such features in GIS-based analytical tasks. The exact context in which such data sets are applied may determine how usable different sources of data are in relation to common GIS spatial analytical tasks and a useful addition to GIS-based analysis going forward could be the derivation of a typology of circumstances in which adopting alternative sources of open data are more appropriate.

Biographical note

Robin Frew is a third year PhD student; this research was funded by Ordnance Survey (OS) but any interpretations of findings are those of the student and do not necessarily reflect the opinions of OS.

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Appendix F - Ordnance Survey Research Workshop poster presentation, February 2016

Ordnance Survey

Usability of geospatial data from an end-user perspective

University of South Wales
Prifysgol De Cymru

This study looked at the usability of a range of geographical data when applied to network-based accessibility modelling, using both basic and more sophisticated methods of measuring accessibility. By conducting sensitivity analyses on a range of demand-side representations, supply-side features and network datasets, assessments were made as to the usability of the data in these contexts.

Usability

What is usability?

	Effectiveness	Efficiency	Satisfaction
Usability characteristics			
Usability elements	Added value Content Purpose Utility Novelty Popularity	Cost Integration and convenience Searchability Security Speed of access Standardisation Legal issues	Authority Trust Caveats on use Certification and Legal defensibility Producer reputation Metadata Visual appearance: Data visualisation Interface design HCI

Quality: Completeness; Accuracy; Logical consistency

How is usability assessed or measured?

Usually retrospectively, by:

- Questionnaire
- Focus groups
- Interviews
- Benchmarking

Or, during use by:

- Observation

Or, pre- or post-procurement, on actual, sample or example data by:

- Expert evaluation

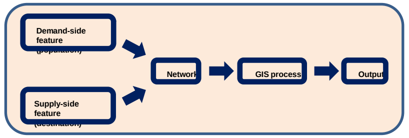
This exercise

Takes a novel approach by conducting **sensitivity analysis** on a range of demand-side representations, supply-side features, network datasets and GIS processes used in typical investigations of accessibility.

Assessments made as to the usefulness of the data used in such tasks, using both basic and more sophisticated methods of measuring accessibility.

Sensitivity analysis

Use an OFAT approach (changing One Factor At a Time) to assess how changes to the inputs affect the output.

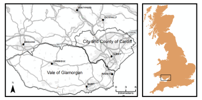


Perform multiple iterations to highlight the effects of each input.

When one thing is changed, is the effect on output large or small? Statistically significant or not? Noticeable using typical visualisation or not making any difference?

Do any of the iterations exhibit anomalies or discrepancies? These were investigated to identify any associated usability and/or quality issues.

Study area



Two study areas were chosen to assess urban/rural issues: Cardiff and Vale of Glamorgan.
Cardiff: mainly urban, population 346 090;
Vale: mainly rural, population 126 336;
Vale is twice the area of Cardiff, with around one third of the population.

Datasets used

	Ordnance Survey	Alternative
Supply-side	Points of Interest	None suitable
	Sites	
	AddressBase Premium	
Demand-side	Code-Point	Census OA centroids
	Address Layer 2	
	AddressBase Premium	
Network	ITN	OSM
	ITN with Urban Paths	
	Open Roads	

Free-to-use third-party supply-side datasets were found to be so overly inclusive as to be unusable, in this context.

Features studied

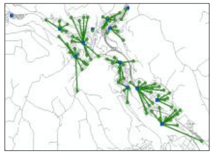
	Cardiff		Vale	
	Number	Distribution	Number	Distribution
Primary schools	93	Clustered	49	Random
Secondary schools	21	Dispersed	9	Dispersed
GP surgeries	63	Clustered	21	Clustered / Dispersed
Sports centres	31	Random	10	Dispersed
Community hubs	76	Clustered	39	Clustered

Features differed in number and in patterns of distribution.

Accessibility modelling

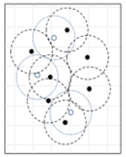
Distance / travel times

Euclidean and network distance



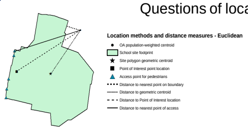
Gravity model

Two-step Floating Catchment Area model



Utilises levels of supply and demand within user-set catchment. Takes into account capacity or size of destination facility (hence 'gravity' model) and overlapping destination catchments.

Questions of location



Different datasets can represent features in GIS in different ways.

- Does the representation of location affect analysis?
- Does the choice of dataset affect analysis?

Tools have been developed to make the calculation of gravity models, etc simpler within GIS. Can the tools cope with new geospatial datasets with higher accuracy and precision?

What has the greater influence: Locational representation or network choice?
Urban areas have been the focus of many studies. Can results be generalised to rural areas?

Techniques used to assess outcomes

Statistical analysis

Assess similarity and difference in distance and 2SFCA scores from each population location (demand point) to nearest facility (supply feature).

Test for similarity: Spearman's Rank Correlation;

Test for difference: Friedman (overall differences) and Wilcoxon (paired comparisons) signed-rank test.

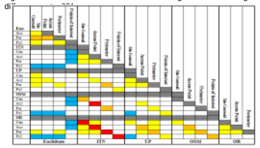
Example of Wilcoxon results. Those comparisons in red have no significant differences at the 5% level. Green = sig at 1%. Black = sig di

Destination Overlap

Do the numerical differences in distance actually result in a different 'nearest destination' being identified?

Or does it make no difference at all?

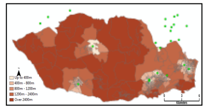
Av. dest'n overlap for schools: red 95-100%, amber 90-95%; yellow 85-90%; blue <75%.



Visualisation

Choropleth (statistical) maps using Census OA polygons are commonly used to illustrate accessibility. Does the use of different datasets result in different map results?

Can other OS datasets be usefully employed in presenting such results?



Example of 'nearest distance' outcome, presented as choropleth map. This map shows Euclidean distance to nearest secondary school, using Sites perimeter, typically the combination resulting in the 'best' accessibility.

Findings

Influence of Network vs. Location

Particularly in a rural context, when the method of locating a supply-side feature was constant but the network varied, outcomes showed little difference.

When the location method varied but the network was constant, differences were significant.

Network consistency

ITN and Open Roads networks returned the highest Destination Overlap figures in both Cardiff and the Vale, for GP surgeries, sports centres and community hubs.

Urban/rural effects

In rural context, changes due to network have less overall effect on results than changes in method of location. Why? Over larger distances, the effects of differences between networks is diminished.

There was a considerable urban-rural split in 2SFCA results, with the Vale returning more non-significant results than Cardiff, indicating a higher level of statistical similarity.

Visualisation

Finer population representations had potential to be more accurate but were challenging in terms of visualisation and interpretation.

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