European Commission

Study on urban mobility – Assessing and improving the accessibility of urban areas

Annexe 1: Task 1 Report - State of the Art report on assessing and reporting accessibility and congestion

Ricardo Energy & Environment

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Executive summary

Study overview

The European Commission (Directorate General for Mobility and Transport) launched this study to improve the understanding of urban accessibility and road congestion in Europe. The study aims to advance the understanding of urban accessibility in order to improve the functioning of urban areas and make the transport system in Europe's urban areas more efficient. The study includes five key tasks:

- Task 1 – State of the Art Review
- Task 2 – Estimation of European urban congestion costs;
- Task 3 – Relative efficiency of urban passenger transport modes;
- Task 4 – Best practice examples for increasing urban accessibility; and
- Task 5 – Policy proposals.

This report is the Task 1 State of the Art Review on accessibility and assessing/improving the accessibility of urban areas. A review of relevant literature was undertaken, which covered:

- Accessibility definitions and scope;
- Metrics in use;
- Modelling techniques and their applications; and
- Policy initiatives affecting accessibility.

The review of the literature was complemented by stakeholder engagement, including telephone interviews and a workshop with key experts and academics in the field of accessibility.

Defining Accessibility

It is clear from the review of the literature that many definitions of accessibility currently exist, including:

- 'the opportunity which an individual or type of person at a given location possesses to take part in a particular activity or set of activities' (Hansen, 1959)
- 'the average opportunity which the residents of the area possess to take part in a particular activity or set of activities' (Wachs & Kumaga, 1973)
- 'the consumer surplus, or net benefit, that people achieve from using the transport and land use system' (Leonardi, 1978)
- 'the extent to which the land use-transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s)' (Geurs & van Eck, 2001)
- 'the number and diversity of places that can be reached within a given travel time and/or cost' (Bertolini, Le Clercq, & Kapoen, 2005)
- 'the ease in meeting one's needs in locations distributed over space for a subject located in a given area' (Cascetta, Carteni, & Montanino, 2013)
- As property of an individual: "Accessibility is a measure of the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time" (Bhat, et al., 2000);

- Property of individuals' surroundings (e.g. the transport-land use system) or particular places: "[Accessibility is] the extent to which the land use-transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s)." (Geurs & van Eck, 2001)

By any of these definitions, it should be clear that accessibility differs from *mobility*, which just refers to the movement of people and goods (Litman, 2011). Accessibility involves consideration of the *opportunities* enabled by mobility.
Urban accessibility can therefore be defined as: "….*the ease of reaching goods, services, activities and destinations in urban areas. It includes factors such as mobility options, travel information, transport network connectivity, land use patterns and cost for both passengers and freight*."

Dimensions of Accessibility

There are typically four dimensions of accessibility, which can be described as follows:

- The **transport dimension** of accessibility comprises the various available options for transport. This component partly determines the disutility an individual would experience in travelling between an origin and destination (or the disutility an agent would experience when transporting their freight between an origin and destination).
- The **land use dimension** of accessibility consists of the amount, quality and spatial distribution of activity locations (or "opportunities" or "destinations") which individuals might want to travel to (or which agents might want to move their freight to).
- The **individual dimension** of accessibility relates to the (different) needs, capabilities and perceptions of (different) individuals. Individuals vary in terms of their physical capabilities, which can affect their feasible set of options for transport. Their options can also be affected by their economic resources, or the time constraints they face in their lives, or the information that is available and salient to them, and so on. There may be analogous situations in freight transport, for example due to the fact that different types of freight need to be handled differently.
- Accessibility also has a **temporal dimension** for several reasons; activities/opportunities are often only available at particular times (for example shops will often close for part of the day) or else it is mandated that certain activities (like work) take place at certain times. Furthermore, individuals are constrained in when they can travel to certain destinations and perform certain activities due to the other activities they must perform (such as work, care, or meeting other individuals) (Geurs & van Wee, 2004).

Accessibility Metrics

There are a range of accessibility measures/indicators in use, which can be grouped into the following categories:

- **Infrastructure-based** – quantify accessibility in terms of the performance of the transport system, e.g. average speed on the road network, or levels of congestion
- **Location-based** – define accessibility in terms of how many individuals/freight loads can access a location, or how many locations an individual/freight load can reach.
- **Person-based** – consider accessibility at the level of individuals e.g. details of the set of employment centres specific individuals can practically access, taking into consideration personal constraints of time or physical ability.
- **Utility-based** – quantify accessibility in terms of utility an individual or individuals derive from being able to access activities/opportunities distributed across space (economic benefit).

Data and modelling

In order to model accessibility, data will be required from a variety of sources, most often relating to the transport system, land use, and the individual. Availability of data and difficulty in obtaining data varies greatly, and can include the undertaking of surveys, stated-preference surveys, consulting timetables, existing maps, traffic monitoring, censuses, intelligent transport systems, interviews etc.
Mathematical and analytical models are often used to operationalise the concept of accessibility. Once calculated accessibility measures (and their distribution over space, time and individuals) are often visualised in modelling suites in order to facilitate understanding by the user.

Accessibility Indicators for Comparing European Cities

One of the objectives of this study is to contribute to the development of a European Urban Mobility Scoreboard, which could be used to facilitate comparison between areas and over time. The review of the literature has highlighted that an extremely diverse set of indicators are used and/or required to quantify accessibility, each with their own advantages and disadvantages, due to the fact that accessibility is "a multifaceted concept, not readily packaged into a one-size-fits-all indicator or index" (Scheurer & Curtis, 2007). Such indicators and their merits were also discussed in detail during our engagement with stakeholders (interviews and workshop). However, it is evident that some indicators would be more useful in developing a scoreboard than others.

In particular, it would be impossible to base city-level accessibility metrics around the use of space-time prisms and other ways of measuring accessibility that are extremely sensitive to individuals' unique circumstances.

The use of infrastructure-based measures of accessibility also have their drawbacks due to the fact that they do not often take into account the spatial distribution (and re-distribution over time) of opportunities/activities. This is fundamental in considering *accessibility* rather than just *mobility*.
After eliminating those possibilities, the remaining possibilities are to use the following types of indicators:

- Location-based measures considering both potential accessibility indicators and/or distance indicators;
- Utility-based indicators.

The literature and engagement with stakeholders have already provided some examples of indicators that fall within these categories. Some examples of the types of indicators that could be used to compare cities are provided in the table below.

Example city comparator accessibility indicators

City comparator example indicators
Number of opportunities e.g. doctors surgeries, jobs, schools etc. within **X** m/km
Number of opportunities e.g. doctors surgeries, jobs, schools etc. within **X** minutes by public transport, private car etc.
Number or proportion of individuals (population) within **X** distance/time of an opportunity.
Potential accessibility to e.g. healthcare, education, jobs etc.

Within this set of options, there will be a trade-off between accuracy, and ease of implementation and interpretation. Accuracy is obviously necessary if comparisons between cities and over time are to be informative. But ease of interpretation is also important if the scoreboard is going to have an influential effect on policymakers, which may rule out the use of utility-based statistics derived from a “black box” (where inputs and outputs are known but there is no knowledge of internal workings).

An important consideration for any selected accessibility metric is the necessary data – including its format, availability and ease of collection. In order to be able to make comparisons between European cities, data supporting accessibility metrics will need to be readily available to most cities, and can potentially be collected at the European level. As the scoreboard is envisaged as facilitating comparisons between areas, there will need to be some careful consideration of the substantial area-level differences between individuals in different parts of the EU. For example, individuals in different countries or even different cities may differ not only in terms of their income but also in terms of how much they are willing to spend on travel as a proportion of their income. Hence the measures should compare accessibility (e.g. time or distance to access opportunities) between cities, but should not provide judgement on what is considered to be acceptable, desirable etc.

Given these considerations the most likely candidates for a European level indicator(s) on accessibility are location-based measures in terms of simple travel distances/times to opportunities. This is supported by the use of these type of indicators in comparative accessibility studies such as the ESPON TRACC study (ESPON, 2015) and UK department for Transport’s Accessibility Statistics (UK Department for Transport, 2014).

Key conclusions

This review has highlighted that Member States including the UK, the Netherlands, and Germany have already taken some steps to let accessibility modelling and analysis inform the decisions governments and municipal authorities take in transport, urban planning, and provision of public services. Inevitably, some areas of the Community lag behind others in terms of the progress made on this front (it is probably the case that larger municipal governments generally lead the way). The CIVITAS initiative – which promotes dissemination between cities of innovative sustainable transport measures – supports projects that link “leading cities” and “learning cities” for this reason. Either CIVITAS or a new initiative could be used to disseminate best practice in the use of accessibility measures as policy-informers.

Use of accessibility measures in a European Urban Mobility Scoreboard would raise the profile of accessibility measurement, but it may prove difficult to distil complex accessibility issues into concise indicators over an area as diverse as Europe.

The EU might also take action to improve levels of urban accessibility with the structural and cohesion funds. Projects to improve accessibility through upgrades to local transport systems have received very significant financial support from the European Regional Development Funds for many years. This review has also highlighted the salience of urban land use to accessibility, and the importance of transport in social exclusion. These are potentially other areas in which the EU might in future offer more financial support. The European Social Fund has historically funded *training* for socially excluded individuals to help them find access to employment – it could in future be used to fund initiatives aimed at improving the *accessibility* of socially excluded groups partly in order to improve their employment prospects.

Finally, it is recommended that there should be increased focus on accessibility rather than mobility. By addressing accessibility, mobility issues will be intrinsically addressed. However, improving urban accessibility is likely to generate more economic and social benefits than mobility alone. It is therefore recommended that the focus sustainable urban mobility initiatives should be widened to address the wider issue of accessibility.

Table of contents

1 Introduction

Ricardo Energy & Environment (UK) and Transporti e Territorio (TRT, Italy) have been commissioned by the European Commission to undertake a study on urban mobility and assessing and improving the accessibility of urban areas. This is the first deliverable for the study.

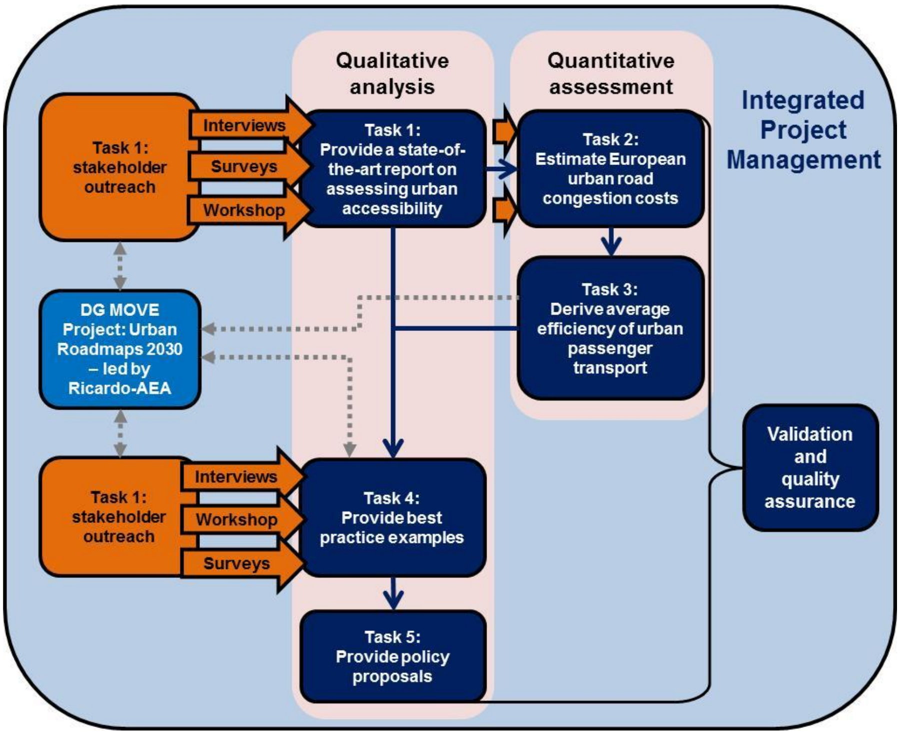
1.1 Study objectives and overview

This study in urban accessibility has been designed in order to maximise the potential for useful outputs that will advance the understanding of urban accessibility in order to improve the functioning of urban areas and make the transport system in Europe's urban areas more efficient.
The study consists of five key tasks, which are as follows:

- Task 1: State of the art report – urban accessibility
- Task 2: Estimation of European urban road congestion costs
- Task 3: Relative efficiency of urban passenger transport modes
- Task 4: Best practice examples – increasing accessibility
- Task 5: Policy proposals.

Figure 1-1 provides an overview of how the different tasks fit together. Each task will result in a stand-alone, final publishable report. Whilst each task will result in the production of a stand-alone report, together the outputs from the project will be used to provide clear guidance on how urban accessibility can be improved, and how the results of such improvement activities can be measured in a consistent manner across the 28 EU Member States (EU28).

Figure 1-1: Overview of study tasks and methodology



1.2 Task 1 State-of-the-Art Report

The objective of Task 1 is to produce a State-of-the-Art Report that presents the latest experience and knowledge on assessing and reporting the accessibility of urban areas, including existing methodologies and metrics.

An important consideration for this task is the distinction between accessibility (which is the focus of Task 1) and congestion (which is the focus of Task 2). Both Tasks are required to review the state-of-the-art in terms of measuring these aspects, and while there is likely to be some overlap in the relevant literature, ensuring a clear and distinct definition of each will minimise any overlaps between the two tasks.

1.3 Task 1 Methodology

In preparing the State-of-the-art report, we conducted a broad search for relevant data and previous research in this area, using a range of approaches:

- Desk-based research (including review of the literature)
- Stakeholder engagement
- Interviews
- Facilitation of a workshop

These approaches are discussed in more detail below.

1.3.1 Desk-based research

The desk-based research involved using targeted key words to search for relevant literature (including peer reviewed journals, professional literature, project reports/studies etc.), grey literature and databases. Our team has very broad European language capabilities, and hence were able to identify and review relevant literature from a wide range of EU countries. This desk-based review of the literature informed the first draft of the State-of-the-Art report that was prepared in Spring 2015 (internal document).

1.3.2 Stakeholder engagement

It was recognised that for this study, literature on its own would not be sufficient for presenting a comprehensive review of experience in assessing urban accessibility. Therefore between May and September 2015 the study team engaged with a wide range of stakeholders via email, interviews and through a stakeholder workshop. Stakeholder were identified via the desk-based research, but also the study team's own contacts in the field of accessibility of urban areas. Potential stakeholders identified included:

- Authors of relevant reports (identified through the review of the literature)
- Key stakeholders in the areas of policy-making
- ITS/ICT solution providers, infrastructure development
- Transport service providers/contractors
- Associations
- City networks; and
- Academics/think tanks.

Initially stakeholders were contacted via email to introduce them to the study, and to ask whether they would be interested in participating in a telephone interview and/or attending a workshop. From the positive responses received, the study team arranged and undertook a series of telephone interviews. The interviews focused on:

- Identification of potential urban accessibility indicators

- Suggestions for common accessibility indicators for comparing European Cities, including identification of potential problems/barriers
- Identification of urban accessibility projects that stakeholders have been involved in or are aware of.

A full list of stakeholders who were interviewed or that provided written contributions can be viewed in Appendix 1.
Following the interviews, the study team invited stakeholders to participate in a workshop with the main aim of reviewing and consolidating initial findings and agreeing on state-of-the-art approaches. The workshop was held on 15th September 2015 at DG MOVE premises, with 17 stakeholders attending (see Appendix 2 for full participant list). The main topics covered during the workshop were as followed:

- Defining urban accessibility (including participant exercise on accessibility metrics)
- Data and modelling (including discussion on existing European data and modelling techniques)
- Congestion and accessibility
- Participant exercise on identifying potential measures to improve accessibility.

The full agenda can be viewed in Appendix 3. Using feedback and suggestions from the stakeholders at and following the workshop (see Appendix 4 – summary of stakeholder workshop), the State-of-the-Art review was updated further to produce this deliverable.

1.4 Overview of the report structure

The remainder of this report is structured as follows:

- Section 2: Accessibility – Definition and Scope
- Section 3: Metrics in use
- Section 4: Modelling techniques and their applications
- Section 5: ICT/ITS solutions
- Section 6: Policy initiatives affecting accessibility
- Section 7: Summary and conclusions

2 Accessibility - Definition and scope

2.1 Basic definition

The specifications for this study define accessibility as:

> "….the ease of reaching goods, services, activities and destinations in urban areas. It includes factors such as mobility options, travel information, transport network connectivity, land use patterns and cost for both passengers and freight."

Various definitions of accessibility have been proposed and used by academics and practitioners. In general there is a great deal of overlap between the definitions, but as yet, no consensus on a precise definition. For example, the 2014 report of the COST Action 'TU1002 – Assessing Usability of Accessibility Instruments' (Brömmelstroet, Silva, & Bertolini, 2014) lists the following definitions:

- 'the opportunity which an individual or type of person at a given location possesses to take part in a particular activity or set of activities' (Hansen, 1959);
- 'the average opportunity which the residents of the area possess to take part in a particular activity or set of activities' (Wachs & Kumaga, 1973); […]
- 'the consumer surplus, or net benefit, that people achieve from using the transport and land use system' (Leonardi, 1978);
- 'the extent to which the land use-transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s)' (Geurs & van Eck, 2001);
- 'the number and diversity of places that can be reached within a given travel time and/or cost' (Bertolini, Le Clercq, & Kapoen, 2005); […]
- 'the ease in meeting one's needs in locations distributed over space for a subject located in a given area' (Cascetta, Carteni, & Montanino, 2013)

By any of these definitions, it should be clear that accessibility differs from *mobility*, which just refers to the movement of people and goods (Litman, 2011). Accessibility involves consideration of the *opportunities* enabled by mobility.

Although definitions of accessibility may have converged somewhat over time as a result of numerous refinements, there are still some differences between various definitions currently in use. For example, some scholars choose to define accessibility as a property of individuals:

> "Accessibility is a measure of the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time."
> (Bhat, et al., 2000)

But others define it as a property of individuals' surroundings (e.g. the transport-land use system) or particular places:

> "[Accessibility is] the extent to which the land use-transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s)."
> (Geurs & van Eck, 2001)

The word *accessibility* is also frequently used in transport literature by academics and practitioners focussed on *making the transport system itself accessible* to a wider range of individuals, for example, wheelchair users. For example Tyler (Tyler, 2002) edited a volume called "Accessibility and the Bus System" which contains an extensive discussion of efforts to make the bus system more accessible to a variety of users.

For the rest of this review, the definition of accessibility used is *"…the ease of reaching goods, services, activities and destinations"*. Both the person-based and place-based perspectives on accessibility are discussed. We also take into account literature by researchers and practitioners on making transport systems more accessible, but our ultimate focus is on ease of access to the *opportunities* that transport connects people or freight to, rather than ease of access of the transport system itself. This definition is echoed in the EPSON-funded TRACC study on urban accessibility, which describes accessibility as a construct of two functions: one representing the activities or opportunities to be reached and one representing the effort, time, distance or cost needed to reach them (EPSOM, 2015).

2.2 Dimensions

2.2.1 The "four dimensions" of accessibility

The concept of accessibility has been decomposed into four "dimensions" or "components": transportation, land use, individuals, and time. For example, this approach is used throughout a review of the advantages and disadvantages of various accessibility indicators in (Geurs & van Wee, 2004).

These four dimensions of accessibility can be described as follows:

- The **transport dimension** of accessibility comprises of the various available options for transport. This component partly determines the disutility an individual would experience in travelling between an origin and destination (or the disutility an agent would experience when transporting their freight between an origin and destination).
- The **land use dimension** of accessibility consists of the amount, quality and spatial distribution of activity locations (or "opportunities" or "destinations") which individuals might want to travel to (or which agents might want to move their freight to).
- The **individual dimension** of accessibility relates to the (different) needs, capabilities and perceptions of (different) individuals. Individuals vary in terms of their physical capabilities, which can affect their feasible set of options for transport. Their options can also be affected by their economic resources, or the time constraints they face in their lives, or the information that is available and salient to them, and so on. There may be analogous situations in freight transport, for example due to the fact that different types of freight need to be handled differently.
- Accessibility also has a **temporal dimension** for several reasons; activities/opportunities are often only available at particular times (for example shops will often close for part of the day) or else it is mandated that certain activities (like work) take place at certain times. Furthermore, individuals are constrained in when they can travel to certain destinations and perform certain activities due to the other activities they must perform (such as work, care, or meeting other individuals).

This conceptual framework has the advantage of letting us consider the full range of accessibility research in our review, from macroscopic considerations (such as land use) through to the microscopic factors that may also affect individuals.

2.2.2 Further conceptual issues relevant to study scope: spatial scale and congestion

This study is concerned with accessibility *in urban areas*, and draws links between urban accessibility and congestion in urban transport networks.
Although literature on accessibility is often focussed at the spatial level of cities and urban conurbations, some studies have explored differences in ease of access to

opportunities at a national and international scale (for example, studies have considered the ease of access areas/individuals/firms have to product markets in other cities). The TRACC project ("Transport Accessibility at regional/local scale and patterns in Europe") funded by the European Observation Network for Territorial Development and Cohesion (ESPON) explored accessibility in Europe at several spatial scales (international, regional, local) and drew cross-national comparisons at each of these scales (ESPON, 2015).

Congestion is a significant problem for many cities in part because of its impacts on accessibility. It is an important sub-component of the *transport dimension* of accessibility, and on the whole, we should expect congestion to have a negative impact on accessibility because it causes delays to travellers which diminish from the ease with which they can access opportunities.

But the observed relationship between congestion and accessibility is not straightforward, for two reasons. Firstly, more developed urban areas tend to have greater accessibility *and* greater levels of congestion – not because congestion has a positive impact on accessibility, but primarily because both those variables tend to increase with the agglomeration of opportunities. (Mondschein, Taylor, & Brumbaugh, 2010)

Secondly, researchers have argued that the relationship between congestion and accessibility may be complicated by *differences between individuals* in different areas that emerge as a result of congestion. In particular, an argument has been made that "experiences with congestion cognitively alter an individual's opportunities choice set" – in more congested areas, individuals prefer to access different sets of opportunities – ones which allow them to overcome the greater congestion (Mondschein, Taylor, & Brumbaugh, 2010). These different preferences are revealed by different patterns of travel behaviour such a different trip lengths and frequencies, it is argued.

3 Metrics in use

Even where scholars agree on a concept of accessibility, there are a multitude of measures they might choose from to measure accessibility. Accessibility is "a multifaceted concept, not readily packaged into a one-size-fits-all indicator or index" (Scheurer & Curtis, 2007); nevertheless, various indicators and indices have been introduced with the aim of informing our understanding of accessibility in the real world and potentially shaping policy. There is no consensus on how to arrange these measures into a taxonomy. Various approaches have been taken, including in reviews by (Geurs & van Wee, 2004); (Bhat, et al., 2000) and (Scheurer & Curtis, 2007). The various types of measure catalogued in these three reviews are listed below.

3.1 Measures

3.1.1 Infrastructure-based measures

Infrastructure-based measures quantify accessibility in terms of the performance of the transport system – for example, the average speed on the road network, or levels of congestion. (Geurs & van Wee, 2004)

- In addition, some accessibility indicators describe transport infrastructure using concepts from **graph theory,** which is the mathematical study of graphs (structures consisting of *nodes,* or points, connected by *edges,* or lines). Graphs can be used to represent transport infrastructure – for example, in a railway network, stations can be thought of as nodes and the links between stations can be thought of as edges. Graph theory gives us a multitude of indicators that might be thought of as characterising the overall accessibility of a whole network, or alternatively, accessibility at particular points in the network. For example, there are metrics in graph theory for describing the number of edges you typically have to traverse to get to other nodes. (Scheurer & Curtis, 2007)
- **Spatial separation measures** are very crude, simple measures of accessibility that use only the geographic distance between points in the infrastructure network as their inputs. This means they effectively ignore the "network constraints" that affect travel between those points in real life. (Scheurer & Curtis, 2007)

3.1.2 Location-based measures

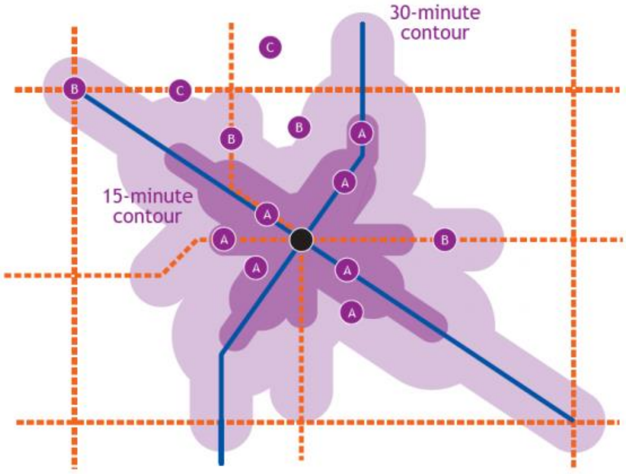
Location-based measures define accessibility in terms of how many individuals/freight loads can access a location, or how many locations an individual/freight load can reach. These measures usually describe accessibility at an aggregate level (e.g. accessibility within a geographic area or among a certain population). For example, the average number of theatres within 30 minutes' walk of adults living in a certain city would be a location-based measure. Location-based measures can be further divided into distance measures and potential accessibility (or "gravity model") measures.

- **Potential accessibility measures** indicate the accessibility of opportunities in one zone to many (ideally all) other zones, but smaller or more distant opportunities have less of an effect on the magnitude of metric. This is done by means of an impedance function to weight the opportunities (usually a negative exponential function, but other functions such as Gaussian and logistic functions have been used). (Geurs & van Wee, 2004)
- **Distance measures** are comparatively simple – instead of using an impedance function to weight the influence of different opportunities, distance measures report the number of opportunities within a given geographic contour, or alternatively, the distance to the closest opportunity. For example, the distance to the nearest food shop

is a distance measure of accessibility, and so is the number of food shops within 100m of a household.

The idea behind **contour** measures is that the area bounded by the contour represents all the places a person (or freight shipment) could move to within a given amount of time or travel cost. (Or, if the accessibility metric is place-based rather than person-based, it represents the places people/freight could arrive from within a given amount of time or travel cost). (Geurs & van Wee, 2004).

Figure 3-1 Illustration of contour measure concept



In Figure 3-1, two accessibility contours are drawn around the black dot at the centre of the picture (representing an individual, the point of reference for the accessibility measure in this example). Opportunities are represented by the spots labelled A, B and C. The "A" opportunities lie within 15 or fewer minutes of travel from the individual and would therefore be counted in the 15 minute contour measure of accessibility. Opportunities labelled A and B both lie within 30 minutes travel time, and the "C" opportunities lie beyond this. Source: (Scheurer & Curtis, 2007)

3.1.3 Person-based measures

Person-based measures necessarily consider accessibility at the level of individuals. They might, for example, give details of the set of employment centres specific individuals can practicably access, taking into consideration personal constraints of time or physical ability.

- One approach to operationalising person-based accessibility is to draw a diagram representing the locations an individual could practicably access at different times (a **space-time** prism) (Scheurer & Curtis, 2007).
- It has also been argued that person-based measures can be similar to location-based measures, but specified at the level of individuals, and sensitive to the differences between them. In theory, therefore, location-based measures can be converted into person-based measures with the application of additional data (Páez, Scott, & Morency, 2012).

3.1.4 Utility-based measures

Utility-based measures quantify accessibility in terms of the utility an individual or individuals derive from being able to access activities/opportunities distributed across space. These measures can be converted into monetary values, although sometimes they are simply reported in terms of arbitrary units which can only be compared (between persons or under different scenarios) within the context of the model used to generate them.

3.1.5 Competition

Accessibility measures can also be designed to take into account the fact that locations have a limited capacity for individuals, and will therefore not be feasible options for some individuals to count among their opportunity set. (Scholars refer to competition for opportunities between individuals/freight). "Competition measures" are identified as one of seven categories of measure in (Scheurer & Curtis, 2007), whereas (Geurs & van Wee, 2004) write about factoring in competition as an optional extension to utility-based or location-based measures.

3.1.6 Studies exploring/using various accessibility measures

Various studies and projects have been undertaken which have involved the development and use of accessibility (and mobility) metrics.

The Sustainable Mobility Project was conducted by the world Business Council for Sustainable Development (WBCSD, 2015), which involved the development of a set of indicators measuring the potential for sustainable mobility in cities around the world. However, the indicator set was not designed so that the sustainable mobility of cities could be compared, rather than other similar cities could use the indicator set to potentially understand where they could improve their local situation.

The indicator set covers four dimensions of sustainable urban mobility, including global environment (GHGs, energy efficiency, etc.), quality of life in the city (indicators on safety, access, etc.), economic success (economic opportunity, public finance, congestion, etc.), and mobility system performance (intermodal connectivity, occupancy rate, etc.) (WBCSD, 2015). The aim of the indicator set is to collate (or estimate where unavailable) the date for each of the indicators, in order to provide an overall assessment of sustainable mobility for the city. 'Performance' of the city's mobility system is then presented in 'radar view' or 'spider charts' to aid cities in identifying their strengths and weaknesses, and subsequently launch targeted actions. As this report has previously acknowledged, there is indeed a great level of overlap between 'mobility' and 'accessibility', and therefore the sustainable mobility indicator set has a number of indicators of interest to accessibility of cities, including: congestion and delays, commuting travel time, access to mobility services, traffic safety, comfort and pleasure, accessibility for mobility impaired groups, affordability of public transport for the poorest group, security (e.g. personal safety/perceptions of safety when travelling), and intermodal connectivity.

In 2014 the second Arthur D Little '*Future of Urban Mobility'* study was published, which included an updated urban mobility index assessing the mobility maturity and performance of 84 cities worldwide (Little, 2014) Like the WBCSD study, the main focus is again on mobility rather than accessibility, but includes related criteria that could be useful in assessing accessibility of cities (e.g. public transport frequency, mean travel time to work, etc.). However, there is a strong focus on the transport aspects, and less consideration for the availability of opportunities, and the individual.

The study did identify key criteria that a city would need to demonstrate in order to perform well across the range of mobility criteria, including affordable transport, clean air, promotion of cycling, safe streets, bike sharing facilities, frequent public transport services, wide-spread car sharing, minor impacts on climate and short travel times.

A study that does focus specifically on accessibility is 'TRansport ACCessibility at regional/local scale and patterns in Europe' (TRACC) (ESPON, 2015). The main aim of the TRACC study was to update results of previous studies on accessibility at the European scale, reviewing/extending indicators used, extending the spatial resolution of indicators, and exploring the likely impacts of policies at the European/national scale to improve global, European and regional accessibility in the light of a range of emerging challenges (e.g., globalisation, energy scarcity, climate change etc.). As mentioned earlier, accessibility in the TRACC study is described as a construct of two functions: one representing the activities or opportunities to be reached, and one representing the effort, time, distance or cost required to reach them. In order to combine these functions, three generic accessibility indicators can be used:

- Travel cost - If only destinations of a certain kind (e.g. cities beyond a certain size) are considered and the impedance function is travel time or travel cost itself, the accessibility indicator is total or average travel cost to a predefined set of destinations
- Access to regional centres – travel time to nearest regionals centre by road and public transport/rail
- Access to health care facilities – travel time to nearest hospital
- Cumulated opportunities – If only destinations within a certain travel time are considered, and the destinations are taken as is, the accessibility indicator measures the number of potential destinations (customers, business contacts, tourist attractions etc.) reachable in a given time:
- Daily accessibility of jobs – Jobs accessible within 60 minutes by road and public transport/rail
- Availability of higher secondary schools – number of secondary schools within 30 minutes travel time
- Potential – If the impedance function takes travel behaviour into account, i.e. the diminishing inclination to travel long distances, the accessibility indicator is a potential indicator. The activity function may take account of agglomeration effects or economies of scale:
- Regional potential accessibility – To population by road and public transport/rail
- Potential accessibility to basic healthcare – potential accessibility to general practice surgeries

In addition to the generic indicators, four further indicators are considered in the TRACC study, including multimodal accessibility, intermodal accessibility, global accessibility and regional accessibility.

The TRACC study used a European-wide accessibility model, which requires data from cities to be collated, including data on a range of opportunities (secondary schools, hospitals, surgeries etc.). The study acknowledges that there is no single standard accessibility indicator that can serve all purposes. A set of accessibility indicators was therefore developed, which takes into account three spatial contexts global, European and regional), and is further differentiated between travel and freight (ESPON, 2015).

Other studies consider accessibility to/of public transport (one aspect of 'accessibility' in urban areas). A recently published paper considers 'measuring access to public transport in European cities' (Poelman & Dijkstra, 2015). The study produced a set of comparable indicators to assess the access to and comparison of the offer of public transport that is easily accessible to the urban population, enabling cities to benchmark themselves against similarly-sized cities. The methodology developed enables s the comparison of cities in an identical manner, taking into account the extent of the urban centre, distribution of population and exact location of public transport stops, and the frequency of departures. However, it is acknowledged that data availability is a constraint, particularly open access to public transport data in the right format. Also, high resolution data on location of jobs at the workplace is also quite rare.

3.2 Taxonomy and distinctions between measures

As mentioned in the previous section, scholars have taken different approaches to grouping accessibility measures into categories. While (Scheurer & Curtis, 2007) identify seven different categories, for (Geurs & van Wee, 2004) there are only four.

From this point on, we adopt the parsimonious taxonomy used in (Geurs & van Wee, 2004). Although it consists of fewer categories than those used in (Scheurer & Curtis, 2007) and (Bhat, et al., 2000), it still provides coverage of all of the types of accessibility metric mentioned in those two sources. The table below illustrates (in approximate terms) the correspondence between the difference categorisations. Note that the "competition measures" identified by (Scheurer & Curtis, 2007) would fall either under the heading of utility-based or location-based measures in (Geurs & van Wee, 2004) rather than being a distinct type of measure.

Table 3-1: Taxonomies of accessibility measures

(Geurs & van Wee, 2004)	(Scheurer & Curtis, 2007)	(Bhat, et al., 2000)
Location-based	Contour measures	Cumulative-opportunities models
	Gravity measures	Gravity-type models
Utility-based	Utility measures	Logsum/Utility models
Infrastructure-based	Spatial separation measures Network measures	Graph theory and spatial separation
Person-based	Time-space measures	Time-space models
	Competition measures	

Various further distinctions are sometimes made in the literature which may cross-cut the categories presented above. For example, we have already mentioned the distinction between person-based and place-based measures of accessibility.

As an additional example, (Páez, Scott, & Morency, 2012) make a distinction between measures of accessibility that include *normative* content, and those that do not. "Normative" accessibility measures entail some view on how things *ought* to be, not just how they are. In (Páez, Scott, & Morency, 2012), the authors observe that normative judgements will often creep in to the formulation of accessibility metrics. For example, when creating contour measures, the creator of the measure will often make a judgement as to what might constitute *reasonable* travel time to a given type of opportunity – in other words, what *ought* to be the maximum amount of travel for individuals needing access to those opportunities. The authors argue that there are alternative ways of formulating distance-based measures which would not entail normative judgement; one way of doing this is to base the travel time threshold used for the contour on the *actual* average travel time of individuals, using survey data. Or, in a more complex variant, the *distribution* of actual travel times among a population could be used (and possibly combined into a weighted average measure for the population).

3.3 Coverage of the four dimensions of accessibility

Accessibility metrics vary in terms of how (or whether) they incorporate consideration of the four dimensions of accessibility (transport, land use, time, and individuals). For example, infrastructure-based measures, which only describe the performance of the transport system, fail to take into account the spatial distribution of activities, i.e. land use. For that reason, it has occasionally been claimed that they should not even be counted as accessibility measures (Scheurer & Curtis, 2007).

The ways in which the various types of accessibility measure typically take into account the four dimensions of accessibility are summarised in the table below, from (Geurs & van Wee, 2004).

Table 3-2: Coverage of the four dimension of accessibility by various types of accessibility measure

		Component			
		Transport component	**Land-use component**	**Temporal component**	**Individual component**
Measure	**Infrastructure-based measures**	Travelling speed; vehicle-hours lost in congestion		Peak-hour period; 24-h period	Trip-based stratification, e.g. home-to-work, business
	Location-based measures	Travel time and or costs between locations of activities	Amount and spatial distribution of the demand for and/or supply of opportunities	Travel time and costs may differ, e.g. between hours of the day, between days of the week, or seasons	Stratification of the population (e.g. by income, educational level)
	Person-based measures	Travel time between locations of activities	Amount and spatial distribution of supplied opportunities	Temporal constraints for activities and time available for activities	Accessibility is analysed at individual level
	Utility-based measures	Travel costs between locations of activities	Amount and spatial distribution of supplied opportunities	Travel time and costs may differ, e.g. between hours of the day, between days of the week, or seasons	Utility is derived at the individual or homogeneous population group level

Source: (Geurs & van Wee, 2004)

3.4 Accessibility metric advantages and disadvantages

Different types of measure have comparative advantages and disadvantages. Their ability to give treatment to the four dimensions of accessibility is one source of advantage or disadvantage. As noted above, infrastructure measures fail to consider the effects of **land use** on accessibility. This means that they cannot be used to evaluate the accessibility impacts of *changes* to land use, for example changes in the distribution of vital services brought about by policy interventions. (Geurs & van Wee, 2004)

Individual constraints and **time constraints** are also not always covered by all measures. The constraints that individuals face are complex, and partly related to how they are able to use their time to perform opportunities. Time is a constraint on individuals in three ways. Firstly, individuals are only able to spare a limited amount of time for travel during their day. Secondly, the opportunities individuals need may only be available at certain times of day – for example, shops open and close on a daily basis. Thirdly, individuals often need to base their movements on a consideration of where other individuals will be at different times, for example, if they have friends to meet and families to care for. Person-based measures can give a detailed consideration to these constraints. Other types of accessibility measure give less consideration to them. Infrastructure-based measures can totally ignore differences between persons, and consequently give very misleading results. (Geurs & van Wee, 2004)

There is other conceptual content in the accessibility literature which only some indicators are capable of capturing. Specifically, **competition effects** are something only taken into account in potential accessibility measures and utility-based measures. Another concept sometimes mentioned in the literature is the idea of **diminishing returns** to accessibility; i.e. the idea that providing an individual who already has a wealth of opportunities available to him with an extra one might result in less additional value than providing that additional opportunity to an individual who currently has few of them. Utility-based measures exhibit the characteristic of diminishing returns. (Geurs & van Wee, 2004)

Accessibility measures also differ greatly in the **data required** to compute them. The data required for infrastructure-based measures is often immediately available. Distance-based measures can also sometimes be computed without additional data collection if there are existing datasets describing activity locations, the transport network, and locations of households, which is often the case. Person-based measures, by contrast, demand extensive amounts of data about individual circumstances which is not typically gathered by travel surveys. (Geurs & van Wee, 2004)

Measures also differ in terms of how easily they can be **interpreted** or **explained** to the general public, practitioners and policymakers. Gravity models and utility-based models create summary indicators of complex sets of facts, and are less transparent than indicators like the number of schools within a reasonable distance by car, or the average speed on roads. With utility-based models, although the process for deriving the final indicator may be complex, there is a distinct advantage to being able to convert the accessibility benefits into **monetary amounts**, as these benefits can be compared like-for-like with associated costs when considering the costs and benefits of a policy intervention. (Geurs & van Wee, 2004).

The table below lists principal advantages and disadvantages of different types of accessibility measure, as well as examples of their application in practice based on evidence from the literature and engagement with stakeholders (interviews and workshop).

Table 3-3: Advantages and disadvantages of different types of accessibility indicators (literature and stakeholder feedback)

Type of measure	Examples of indicators	Comparative advantages	Comparative disadvantages	Examples of application in practice
Infrastructure-based	Travel times (door to door, parking time) Total time 'lost in congestion' Operating speed on the road network Distances between stations Number of interchanges required for travel between stations Reliability of modes	Necessary data and models are often readily available, for example from travel surveys, or models used for transport planning and operations. They are usually easily measured and quantified - Therefore potentially important for comparing accessibility between cities (available data). Can be used to inform transport planning (and therefore improving accessibility).	The measures do not take into account prospective land-use impacts of transport interventions. The measures fail to take into account the impact of land use policy on accessibility (i.e. by redistributing opportunities spatially). The measures tend to be poor in the treatment of temporal constraints and individual characteristics. This can lead to misleading results, for example when comparing accessibility levels of different cities.	The Dutch National Transport Policy Plan was evaluated using travel speed as its measure of accessibility. Congestion and total time lost in congestion were used as accessibility measures in the UK's 10-year transport plan in 2000. (Ferrari, Berlingerio, Calabrese, & Reades, 2014) discuss the accessibility of a rail network in terms of the number of interchanges passengers typically need to make.

Type of measure	Examples of indicators	Comparative advantages	Comparative disadvantages	Examples of application in practice
Location-based: *Distance measures*	Distance/time between two points (e.g. distance between home and nearest shop) Number of opportunities reachable within a given travel time, distance or travel cost (e.g. number of shops within 1 hour walk or transit). Number of individuals within a given distance/time of a selected destination	The necessary data can be relatively easy to gather compared to the data needed for some other measures. For example, data on population locations, opportunity locations and public transport services may all already be available as public datasets or gathered by companies in the private sector (possibly available at the national/EU level). Links people to opportunities – which provides for a good combination of personal dimensions and qualitative measurement.	The measures do not take capacity issues into account, for example the restricted capacities of schools and hospitals. The measures do not take into account individuals' preferences for different opportunities, for example their preference for one type of shop over another. Measures reporting the number of opportunities within a given radius are insensitive to whether the opportunity is located just within the perimeter, or right next to the individual seeking to access the opportunity. Possibly many other external factors that can play a role which are not related to transport/land use etc. – not taken account of in location-based indicators	The UK Department for Transport's Accessibility Statistics (UK Department for Transport, 2014) describe typical travel times to opportunities for area populations and sub-populations, and have been used to inform local transport planning and monitor progress towards nationally-defined objectives.

Type of measure	Examples of indicators	Comparative advantages	Comparative disadvantages	Examples of application in practice
Location-based: *Potential accessibility ("gravity model") measures*	"The accessibility of opportunities in zone i to all other zones (n) in which smaller and/or more distant opportunities provide diminishing influences [through use of an impedance function]." (Geurs & van Wee, 2004) Examples of impedance functions include negative exponential, Gaussian and logistic functions.	These measures are an improvement on contour-based measures insofar as they take the disutility of travel into account, by including a distance decay function. The measures can be easily computed using existing land-use and transport data. The measures can be used to evaluate differences between socioeconomic groups.	The measures are not easy to interpret or explain to audiences unfamiliar with them. The measures do not typically include "competition effects" or temporal constraints (although academics have developed more elaborate potential accessibility measures which are capable of taking those additional constraints into account).	Gravity-based measures have been used to quantify the accessibility of different neighbourhoods in Bogota (Bocarejo S. & Oviedo, 2012). The authors make the impedance function sensitive to the amount of money individuals budget for travel in those neighbourhoods, in order to explore income-related disparities in accessibility. The UK Department for Transport produces gravity model measures of accessibility (UK Department for Transport, 2014).

Type of measure	Examples of indicators	Comparative advantages	Comparative disadvantages	Examples of application in practice
Person-based	Space-time prisms showing the opportunities that can potentially be reached by individuals, taking into account their personal constraints There are a number of factors that are likely to affect accessibility for individuals: ▪ Perceptions of accessibility – satisfaction, ease of access, comfort/pleasure (obtained via interview) ▪ Affordability (monetary cost, willingness to pay €) ▪ Safety and security – perception, chance of being robbed, exposure rate of crime ▪ Health – health benefits of walking and cycling ▪ Accessibility for impaired people – to measure their access ▪ Personal travel time to work (and other key destinations) ▪ Outcome based measures – number of people who can	Because these measures are sensitive to differences between individuals, they can be used to explore patterns of inequality and consider the role of transport in "social exclusion". Enables investigation of specific segments of the population	The measures do not take into account competition effects. They are difficult to create in practice because they demand very extensive data, including data on time constraints of individuals that are not usually available in travel surveys. At present, these metrics are usually focussed on short-term effects of policy interventions, and not geared towards understanding how long-term land use changes would affect daily household activity and travel patterns.	(Schwanen & de Jong, 2008) use space-time accessibility modelling to present "a case study of a highly educated mother who has to reconcile fixed employment times, chauffeuring her son to childcare, and a lengthy commute via the congested highways around Utrecht in the Netherlands." (Horner & Wood, 2014) describe the accessibility of individuals to food shops, taking into account their activity patterns and available time budgets.

Type of measure	Examples of indicators	Comparative advantages	Comparative disadvantages	Examples of application in practice
Utility-based	The logsum measure The doubly-constrained entropy model Cost by mode to destinations Land value around transport access points versus land value in unconnected area.	The logsum measure can be linked to microeconomic theory and allow for calculations of consumer surplus. The measures can be used in economic evaluations, for example in cost-benefit analyses that also consider costs of interventions. The measures are capable of capturing benefits resulting from changes to land use. Utility-based models show diminishing returns to improvements in accessibility, capturing the idea that it may be better to focus improvements on places/persons with relatively low accessibility. Allow highest level of detail – targets measures for individual persons	The measures are comparatively difficult to understand or explain to lay audiences, (although when results are reported as monetary values this can be helpful to policymakers). Little work has been done to integrate the temporal dimension of accessibility into these measures. You cannot compare quantities of utility across differently-specified models, so all comparisons (e.g. between individuals or between scenarios) have to be made within the context of a single model. However, if utility is (robustly) converted into monetary benefits, in principle, comparisons might be made on that basis. Difficult to measure at a large scale	The TIGRIS XL land use and transport interaction model for the Netherlands can be used to model the accessibility benefits of transport interventions and land use changes, and quantify these benefits in monetary terms (Zondag, de Bok, Geurs, & Molenwijk, 2015)

3.5 Accessibility data and data collection methods

This section outlines the potential data that is required relating to land use, individuals, the transport system, and variability over time in order to measure accessibility, and describes some of the principal sources of data and ways of collecting data related to accessibility. In order to compute an accessibility measure, data may need to be collected covering each of the four dimensions of accessibility, i.e. the transport system, land use, individuals, and changes over time.

3.5.1 Transport system

Transport system data

Almost all accessibility models and measures will incorporate data on travel times between zones or locations. This data may need to be derived from other data about the transport system, including

- **Data on the provision of transport infrastructure**, for example the layout of the road network or the spatial distribution of railway stations
- **Data on the provision of (public) transport services**, e.g. timetable data of bus and train services sufficient to understand the frequency and speed of services, routes served, possible interchanges, etc.
- **Data on the performance of the transport network**, for example information on average road speeds, delay, and reliability.

Data on costs of travel (in particular fares and fuel) is also often collected, or estimated on the basis of typical costs per unit distance.
Data on the actual performance of a transport network is usually very important, because *congestion* can add considerably to travel time, especially during periods of peak demand. When demand approaches or exceeds capacity, delay often occurs: road space fills up with vehicles, necessitating slower driving or queueing. Public transport vehicles and infrastructure can also fill up forcing vehicles to move slower and passengers to queue. This delay means that in congested conditions, passengers' ease of access to opportunities is lower than it would be under uncongested conditions.

As well as typical delay, another characteristic of transport system performance that impacts on accessibility is the *reliability* of the system. If it is the case that the amount of time it takes to travel between an origin and destination changes in an unpredictable way from one day to the next, this can add to the cost of travel and effectively reduce accessibility. For example, if an individual is aware that journeys along a certain train link are often delayed significantly without prior warning, the individual may have to set aside more time for travel (arriving at the origin station earlier) than they otherwise would have, or else decide the journey is too inconvenient to make at all.

Various other aspects of the transport network also affect accessibility, including the "quality and environment" of the transport system, and the provision of information for passengers: the comfortableness of waiting areas, the helpfulness of public transport staff, the availability of information prior to travel and the availability of information during travel are all examples of factors affecting the disutility of travel and therefore the impedance to accessing opportunities (Abley & Halden, 2013).

Stakeholders via interviews and the workshop also identified potential sources of data, including that related to the transport system. The GTFS exchange website (www.gtfs-data-exchange.com) provides the opportunity for transit operators (worldwide) to make transport timetable information freely available. The international Organisation for Public Transport Authorities and Operators (UITP) has been involved in the development of a number of databases which have resulted in the provision of potentially relevant data, including the Urban Mobility Database and the Millennium Cities Database (last updated

2015). When considering urban transport interchanges themselves, UITP was involved in the development of the NODES tool (New Tools for Design and Operation of Urban Transport Interchanges) which enables practitioners to assess, benchmark and improve urban transport interchanges. Whilst such databases and sources of data are available, other studies have struggled with identifying appropriate transport related data, which is publicly available and in the right format (Poelman and Dijkstra, 2015). However, such data is expected to increase in its availability over the coming years.

Transport system data collection

Data on the provision of (public) transport services can be gathered from timetables published by transport operators. In the UK, the Department for Transport (DfT) compiles public transport timetable data gathered by operators and local government into a unified national database known as the National Public Transport Data Repository. This dataset describes all public transport services throughout a single week in October (the dataset is updated each year) on all modes. One of the main purposes of the data is to allow local government entities to produce accessibility indicators in the software tool Accession (UK Department for Transport, 2015).

Data on the provision of transport infrastructure would include things like data on the layout of the road network. Such data is available from cartographers. For example, (Baradaran & Ramjerdi, 2001) used a map of the European road network provided by the Institute of Spatial Planning and the University of Dortmund. Other aspects of transport infrastructure that potentially impact accessibility may not be described by readily available datasets – for example, the barriers some users face to accessing the bus system, discussed in (Tyler, 2002), consist in things such as the vertical separation between buses and the edge of the pavement at a bus stop. This data might only be collectable first-hand, through site audits.

Data on the performance of the transport network would include things like travel times by car under normal traffic conditions, measures of congestion and delay, and measures of the reliability of public transport services.

Congestion is the phenomenon of capacity being oversubscribed with demand. Therefore congestion is sometimes measured in terms of the amount of demand on a transport link in proportion to the capacity on that link. Therefore researchers have sometimes used road traffic volume-to-capacity ratios as measures of congestion when investigating effects on accessibility (Mondschein, Taylor, & Brumbaugh, 2010). However, a measure of congestion that can be used more directly in accessibility analysis is the amount of additional travel time incurred by passengers as a result of congestion. Therefore researchers including the Joint Research Council have worked on quantifying congestion in terms of average speeds in congested conditions or average delay per kilometre travelled (JRC, 2012).

Reliability can be understood as a measure of how consistent travel times at a particular time of day are from one day to the next. Measuring reliability therefore necessarily requires repeated measurements of travel time on different occasions. Variability in these measured times can then be compared, for example in terms of the standard deviation of travel time, as a measure of reliability.

The data on travel times in real-world conditions could come from various sources. Firstly, transport networks are routinely monitored by sensors placed in and around transport infrastructure, such as induction loops or cameras on the road network for measuring traffic speeds, volumes, and delay. Secondly, data might be gathered manually, for example by travelling on a bus route several times and recording the actual time taken to complete it. Thirdly, GNSS[1] trackers can be placed on vehicles to

[1] Global Navigation Satellite System

measure travel times and speeds. For example, the UK Department for Transport (DfT) makes use of a dataset of observed average road speeds called Trafficmaster, which is derived from sustained Global Navigation Satellite System (GNSS) tracking of vehicle movements. This data is gathered by a private company; the fleet it draws the data from consists of over 100,000 vehicles using other products from the company which require them to install a GNSS tracking device (Teletrac, 2015).

3.5.2 Individuals

Data on individuals

Various **attributes of individuals** are likely to affect their accessibility, such as

- Mobility-related characteristics specific to individuals, such as whether they own and can drive a car, and whether they have physical or sensory disabilities
- The age of the individual
- "Cultural factors" including gender, ethnicity and faith
- Employment status, what individuals are able to afford, and other aspects of individuals' economic activity
- The responsibilities of the individual, such as their responsibilities to care for others

(Abley & Halden, 2013)

The **activity patterns** and actual travel behaviour proclivities of individuals also greatly affect their accessibility. Individuals' activity schedules – such as their mandatory periods of work, education, or care for others – place spatial-temporal constraints on their accessibility. Individuals also differ in terms of how far they are willing to walk to access public transport (Páez, Scott, & Morency, 2012).

There can also be significant **variability in the way individuals interact with the transport system**. For example, physical features of the transport system like hills, curbs and steps can present an impedance to some users but not others (Abley & Halden, 2013). Some users may also feel unsafe or find using parts of the transport system mentally burdensome in a way that other users might not (Jones, 2012). Therefore data on *perceived* barriers to use of the transport system can be relevant to understanding accessibility.

Individual data collection

Attributes of individuals which may have a bearing on accessibility, such their age, employment status, and whether they have access to a car they can use, are often asked about in travel surveys and other social surveys. Stated preference surveys can also be used to understand underlying preferences and variation across individuals in those preferences. For example, (Bocarejo S. & Oviedo, 2012) used stated preference surveys in Bogota to establish the amount of time and percentage of income individuals were willing to spend on accessing work, then used this to produce measures of accessibility that were sensitive to the different affordability constraints different individuals face.

The **actual travel and activity patterns** of individuals are also measured by travel surveys, or might be derived from smartcard data in intelligent transport systems. Many travel surveys incorporate "travel diaries" for individuals to give details of all the trips they made over a recent period of time. (Time use surveys are another potential source of data on activity patterns.) In principle, information on the actual activity patterns of individuals can be used to construct space-time prism measures of accessibility. The information that travel diaries can provide for constructing time-space prisms is limited, and so scholars have sometimes tried to flesh out diary data with reasonable assumptions in order to establish the temporal and spatial constraints different individuals face. For example, in a study of individuals' accessibility in Ghent, Belgium, (Neutens, Delafontaine, Scott, & De Maeyer, 2012) assume that the work and education activities that individuals report in their travel diaries are "fixed" and so visits to certain other activities would have to fit around the need to be at a specific workplace/college/school at specific times. To capture the complex spatial-temporal constraints individuals face in a more comprehensive way, as is done in (Schwanen & de Jong, 2008), in-depth interviews or other qualitative research methods are needed.

Variability in individuals' interactions with the transport system can be explored through interviews, directly observed in the field, or observed in laboratory settings. University College London's Pedestrian Accessibility Movement Environment Laboratory (PAMELA) is a laboratory that has been used to observe interactions between individuals and transport infrastructure, such as the boarding and alighting of trains. Such laboratory experiments have been used to establish facts about how the ergonomic design of transport infrastructure affects its use by mobility-restrained individuals (University College London, 2015). As an example of qualitative data collection, (Jones, 2012) used focus groups to understand physical and psychological restrictions affecting individuals' ability to use the transport system in Yorkshire, UK.

3.5.3 Land use

Land use data

Data on locations of individuals and opportunities is fundamental to any accessibility measure that takes the land use dimension into account. Academics and practitioners have computed accessibility measures with reference to many different types of activity (individual studies will often only focus on one activity type, such as food shopping). Abley and Halden list the following as opportunities that are frequently included or merit inclusion in accessibility studies:

- "Employment, education and training: employment locations, job centres, childcare facilities, nurseries, schools, colleges, universities, training centres
- Health and social: general practitioners' surgeries, health centres, hospitals, dentists, social security offices, drop-in and day care centres, youth services, citizens' advice bureaux, legal services
- Shopping and leisure: shops/shopping centres, cinemas, theatres, sports centres, outdoor activity opportunities, centres for religious activity, pubs, clubs, post offices, financial services"

(Abley & Halden, 2013)

Employment locations and food shops recur frequently in the literature. Data on certain other opportunity types are only occasionally used. For example, the UK Department for Transport's accessibility indicators feature employment locations, educational institutions, and shops, which seem to be relatively uncontroversial choices as they are accessed on a daily basis by many people. But hospitals also feature in the (limited) set of location types, which is interesting insofar as most individuals will not frequently need access to a hospital – although at certain times or for certain sub-groups of the population, that access can be extremely important. At present, some types of location/service which are argued to be of major societal importance are still rather neglected in the accessibility literature, for example childcare facilities (Páez, Scott, & Morency, 2012).

Land use and urban form over an area is often described using summary indicators, such as population density or job density. When academics have investigated the effects of urban form on travel behaviour, they have tested the explanatory power of summary indicators describing the **"density, diversity, and design"** of urban form. *Diversity* of land use refers to the extent to which different activities are segregated into different areas, or mixed together. *Density* of land use refers to the amount or number of something (for example jobs, households, or shops) per unit area. *Design* is a very broad concept, and might include such considerations as whether an urban area tends to comprise many gridded streets which facilitate navigation on foot, or cul-de-sacs which potentially lengthen journeys, for example. Or it might also refer to physical factors which make an environment more or less navigable to persons with physical or sensory disabilities. In the literature on transport-land use interaction, many different summary indicators of density, diversity and design have been developed and used as potential explanatory variables (Ewing & Cervero, 2010).

Land use data collection

Data on locations of individuals and opportunities is often gathered by surveys. Censuses provide high-quality data on the spatial distribution of individuals, although if this data needs to be supplemented and matched with other information about individuals (such as their travel behaviour) census surveys may be insufficient. Other types of survey that may have relevance to land use include employment surveys; the UK Department for Transport constructs distance-based measures of accessibility to jobs partly on the basis of an official labour market survey sent to employers which generates data on the locations of jobs. (UK Department for Transport, 2012)

Databases of locations of opportunities also often pre-exist for other purposes. For example, central governments keep information on the locations of schools, hospitals, and other public services. Data on the spatial distribution of certain types of opportunity will often be held by the private sector too, for example, the UK Department for Transport uses a private company's data on the locations of food shops in order to compute its shopping accessibility metrics. That data exists to serve another purpose, i.e. to meet the demand among retailers for intelligence on the locations of their rivals' outlets. (UK Department for Transport, 2012)

4 Modelling techniques and their applications

4.1 Modelling techniques

Mathematical and analytical models are often used to operationalise the concept of accessibility. For some types of accessibility measure, mathematical expressions are essential to our understanding of the meaning of the measure.

Other measures, such as distance-based measures of accessibility, may be intuitively understood without reference to mathematical notation. Still, the estimation of those measures is often a complicated process, and can involve the use of complex analytical models.

Once calculated, accessibility measures (and their distribution over space, time and individuals) are often visualised in modelling suites in order to facilitate understanding by the user.

4.1.1 Mathematical functions

Mathematical formulae must be used to generate utility-based and potential (or "gravity model") measures of accessibility.

Potential accessibility measures can be specified in a number of different ways. One of the most common ways of specifying a potential accessibility measure is as follows:

$$A_i = \sum_{j=1}^{n} D_j e^{-\beta c_{ij}}$$

Where

- A_i provides the measure of accessibility in zone *i* to all opportunities *D* in zone *j*
- c_{ij} is the generalised cost of travel between *i* and *j*
- β is the cost sensitivity parameter.

This equation uses a negative exponential impedance function, but other impedance functions are also sometimes used, such as power, Gaussian or logistic functions. (Geurs & van Wee, 2004)

Utility-based measures of accessibility represent the benefits of accessibility as the total benefit of sets of discrete choices. One type of utility-based measure is the logsum, which represents the total expected utility of an individual's choice set, and has the following form:

$$A_i = \ln\left(\sum_{k=1}^{m} e^{V_k}\right)$$

Where

- A_i is the maximum expected utility for *i*
- V_k comprises transport-related, temporal and spatial determinants of utility.

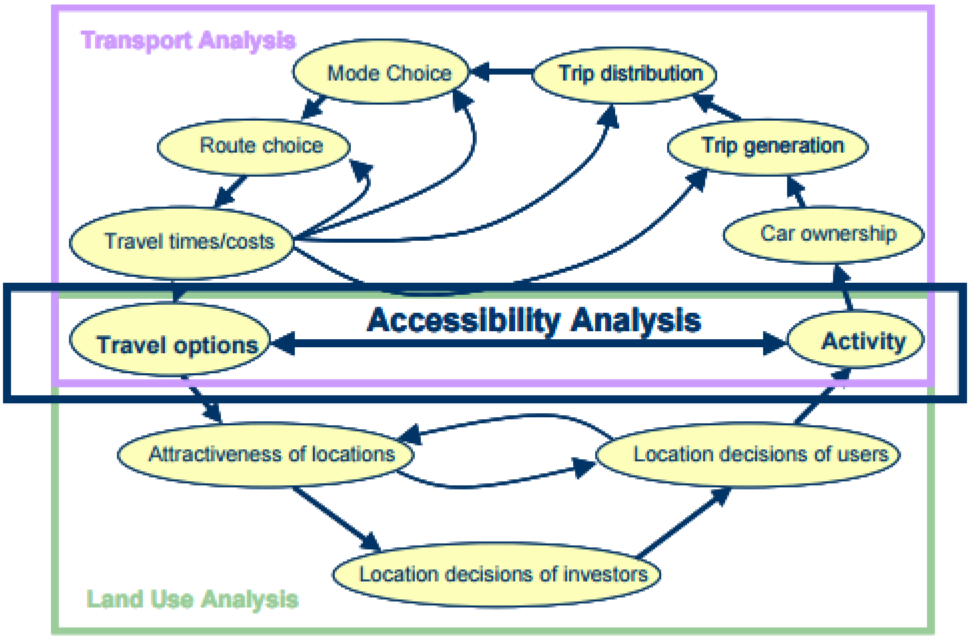
(Geurs & van Wee, 2004)

Alternatively, utility-based measures can be based on the double-constrained entropy model (Martinez & Araya, 2000), the results of which should be equivalent to the logsum (Geurs & van Wee, 2004).

4.1.2 Analytical models

Analytical models capable of providing location-based and utility-based measures of accessibility combine, at a minimum, (1) data on the spatial distribution of opportunities and (2) data on the transport system. Some accessibility models will contain little additional functionality other than the ability to combine that data and generate outputs. Other models capable of producing accessibility metrics might have significant additional functionality, including the ability to model changes to transport supply and demand and the effect this has on travel costs, the ability to model land use changes, and the ability to model transport-land use interaction (Abley & Halden, 2013). Stages that can be involved in fully-blown transport and land use interaction models are shown in the figure below. Many of these stages are captured in models like the TIGRIS XL demand model developed for the Netherlands, which outputs utility-based accessibility metrics, and can therefore be used to place a monetary value on the accessibility benefits of transport system interventions and/or changes to land use.

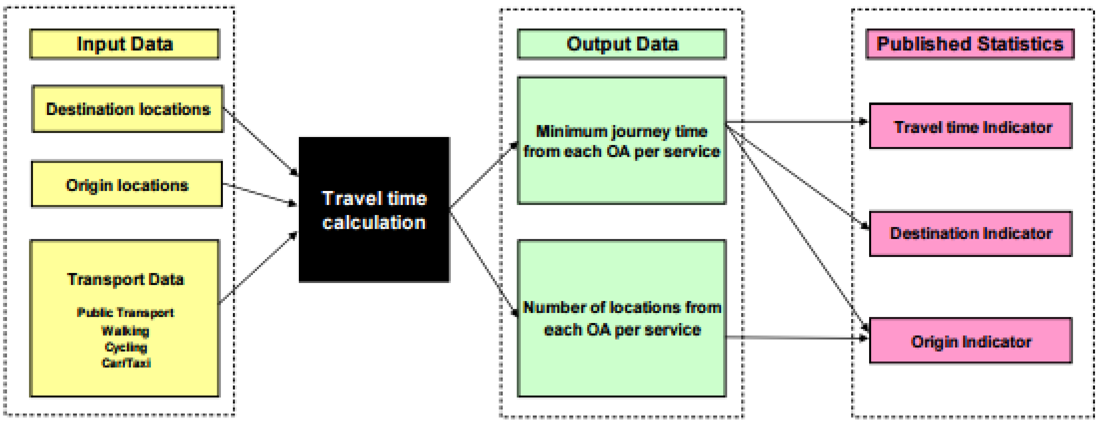
Figure 4-1: Accessibility analysis in relation to stages of transport demand modelling



Source: (Abley & Halden, 2013)

By contrast with complex demand models like TIGRIS XL, the UK Department for Transport's accessibility metrics are derived only from consideration of currently possible travel times and the current spatial distribution of opportunities. Computation of travel times takes place off a matrix of travel times between points by various modes. (UK Department for Transport, 2012).

Figure 4-2: UK Department for Transport accessibility statistics calculation process



Source: (UK Department for Transport, 2012)

Models have also been developed to generate space-time prisms of individuals' potential choice sets, in order to afford especially careful treatment to the individual and temporal dimensions of accessibility. These models are relatively rare in part because they require very detailed data on individuals which is not usually available. An example would be the model developed to explore individuals' access to government offices in (Neutens, Delafontaine, Scott, & De Maeyer, 2012), which was applied to detailed travel diary data from a small sample of individuals. The model was used to calculate, among other things, the number of days in each week in which specific individuals would be able to access government offices, given their individual spatial-temporal constraints.

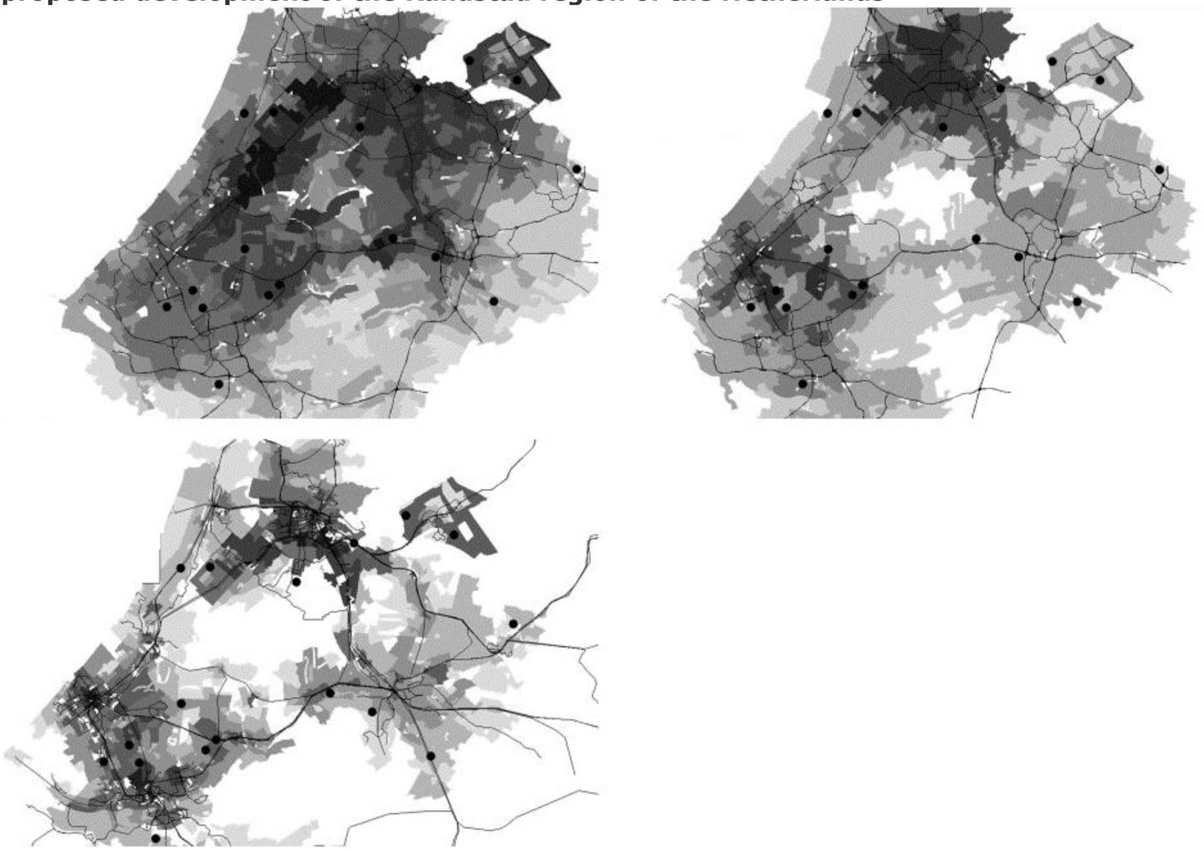
4.1.3 Visualisation

Model outputs are often presented as 2-dimensional maps showing spatial variation in accessibility. Temporal variation can also be shown by presenting 2-dimensional maps of accessibility at different times. Toolsets have also been developed for visualising space-time prisms in geographic information systems (Charleux, 2014).

Visualisation is an important part of model functionality. A recent COST action assessing the usability of various accessibility instruments found that functionality for presenting model outputs in map form contributed very significantly to the usability of those instruments by practitioners (Brömmelstroet, Silva, & Bertolini, 2014).

These maps will frequently take the form of "heat maps", where different levels of accessibility are represented with different colours. For example, Figure 4-3, taken directly from (Bertolini, Le Clercq, & Kapoen, 2005), shows modelled levels of accessibility in the Dutch conurbation surrounding Amsterdam, Rotterdam, The Hague and Utrecht ("The Randstad"). In these maps, accessibility is operationalised in terms of a distance-based measure, namely the number of employment centres and concentrations of non-daily services within 30 minutes of travel time. Darker colours represent greater ease of access to these centres. The map in the top left shows accessibility by car in uncongested conditions, the top right shows the same in congested conditions, and the bottom left shows accessibility by public transport.

Figure 4-3 Visual representation of distance-based accessibility measures in a model of proposed development of the Randstad region of the Netherlands



Clockwise from top left: Accessibility by car in uncongested conditions, by car in congested conditions, and by public transport. Source: (Bertolini, Le Clercq, & Kapoen, 2005).

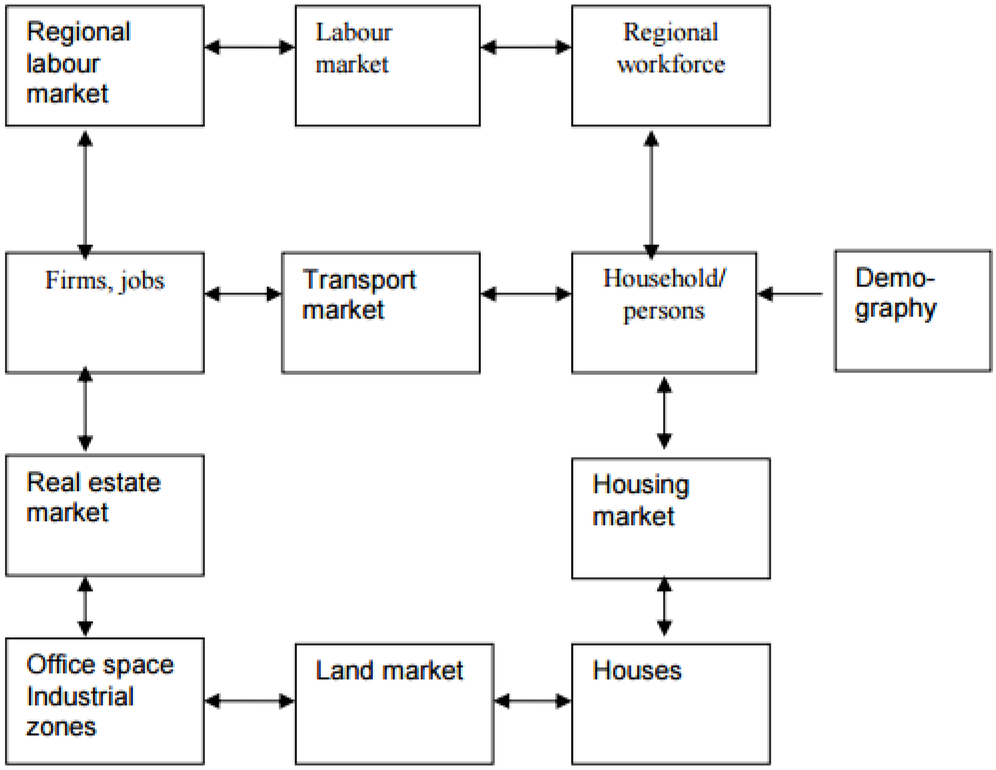
4.2 Example applications of accessibility models

4.2.1 TIGRIS-XL

The Dutch Ministry of Infrastructure and the Environment has developed a transport-land use interaction model capable of calculating several different types of accessibility measure. The model, TIGRIS-XL, has been applied to several policy studies since the first version of the model was finalised in 2006. As a transport-land use interaction model, it functions as a set of sub-models dealing with phenomena such as residential location and job location (see

Figure 4-4)

Figure 4-4: Functional design of the TIGRIS-XL model



(Zondag, de Bok, Geurs, & Molenwijk, 2015)

The model is capable of calculating infrastructure-based utility measures such as cumulative hours 'lost' in congestion, location-based accessibility measures such as the number of jobs that can be reached within 45 minutes by car or public transport, and a utility-based measure of accessibility (the logsum). The logsum measure allows for quantification (and monetisation) of the accessibility benefits of land use changes as well as changes to the transport system. The logsum is also used internally in the model, as a means of firms' and individuals' decisions to optimise their locations. Some of the key parameters driving those behaviours in the model were derived from regression analyses of social surveys of the actual population of the Netherlands. The model calculates accessibility benefits on a disaggregate basis, taking into account differences in 'person types' (of which there are over 350) and journey purposes.

A demonstration use of the model to prospectively appraise transport interventions is described in (Zondag, de Bok, Geurs, & Molenwijk, 2015). The model was used to

appraise several options for public transport investments in the corridor between Amsterdam Schiphol Airport, Amsterdam, and Almere (a new town located 30km East of Amsterdam on reclaimed land). The options assessed were based on local government proposals for developing Almere and adding capacity to the public transport system.
According to the model, the transport investments would have a modest impact on location choices of firms and households. The impact on location choices was thought to be modest because Holland already has a dense transport network and land use is heavily regulated by government.

Since the model was capable of producing infrastructure-based measures of the benefits of transport interventions, these were compared with the logsum measure. The monetised logsum benefits were 10-30% higher than the benefits of reduced travel costs estimated using the "rule of half" commonly applied in transport appraisals. The authors attributed the difference in estimated benefits to two factors, one of which was just the greater precision afforded by more disaggregated modelling of individuals. The second reason was that the rules of half provides inaccurate estimates of accessibility benefits of transport interventions when those interventions alter the spatial distribution of opportunities. Even the modest changes of location brought about by the intervention under study had a significant effect on the accessibility benefits of some users.

4.2.2 UK Department for Transport's Accessibility statistics

The UK Department for Transport (DfT) developed location-based measures of accessibility which have been used as part of the evidence base for local and central government decision making.

The Department first published statistics like these in 2005, and has released them annually since 2007 (UK Department for Transport, 2014). The indicators are all examples of location-based measures of accessibility. Three types of distance-based (or contour) measure are published:

- "Travel time" indicators report the shortest time taken by users (on average, among the population within small area) to reach the nearest destination, for example and employment centre.
- "Destination" indicators report the proportion of users in an area that can access a service within a certain time – for example, the percentage of 16-74 years olds within 20 minutes of an employment centre.
- "Origin" indicators look at the number of opportunities within reach of users in a specified area (contour), for example, the number of jobs located within 20 minutes of a local administrative area

(UK Department for Transport, 2014)

The opportunity types included in the statistics comprise employment, town centres, food stores, local medical services (general practitioners' offices), hospitals, primary schools, secondary schools, and further education institutions.

The origin and destination indicators rely on defined thresholds representing what is assumed to be a reasonable travel time for a given trip purpose; for example, the indicators for accessibility of schools report the number of schools (or users) within 20 minutes and within 40 minutes of users (or schools) by public transport or active modes. Rather than being arbitrarily defined, these thresholds are based on the actual distribution of travel times found in the results of a national travel survey. The lower threshold is the median travel time for trips to that opportunity type, and the upper threshold is a value lying in the 80^{th}-90^{th} percentiles of observed travel times. (UK Department for Transport, 2012)

In addition, the Department calculates what it describes as "continuous" indicators of origin and destination accessibility, or *potential accessibility / gravity model* measures in

the terminology of Geurs and van Wee (Geurs & van Wee, 2004). These indicators weight the population within a geographic area by a negative exponential function of travel time to the relevant opportunity.
Travel times are estimated on the basis of a relatively detailed, assumption-laden process. A sparse matrix of travel times between zones/locations by different modes is built up from data including road network maps and timetables of public transport services.

Some of the indicators the Department calculates are partially person-based, insofar as they provide location-based measures of accessibility for certain sub-sections of the population, including households without a car, people in receipt of unemployment insurance, and children in receipt of state-subsidised school meals.

4.2.3 Other examples

Academics regularly produce new and innovative accessibility models and apply them to real-life urban environments to demonstrate their potential use or substantiate an empirical finding. For example, (Bocarejo S. & Oviedo, 2012) developed an accessibility model for Bogota which quantifies accessibility using a potential accessibility (gravity model) measure, but took the unusual step of making the cost function in the equation sensitive to individuals' incomes. This elaboration effectively allows the model to consider how individuals' accessibility levels are (differently) affected by their (different) budgets for transport expenditure. The authors then used the model to quantify the potential benefits of different policies for improving the city's bus rapid transit system. Notably, the authors found that the accessibility benefits of investing in the system to expand the network were not as great as the accessibility benefits of spending a comparable amount on further subsidisation of fares.

5 ICT / ITS solutions

5.1 Accessibility modelling software

Software accessibility models rely on Geographic Information Systems (GIS) and relational databases. To a greater or lesser extent, each will also rely on bespoke programming to put the GIS and relational database to use in an efficient and user-friendly way. (Abley & Halden, 2013)

5.1.1 Transport Demand models

As indicated in the previous section, some transport demand models may be readily equipped to perform accessibility analysis. For example OmniTRANS, Visual-TM and Cube – all software packages designed to be picked up by transport planners and applied to their own cities – are capable of producing accessibility indicators (Abley & Halden, 2013). Each of these models gives significant attention to the transport system dimension of accessibility by calculating the deterrence/disutility of travel. In particular, travel time is given central importance. The cost of travel is modelled, but tends to be given simpler treatment, e.g. public transport fares are estimated on the basis of distance. The land use dimension is typically treated as external to the model. The individual dimension might be considered in terms of differences between persons living in different areas, confined to different modes, or making trips for different purposes, and in some cases the differences between individuals can be output from the model.

Table 5-1: Examples of demand models with accessibility indicator functions

Model	Estimation of travel time and cost	Land use interaction	Accessibility indicator calculation and output
OmniTRANS (Omnitrans International – Netherlands)	Outputs average times by all modes and real-time simulations for traffic, but not clock-time public transport options. Costs estimated from distance.	Database functionality allows accessibility impacts of land use scenarios to be compared.	Optimised to compare access for different people groups using Cube functions and mapping interfaces.
Visual-TM (Peter Davidson Consultancy, UK)	Outputs average times for trips by all modes. Costs estimated from distance.	Land use as an input but not interactive.	Use of map-point GIS software provides a visual interface and data management for comparing impacts on different groups of people.
Cube (Citilabs, UK)	Outputs average times by all modes and real-time simulations for traffic, but not clock-time public transport options. Costs estimated from distance	Land use as an input but not interactive.	ArcGIS interface provides mapping options for indicators.

Source: (Abley & Halden, 2013)

5.1.2 Specialist accessibility models

There are also a large number of other models that have been developed to perform accessibility analysis without the functionality for transport demand modelling. Due to their more restricted functionality, these models are often cheaper (Abley & Halden, 2013).

Table 5-2: Examples of models with accessibility indicator functions but no demand modelling capability

Model	Estimation of travel time and cost	Accessibility indicator calculation and output
Accession (Citilabs, UK)	Calculates journey times based on scheduled arrival and departure times.	Various contour and continuous functions are optimised for indicator and mapping outputs.
ICON (MCRIT, Spain)	Time and distance using average speeds using road networks.	GIS-based model to optimise regional accessibility indicator calculation.
AccessMAP – (CSIR Transportek, South Africa) the AccessMAP	Based on distance using GIS systems.	GIS based with indicators originally designed for planning new public facilities such as health centres but extended to investigate transport investment options.
ABRA (Colin Buchanan and Partners, UK)	Scheduled journey times from public transport timetables.	Spreadsheet based accessibility indicator calculation.
ACCALC (Scottish Executive, UK)	Travel times and costs not calculated but taken as outputs from transport models	Functions to assist users to specify and output indicators for analysis and mapping.
Capital – 'Calculator for public transport accessibility in London' (TfL, UK)	Public transport times from strategic public transport model for London and walking times estimated using GIS from distance from origin to the nearest modelled node.	Links to London's planning and development GIS for indicator calculation and output.
PTAM (West Yorkshire Passenger Transport Executive, UK)	A hierarchy of public transport nodes is determined and walk times to these from small local areas are calculated.	Travel time for users to services.
AutoPTpath	Highly optimised routing algorithms to be able to calculate optimal journey times for very large numbers of zones. Uses scheduled departure and arrival times for public transport.	Links to GIS for mapping.
WALC (University of Westminster, UK)	ArcGIS based with travel times for walkers being estimated and weighted based on obstacles faced (eg including	Population catchment indicators are output based on a set of destinations.

	steep hills).	
Amelia (UCL, UK)	GIS used to allow user defined attributes to be allocated to links in the network to calculate travel times.	User consultations and focus groups being used to define parameters for indicators.

Source: (Abley & Halden, 2013)

Another advantage of some of the specialist accessibility models is that they allow deterrents of travel other than travel time and cash costs to be brought into the computations. For example, some of these models can be set up so that unlit streets are removed from the transport network at night, to represent the fact that individuals may feel too unsafe on those streets to consider them as real options for travel. Accessibility models, such as CAPITAL, PTAM, WALC, Amelia and ACCALC, have functionality for non-time deterrents. (Abley & Halden, 2013)

5.1.3 Interrogation of intelligent transport systems' data and models

Models originally built to provide journey planning services can also be harnessed to investigate accessibility issues. For example, (Ferrari, Berlingerio, Calabrese, & Reades, 2014) used smartcard data and an existing journey planner to model the potential impacts of making particular metro stations in London wheelchair-accessible.
The authors developed a method of quantifying the impacts on the accessibility of wheelchair users of different potential station upgrade decisions. Firstly, origin-designation matrices of current travel patterns were derived from smartcard data held by the transport provider. The transport provider's journey planner was then used to derive journey times for individuals who are only able to use wheelchair-accessible stations and buses, and compare these with the travel times of individuals not facing those constraints. Various options for upgrading sets of stations to make them wheelchair-accessible were then tested on the basis of those travel time estimates and comparisons.

The authors' preferred measure of accessibility was the cumulative travel time of all wheelchair users (assuming fixed origins and destinations before and after the intervention). This would count as an infrastructure-based measure according to the categorisation in (Geurs & van Wee, 2004).

The modelling exercise revealed that when planners have the resources to upgrade several (but not all) stations at once, the optimum choice of the set of stations is non-obvious, at least in the example of London. This was partly due to the complexity of the system as it stands, and partly due to the fact that the system currently exists in a semi-accessible state for wheelchair users.

6 Policy initiatives affecting accessibility

This section explores a range of potentially significant policy initiatives that can affect accessibility in urban areas.

6.1 Land use policy initiatives

The notion that planners of transport networks and the urban environment should be concerned with *accessibility* in addition to (or instead of) mobility provided support for various doctrinal developments in urban planning. These include "New urbanism" or "neo-traditional development," which originated in North America in the 1980s. Proponents of new urbanism (who include academics and professional planners) advocate for various principles and features in urban design including, for example, the use of gridded and densely-intersecting street networks to improve the accessibility of neighbourhoods on foot. To a large extent the movement is a reaction to trends in urban development – such as sprawling suburbs with copious cul-de-sacs – which are more typical of North America than Europe. Another transport/urban planning concept to have gained signification traction in North America is "Transit-oriented development". Transit-oriented developments centre on public transport access nodes such as railway stations or Bus Rapid Transit stops, and consist of high-density, mixed-use development mainly located within reasonable walking distance of the stop, as well as various features designed to encourage alternatives to travel by car, such as limited or restricted parking. In Europe, planning initiatives are rarely labelled with the terms "new urbanism" or "transit-oriented development", possibly because some of the characteristics of those movements are native characteristics of many European settlements. But similar ideas about the land use dimension of accessibility have clearly been relied upon in various national or regional policies in European countries, including the "Finger Plan" for Copenhagen or the Dutch "Vinex" policy.

Copenhagen's "Finger Plan" was produced by Danish town planners in 1947. It set out plans for the future spatial expansion of Copenhagen in a way that would confine development to a set of five corridors or "fingers" radiating out from the city centre. Each of these corridors would contain a railway line, whose stations would act as focal points for development. The plan was therefore an example of transit-oriented development before the term had been invented. (Knowles, 2012).

Dutch spatial planning policy developed in the late 1980s and early 1990s – known as "Vinex" – set priorities for urban development in the Netherlands partly with reference to the expected consequences for accessibility and travel behaviour. New housing developments were to be accommodated within existing city limits, or failing that, at the edges of the cities, or else nearby. One of the benefits for the inhabitants of these new homes of their location in densely-populated areas would be greater accessibility by public transport (Snellen & Hilbers, 2005).

Academics have debated the effects of land use on travel behaviour for decades. An influential work on the relationship between urban density and mobility was published in 1989 (Newman & Kenworthy, 1989) and since then hundreds of papers have been written on the topic (Ewing & Cervero, 2010). Practitioners have been aware of the idea that land use policy might be used to affect travel behaviour for many years. For example, in the United Kingdom, between 2001 and 2012 the government's official planning policy statements included the following text:

> "By shaping the pattern of development and influencing the location, scale, density, design and mix of land uses, planning can help to reduce the need to travel, reduce the length of journeys and make it safer and easier for people to access jobs, shopping, leisure facilities and services by public transport, walking, and cycling."

(UK Department for Communities and Local Government, 2011)

But the question of whether land use change can actually have a significant effect on travel behaviour is still controversial. Among several issues at stake in this debate is the idea of *residential self-selection*; the hypothesis that some people may choose to move their home to a certain type of area in order to allow them to realise a certain pattern of travel behaviour. (For example, some people may prefer to live in the city centre because it allows them to walk, while others may enjoy using a car and choose the suburbs accordingly.) If residential self-selection is a significant force, changes to land use may not result in significant changes in travel behaviour. So far a very limited number of quantitative studies of the influence of land use have been designed to take residential self-selection into account (Ewing & Cervero, 2010).

It has also been suggested that decreasing the spatial separation of activities might have little or no effect on the amount of travel individuals perform because they often prefer to travel to better quality locations rather than keep their travel time "savings" for non-travel activity. Indeed, there is a body of empirical work suggesting that at a societal level, average daily travel time has remained constant for many decades, suggesting individuals have constant "travel time budgets" (van Wee, 2011).

The debate implies that it is still unclear what the actual *effect* would be (in terms of mobility, or emissions, for example) of improving accessibility through changes to land use. In addition to the lack of conclusive research, there is also a lack of modelling tools for relating the daily activity and travel patterns of individuals to transport-land use interaction (Geurs & van Wee, 2004).

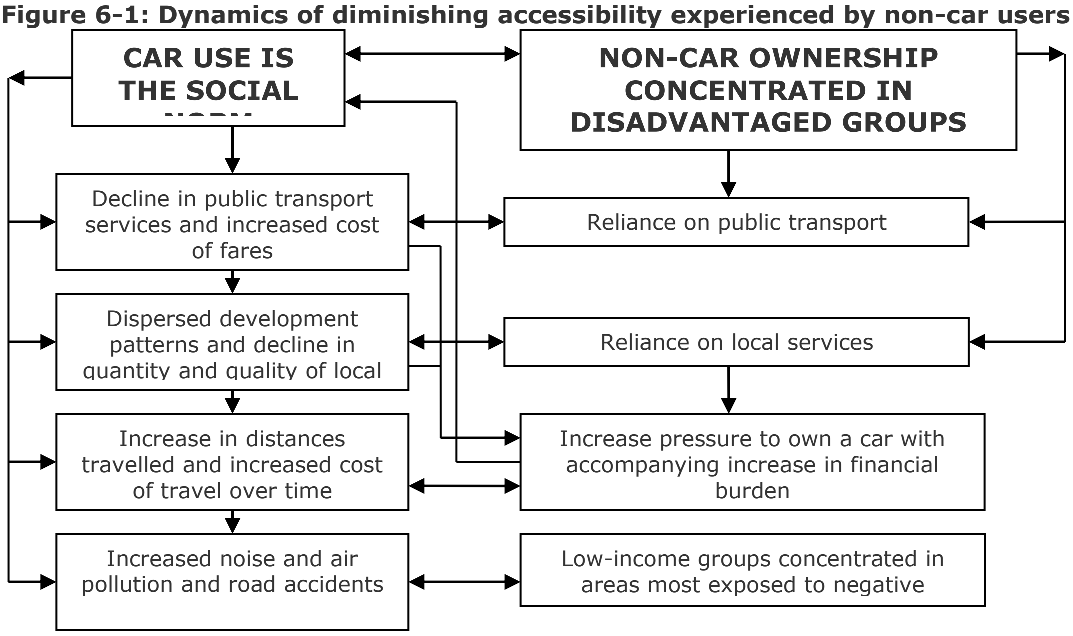
6.2 Social exclusion

Social exclusion has been defined as "a shorthand label for what can happen when individuals or areas suffer from a combination of linked problems such as unemployment, poor skills, low incomes, poor housing, high crime environments, bad health and family breakdown" (UK Social Exclusion Unit, 2001). Policymakers in Europe identified social exclusion as a particular issue for areas on the periphery of urban centres, and the UK's Social Exclusion Unit took up the issue of links between social exclusion and accessibility.

This culminated in a watershed report (UK Social Exclusion Unit, 2003) on social exclusion and transport which greatly informed the UK's policy approach to accessibility analysis and strategy, as well as influencing policymakers in other countries (Lucas, 2012). The report advocated for an accessibility planning approach to public transport provision in order to tackle transport-related social exclusion. It recommended that work should be focussed on low-income populations and concentrate on providing good accessibility to work, education, healthcare and food shopping, and (to a lesser extent) participation in social life and leisure activities. Land use change was also highlighted as a potential means of partly addressing some social exclusion problems. (Lucas, 2012).

Transport-related social exclusion remains an active area of research many years after the publication of the 2003 landmark report by the UK's social exclusion unit. There are now a varied set of methodologies for identifying and measuring transport-related exclusion, which continue to be refined. Several features of the transport system contributing to social exclusion have been identified by Church *et al.* (2000). These include economic exclusion (high monetary costs of travel limiting access), geographical exclusion (too far away from facilities or transport services), time-poverty (combined work, household and child-care duties preventing mobility), fear-based exclusion (non-use of public spaces or transport due to fear for personal safety), space exclusion (security preventing access to facilities for certain groups) and physical exclusion (lack of disabled facilities or low-floor buses preventing accessibility). Lucas (2012) focuses on the dynamics of decreased accessibility for disadvantaged groups as a result of increased car use (see Figure 6-1).

Figure 6-1: Dynamics of diminishing accessibility experienced by non-car users



Source: Lucas (2012)

In the UK, policymakers' actual efforts to address the issues have been characterised as mixed and in decline (Lucas, 2012), owing in part to lack of sufficient subsidy for transport system costs as well as a shift away from 'social exclusion' as an item on the transport policy agenda. However, where transport policies targeted at disadvantaged populations were introduced, they tended to be successful in increasing mobility and reducing social exclusion (Bristow *et al.* (2008), Lucas *et al.* (2008)). Elements of the government's original (and pioneering) accessibility planning approach to tackling social exclusion have now been overturned. One possible topic for future research is the impact of austerity measures across Europe on transport-related social exclusion (Atkins & CRSP, 2012).

6.3 Accessibility of the transport system

Over time, governments have gradually made greater efforts to improve the accessibility of transport systems by taking steps such as investing in more accessible infrastructure or mandating that public transport vehicles meet certain minimum standards of accessibility for persons of reduced mobility. For example, one of the EU's technical specifications for interoperability of the EU rail system sets standards for making rail vehicles accessible for persons with reduced mobility (European Commission, 2014). Against this background, research relating to the accessibility of the transport system continues on several fronts.

Some researchers continue to deepen our understanding of how persons with reduced mobility interact with the transport system. For example, Holloway and Tyler propose a model for quantifying the additional work wheelchair users must perform in order to propel themselves along a footway with a crossfall gradient (a gradient perpendicular to the direction of travel) (Holloway & Tyler, 2013). One of the uses of research like this, other than understanding the current limitations to accessibility of transport systems, is in informing future approaches to designing those systems or specifying minimum standards for them.

Researchers also continue to investigate possibilities for quantifying or otherwise summarising accessibility for passengers of reduced mobility at an aggregate level. For example a recent FP7 project on describing the accessibility of transport in Europe developed a proposed set of indicators and a self-assessment toolset that cities could use to evaluate the level of accessibility of their transport systems. (SINTEF, 2010)

Finally, there is a body of research focussed on finding ways to improve the accessibility of the transport system in innovative ways, ranging from low- to high-tech. For example, as a relatively low-tech innovation, in the early 1990s special kerbs were designed which allow bus drivers to approach bus stop platform much more closely without damaging the vehicle tires, reducing the gap between vehicle and platform so that passengers of reduced mobility are less likely to face difficulties boarding the vehicle (Tyler, 2002). Other, more high-technology avenues for improving the accessibility of the transport system in innovative ways include intelligent transportation systems (ITS), accessible data, wireless communications, mobile computing, robotics, artificial intelligence, and object detection navigation (Yousuf & Fitzgerald, 2012).

6.4 Accessibility and economic development

The accessibility of an area and its level of economic activity are closely linked – because many of the opportunities commonly taken into account in accessibility metrics are opportunities to engage in some form of economic activity; such as working or paying for services; or buying, selling and transporting goods.

One topical research question touched on in the TRACC project (ESPON, 2015) is the causal link between accessibility and economic development at a regional scale. The project authors concluded that "good accessibility is a precondition for economic development" – other things being constant, regions with access to deeper product and labour markets are more economically successful. However, the strong correlation between accessibility and indicators of economic activity might to a large extent just reflect the fact that both are linked to agglomeration of urban areas over time. TRACC's review of the evidence suggested that it is very difficult to link *changes over time* in economic activity to changes in levels of accessibility. Large changes in accessibility seem to only be associated with rather small changes in economic development. However, the effect is much more significant for areas which start from a low level of accessibility than areas that start from a high level.

6.5 Accessibility case studies

6.5.1 Local accessibility planning in the UK

In 2004, the UK central government began providing guidance and support to local government entities to help them tackle the accessibility problems of disadvantaged groups (Atkins & CRSP, 2012). This policy followed on from highly influential research by the government's special unit for analysis of "social exclusion" (UK Social Exclusion Unit, 2003).

The guidance from central government described a process for developing, implementing and monitoring a plan for improving accessibility at a local level. According to the guidance:

> "Accessibility planning focuses on promoting social inclusion by tackling the accessibility problems experienced by those in disadvantaged groups and areas. These might include the availability, affordability and accessibility of local public transport, the design, location and delivery of non-transport services, and the ability of the community to reach those services by foot or cycle. It also focuses on access to those opportunities that are likely to have the most impact on life chances: employment, education, health care and food shops"
> (UK Department for Transport, 2005)

Central government also provided local government with free copies of Accession to perform formal modelling of accessibility. The benefits of using Accession were envisaged as follows:

> "Use of Accession can help authorities to identify local areas and communities that are poorly served by jobs, local facilities or transport services and undertake a wide range of investigations for policy and planning purposes. It can also help authorities to develop, and evaluate the benefits of, potential alternative solutions. These should include enhancement of service provision as well as transport solutions"
> (UK Department for Transport, 2005)

As well as being supported by central government in this way, local government was required to submit an "accessibility plan" to central government as part of a wider transport plan, and to submit reports monitoring progress towards the goals in those plans.

In 2008, local government entities and central government negotiated a set of "Local Area Agreements" (LAAs) that would have made future funding for transport partly contingent on the delivery of agreed targets relating to accessibility planning. Some of these targets were set with reference to the UK's Accessibility Statistics, such as 'Access to services and facilities by public transport walking and cycling' and 'working age people with access to employment by public transport (and other specified modes)'. However, with a change of national government in 2010 those agreements were abolished, and the accessibility plans of local government are no longer formally assessed by the Department for Transport.

An evaluation of UK accessibility planning policy in 2012 commissioned by the Department for Transport concluded that the guidance provided by central government had been useful and ought to be re-issued. The evaluation stated that accessibility modelling was important, but highlighted that the software that had been issued to local government (Accession) had seen limited improvements over the years and there was a need to improve its functionality in certain respects, such as the way Community and Demand Responsive Transport (two types of initiative included in accessibility plans) was modelled.

6.5.2 Use of accessibility statistics in the UK

The accessibility statistics developed by the UK Department for Transport were developed to help local government entities "develop their evidence base" for transport interventions aimed at improving accessibility (UK Department for Transport, 2014), but they have also been used by *national* government to monitor progress towards national policy objectives, and referred to on an ad-hoc basis when considering the impacts of various policies affecting the spatial distribution of activities.
The UK Department for Transport's 2012-2015 business plan (UK Department for Transport, 2012) identified an accessibility indicator as one of its "impact indicators" to "help the public assess the effects of [the Department's] policies and reforms". The indicator was meant to relate to the Department's aim to "promote a transport system that is accessible and socially inclusive". The particular indicator used is an index that combines (1) travel time by public transport to key services with (2) car ownership levels. The indicator of travel time by public transport to key services is itself a weighted combination of measures of travel times to various important services. (UK Department for Transport, 2012).

In addition, Halden identifies the following examples of the government departments making reference to the accessibility statistics when considering the impacts of policies affecting the spatial distribution of opportunities:

- "As part of the liberalisation of the market for pharmacy services, the Department for Health investigated travel times to pharmacies and dispensing GPs for car and non-car available trips. This informed an investment programme to support pharmacies, where closures might have otherwise adversely affected accessibility.

- The Legal Services Commission planned travel times to eight categories of legal aid service across England and Wales to ensure that when commissioning services, the providers were located in accessible locations for car and non-car available trips.
- When considering rural post office closures across England the department for rural affairs (DEFRA) used travel time data by public transport to rural post offices.
- Travel times to rural services are monitored annually for the State of the Countryside report (CRC 2010) including free cash machines, pubs, post offices, grocers, services included in the core accessibility indicators.
- In order to assist in decisions about the location of courts the Department of Justice used analysis of travel to inform decisions on investment and closures.
- The National Consumer Council used analysis of the locations of cash machines to identify locations where citizens only had a pay per use facility available. They then used this to negotiate with the banks for over 600 additional cash machines to become free to use."

(Halden, 2011)

Halden also identified examples of what he characterised as "widespread abuse" of accessibility statistics. The UK Department for Transport publishes several hundred different indicators of accessibility for local government to pick and choose from, which has led to the following problems: "National measures are adopted by local authorities […] without questioning whether the assumptions are relevant," "Planning decisions have been made […] without sufficient thought about what indicator might be relevant or useful," and "indicators have been used tactically, to make the case for a development look artificially strong or weak" (Halden, 2011).

6.5.3 Use of accessibility measures by Swedish local government

Regional and city government in Sweden has shown an increasing interest in accessibility modelling in recent years, "brought forward by the use of GIS in Swedish municipalities and an extensive access to geographic data" (Hull, Silva, & Bertolini, 2012). Accessibility measures have been used to inform town planning decisions, for example, Stockholm's park program has been informed by use of measures of accessibility of parks, and other cities are also sympathetic to the use of accessibility measures for park planning. Gothenburg municipality has suggested that provision of car parking should be linked to accessibility of public transport. (Hull, Silva, & Bertolini, 2012)

6.5.4 Accessibility standards in Germany

German government has given legal force to certain minimum standards of accessibility of vital services such as education and healthcare. These standards are set out in spatial planning legislation that also aims to discourage urban sprawl. Cities are placed into categories and various accessibility standards apply to cities in certain categories. The standards are defined in terms of travel time.

Accordingly, local government uses accessibility models to quantify actual levels of accessibility to the aforementioned vital services. In particular, they will often use contour measures of accessibility by public transport – either the percentage of the population living within a certain distance of a public transport stop, or measures of the opportunities that can be reached within a certain travel time. (Hull, Silva, & Bertolini, 2012)

7 Summary and conclusions

7.1 Urban accessibility

This State of the Art Review of urban accessibility has shown that a range of definitions for accessibility exist. However, it is acknowledged that accessibility can be defined as "….the ease of reaching good, services, activities and destinations in urban areas. It includes factors such as mobility options, travel information, transport network connectivity, land use patterns and cost for both passengers and freight".
From a review of the literature, urban accessibility tends to have four distinct dimensions. These are as follows:

- The **transport dimension** of accessibility comprises the various available options for transport. This component partly determines the disutility an individual would experience in travelling between an origin and destination (or the disutility an agent would experience when transporting their freight between an origin and destination).
- The **land use dimension** of accessibility consists of the amount, quality and spatial distribution of activity locations (or "opportunities" or "destinations") which individuals might want to travel to (or which agents might want to move their freight to).
- The **individual dimension** of accessibility relates to the (different) needs, capabilities and perceptions of (different) individuals. Individuals vary in terms of their physical capabilities, which can affect their feasible set of options for transport. Their options can also be affected by their economic resources, or the time constraints they face in their lives, or the information that is available and salient to them, and so on. There may be analogous situations in freight transport, for example due to the fact that different types of freight need to be handled differently.
- Accessibility also has a **temporal dimension** for several reasons; activities/opportunities are often only available at particular times (for example shops will often close for part of the day) or else it is mandated that certain activities (like work) take place at certain times. Furthermore, individuals are constrained in when they can travel to certain destinations and perform certain activities due to the other activities they must perform (such as work, care, or meeting other individuals) (Geurs & van Wee, 2004).

7.1.1 Urban accessibility and mobility

'Mobility' is mentioned in the definition of accessibility. However, it is distinct from 'accessibility', although often used interchangeably. Mobility refers primarily to the movement of people and goods, typically via the transport system, whereas accessibility involves the considerations of the opportunities enabled by mobility, therefore considering the land use element.

It is this consideration of opportunities and land use that adds further complexity to accessibility as a concept. Whilst transport opportunities can be plentiful, with good physical access to vehicles, and high frequency (all indicators of mobility), they may not connect individuals with their desired opportunities.

In the EU there has recently been focus on and support for Sustainable Urban Mobility Plans (SUMPs), which aim to improve the accessibility of urban areas and provide high-quality and sustainable mobility and transport to, through and within the urban area. SUMPs aim to address all relevant modes of transport, whilst encouraging a shift towards more sustainable modes. However, the opportunity/land use aspects of accessibility are absent from this approach.

Whilst improving urban mobility will certainly help to achieve a range of economic and social benefits, improving urban accessibility is likely to generate more economic and social benefits than mobility alone. It is therefore recommended that the focus of SUMPS should be widened to address the wider issue of accessibility, which incorporates mobility.

7.1.2 Urban accessibility and congestion

As noted in the introductory section of this review, the relationship between urban accessibility and congestion is not completely straightforward. Congestion constrains and reduces mobility, and this means that – other things being equal – it has a negative causal effect on accessibility. But congestion and accessibility are also linked in another way: both tend to increase with agglomeration of opportunities. Therefore, when drawing comparisons between areas in terms of their levels of accessibility and congestion, we may find that areas with greater levels of congestion also have greater levels of accessibility, despite the negative causal effect of congestion on accessibility.

Another factor which potentially complicates comparisons between urban areas in terms of their levels of congestion and accessibility is the variation between *individuals* in those areas. If individuals in different areas desire quite different opportunities – either because they cognitively 'adapt' to their environments or because they residentially self-select into them – there is a risk that accessibility measures could overstate the effect of congestion on accessibility in more-congested areas.

In summary, we can say that the cross-sectional relationship between congestion and accessibility is contingent on the facts within the individual and land use dimensions of accessibility. Still, boosting mobility over time in a city by alleviating congestion will (other things being equal) increase accessibility.

7.2 Accessibility metrics

Like the various dimensions of accessibility, there are also a number of types of accessibility metrics available. These include the following:

- **Infrastructure-based measures** quantify accessibility in terms of the performance of the transport system – for example, the average speed on the road network, or levels of congestion. (Geurs & van Wee, 2004). Further categories in this type of measure include:
- In addition, some accessibility indicators describe transport infrastructure using concepts from **graph theory,** which is the mathematical study of graphs (structures consisting of *nodes,* or points, connected by *edges,* or lines). Graphs can be used to represent transport infrastructure – for example, in a railway network, stations can be thought of as nodes and the links between stations can be thought of as edges. Graph theory gives us a multitude of indicators that might be thought of as characterising the overall accessibility of a whole network, or alternatively, accessibility at particular points in the network. For example, there are metrics in graph theory for describing the number of edges you typically have to traverse to get to other nodes. (Scheurer & Curtis, 2007)
- **Spatial separation measures** are very crude, simple measures of accessibility that use only the geographic distance between points in the infrastructure network as their inputs. This means they effectively ignore the "network constraints" that affect travel between those points in real life. (Scheurer & Curtis, 2007)
- **Location-based measures** define accessibility in terms of how many individuals/freight loads can access a location, or how many locations an individual/freight load can reach. These measures usually describe accessibility at an aggregate level (e.g. accessibility within a geographic area or among a certain population). For example, the average number of theatres within 30 minutes' walk of adults living in a certain city would be a location-based measure. Location-based

measures can be further divided into distance measures and potential accessibility (or "gravity model") measures. Further categories in this type of measure include:

- **Potential accessibility measures** indicate the accessibility of opportunities in one zone to many (ideally all) other zones, but smaller or more distant opportunities have less of an effect on the magnitude of metric. This is done by means of an impedance function to weight the opportunities (usually a negative exponential function, but other functions such as Gaussian and logistic functions have been used). (Geurs & van Wee, 2004)
- **Distance measures** are comparatively simple – instead of using an impedance function to weight the influence of different opportunities, distance measures report the number of opportunities within a given geographic contour, or alternatively, the distance to the closest opportunity. For example, the distance to the nearest food shop is a distance measure of accessibility, and so is the number of food shops within 100m of a household.
- The idea behind **contour** measures is that the area bounded by the contour represents all the places a person (or freight shipment) could move to within a given amount of time or travel cost. (Or, if the accessibility metric is place-based rather than person-based, it represents the places people/freight could arrive from within a given amount of time or travel cost). (Geurs & van Wee, 2004).
- **Person-based measures** necessarily consider accessibility at the level of individuals. They might, for example, give details of the set of employment centres specific individuals can practicably access, taking into consideration personal constraints of time or physical ability.
- One approach to operationalising person-based accessibility is to draw a diagram representing the locations an individual could practicably access at different times (a **space-time** prism) (Scheurer & Curtis, 2007).
- It has also been argued that person-based measures can be similar to location-based measures, but specified at the level of individuals, and sensitive to the differences between them. In theory, therefore, location-based measures can be converted into person-based measures with the application of additional data (Páez, Scott, & Morency, 2012).
- **Utility-based measures** quantify accessibility in terms of the utility an individual or individuals derive from being able to access activities/opportunities distributed across space. These measures can be converted into monetary values, although sometimes they are simply reported in terms of arbitrary units which can only be compared (between persons or under different scenarios) within the context of the model used to generate them.

7.3 Considerations on a European city level accessibility metric

One of the objectives of this study is to contribute to the development of a European Urban Mobility Scoreboard, which could be used to facilitate comparison between areas and over time. However, the review of the literature has highlighted that an extremely diverse set of indicators are used and/or required to quantify accessibility, each with their own advantages and disadvantages, due to the fact that accessibility is "a multifaceted concept, not readily packaged into a one-size-fits-all indicator or index" (Scheurer & Curtis, 2007).

Such indicators and their merits were also discussed in detail during our engagement with stakeholders (interviews and workshop). However, it is evident that some indicators would be more useful in developing a scoreboard than others. In particular, it would be nearly impossible to base city-level accessibility metrics around person-based measures such as the use of space-time prisms and other ways of measuring accessibility that are extremely sensitive to individuals' idiosyncratic circumstances.

The use of infrastructure-based measures of accessibility also have their drawbacks due to the fact that they do not often take into account the spatial distribution (and re-distribution over time) of opportunities which is fundamental to operationalising *accessibility* rather than just *mobility*.

After eliminating those possibilities, the remaining possibilities are to use the following types of indicators:

- Location-based measures considering both potential accessibility indicators and/or distance indicators;
- Utility-based indicators.

The literature and engagement with stakeholders have already provided some examples of indicators that fall within these categories. Some examples of the types of indicators that could be used to compare cities are provided in Table 7-1.

Table 7-1: Example city comparator accessibility indicators

City comparator example indicators
Number of opportunities e.g. doctors surgeries, jobs, schools etc. within **X** m/km
Number of opportunities e.g. doctors surgeries, jobs, schools etc. within **X** minutes by public transport, private car etc.
Number or proportion of individuals (population) within **X** distance/time of an opportunity.
Potential accessibility to e.g. healthcare, education, jobs etc.

The opportunities and modes of key importance to accessibility in cities will need to be explored and identified when developing the mobility scoreboard. Within this set of options, there will be a trade-off between:

(a) Accuracy, and
(b) Ease of implementation and interpretation.

Accuracy is obviously necessary if comparisons between cities and over time are to be informative. But ease of interpretation is also important if the scoreboard is going to have an influential effect on policymakers, which may rule out the use of utility-based statistics derived from a "black box".

Clearly an important consideration for any selected accessibility metric is the necessary data – including its format, availability and ease of collection. In order to be able to make comparisons between European cities, data supporting accessibility metrics will need to be readily available to most cities, and can potentially be collected at the European level.

As the scoreboard is envisaged as facilitating comparisons between areas, there will need to be some careful consideration of the substantial area-level differences between individuals in different parts of the EU. For example, individuals in different countries or even different cities may differ not only in terms of their income but also in terms of how much they are willing to spend on travel as a proportion of their income. The aforementioned issue of individuals adapting to congestion is another example of the potential importance of area-level differences in individuals. The measures should compare accessibility (e.g. time or distance) between cities, but should not provide judgement on what is considered to be acceptable, desirable etc.

The mobility scoreboard will be important when considering urban level actions. The CIVITAS project has demonstrated that there are a wide variety of mechanisms that are available to improve accessibility (and mobility) in urban areas. Through the availability and use of the right indicators, cities will be able to identify and focus on those aspects of accessibility that require action and subsequently employ appropriate measures.

Given these considerations the most likely candidates for a European level indicator(s) on accessibility are location-based measures in terms of simple travel distances/times to opportunities. This is supported by the use of these type of indicators in comparative accessibility studies such as the ESPON TRACC study (ESPON, 2015) and UK department for Transport's Accessibility Statistics (UK Department for Transport, 2014).

7.4 Emerging findings for EU level action

This review has highlighted that Member States including the UK, the Netherlands, and Germany have already taken some steps to let accessibility modelling and analysis inform the decisions governments take in transport, urban planning, and provision of public services. Inevitably, some areas of the Community lag behind others in terms of the progress made on this front (it is probably the case that larger municipal governments generally lead the way). The CIVITAS initiative – which promotes dissemination between cities of innovative sustainable transport measures – supports projects that link "leading cities" and "learning cities" for this reason. Either CIVITAS or a new initiative could be used to disseminate best practice in the use of accessibility measures as policy-informers.

Use of accessibility measures in a European Urban Mobility Scoreboard would raise the profile of accessibility measurement, but as noted previously, it may prove difficult to distil complex accessibility issues into concise indicators over an area as diverse as Europe. Although location-based measures in terms of simple travel distances/times to opportunities would be the most likely candidates.

The EU might also take action to improve levels of urban accessibility with a range of coordinated funds that are available. This review has also highlighted the salience of urban land use to accessibility, and the importance of transport in social exclusion. These are potentially other areas in which the EU might in future offer more financial support.
Relevant European funding opportunities include the following:

- European Structural and Investment Funds (ESIFs): Responding to needs of the real economy by supporting job creation and by getting the European economy growing again in a sustainable way.
- European Cohesion Fund: Aims to reduce economic and social disparities and to promote sustainable development in Member States with a Gross National Income (GNI) per inhabitant of less than 90% of the EU average.
- European Regional development Fund (ERDF): Projects to improve accessibility through upgrades to local transport systems have received very significant financial support from the European Regional Development Funds for many years.
- European Social Fund (ESF): Main instrument for supporting jobs, helping people get better jobs, and ensuring fairer job opportunities for EU citizens. The ESF has historically funded *training* for socially excluded individuals to help them find access to employment – it could in future be used to fund initiatives aimed at improving the *accessibility* of socially excluded groups partly in order to improve their employment prospects.

Finally, as mentioned above, it is recommended that there should be increased focus on accessibility rather than mobility. By addressing accessibility, mobility issues will be intrinsically addressed. However, improving urban accessibility is likely to generate more economic and social benefits than mobility alone. It is therefore recommended that the focus should be widened to address the wider issue of accessibility.

Appendices

Appendix 1 – Stakeholder Engagement - Interviews/written responses

Interviews undertaken	Discussions held with/written contributions received
Angela Curl, Glasgow University, UK	Annika Stienen, UITP
Bert van Wee, Technische Universiteit Delft, NL	Laura Rozzo / Chris vanderhoegaerden, European Express Association (EEA)
Cecília Silva, Oporto University, PT	
Karen Lucas, Institute for Transport Studies, University of Leeds, UK	
Nick Tyler, University College London, UK	
Derek Halden, Derek Halden Consultancy, UK	
Benedicte Swennen and Holger Haubold, European Cycling Federation (ECF)	
Jan Ritsema van Eck, Environmental Assessment Agency, Department of Urbanisation and Transport, NL	
Jose Manuel Viegas, International Transport Forum (OECD)	
Francoise Guaspare, ERRIN Network	
Henk Vanderkamp, European Council of Spatial Planning	
Nicolas Gaubert, Federation nationale des travaux publics	
Feunsanta Martinez Sans, ACEA	
Yarron Hollander, TfL (UK)	

Appendix 2 – Workshop Attendees

Workshop participants – 15th September 2015

Name	Organisation
Study Team	
Guy Hitchcock	Ricardo Energy & Environment
Charlotte Brannigan	Ricardo Energy & Environment
Angelo Martino	TRT
Davide Fiorello	TRT
European Commission	
Mans Lindberg	DG MOVE
Workshop Participants	
Ruud van der Ploeg	European Metropolitan Transport Authorities (EMTA)
Giacomo Lozzi	Polis - European Cities And Regions Networking For Innovative Transport Solutions
Feunsanta Martinez-Sans	European Automobile Association (ACEA)
Stephan Herbst	Toyota Europe
Marcelo Vollmann	Renault
Annick Roetynck	Battery, Hybrid and Fuel Cell Electric Vehicles (AVERE)
Holger Haubold	European Cyclists' Federation (ECF)
Leonardo Dongiovanni	European Rail Industry (UNIFE)
Christine Le Forestier	European Construction Industry Federation (FIEC)
Annika Stienen	International Association of Public Transport (UITP)
Chris Van Hoegaerden	European Express Association (EEA) - UPS
Marjan Vanherwijnen	ESPON (TRACC study)
Ian Catlow	Mayor of London's Office – Transport for London (TfL)
Angela Curl	Glasgow University (UK)
Susanne Böhler-Baedeker	Rupprecht Consult, Koln (DE)
Nicolás Ibáñez-Rivas	European Commission - DG Joint Research Centre (JRC)
Carlos Roman	Inrix

Appendix 3 - Stakeholder Workshop – Agenda

Assessing and improving access to urban areas - Stakeholder workshop

Date: Tuesday 15th September, 9.30am
Location: DG MOVE, Rue De Mot 28 B-1049 Brussels

Time	Session	Lead
9.30	**Registration**	
10.00	**Welcome**	DG MOVE
10.05	**Introduction** to the Project and overview of the day	Guy Hitchcock Ricardo Energy & Environment
10.15	**Defining Urban Accessibility** • Presentation of state-of-the-art-review: definitions and metrics used • Questions and feedback on SOTA	Charlotte Brannigan Ricardo Energy & Environment
10.45	**Participant exercise** – accessibility metrics • Identify metrics you have used or are aware of • Put them in the taxonomy defined in SOTA • Do pros/cons in relation to EU metric	All, facilitated by Ricardo Energy & Environment, TRT
11.30	**Break**	
12.00	**Data and modelling** • Presentation of state-of-the-art-review: data used and collected, modelling • Questions and feedback	Charlotte Brannigan Ricardo Energy & Environment
12.30	**Discussion question**: what data and modelling techniques might be readily available across cities in Europe to allow a common approach	All, facilitated by Ricardo Energy & Environment, TRT
13.00	**Lunch**	

14.00	**Congestion and accessibility**
	• Presentation
	  ○ Link between congestion and accessibility
	  ○ Congestion metrics
	  ○ Assessing the costs of congestion
	• Questions and feedback
		Davide Fiorello
		TRT

14.30	**Participant exercise** – measures to improve	All, facilitated by

	accessibility • Introduce exercise • Identify local measures and group under component • EU policies to support improvement	Ricardo Energy & Environment, TRT
15.30	**Wrap up and next steps**	Guy Hitchcock Ricardo Energy & Environment
16.00	**Close**	

Appendix 4 - Summary of Stakeholder Workshop

INTRODUCTION

Guy Hitchcock (Ricardo Energy & Environment), the study's project manager, gave a brief introduction to the aims of the study and key tasks being performed by Ricardo Energy & Environment and TRT.

DEFINING URBAN ACCESSIBILITY

Charlotte Brannigan (Ricardo Energy & Environment) gave an overview of work undertaken to date on Task 1: State of the Art Review of urban accessibility, focusing on defining accessibility and the metrics that are used to measure it (see PowerPoint).

- It was confirmed that the focus of the study is on **urban** accessibility
- It will consider, amongst other aspects, the availability of transport
- Outputs will hopefully be metrics that will enable benchmarking between larger metropolitan areas
- The focus of this session is identifying appropriate accessibility-related metrics

Breakout Exercise 1 – Accessibility metrics, including pros and cons

Participants were asked to identify accessibility metrics for the following dimensions of accessibility: infrastructure, transport, individual and temporal. They were subsequently asked to identify the pros and cons of using such types of metrics when trying to compare the accessibility of European cities. Responses are summarised in the following tables.

Table A4-1: Summary of responses – Infrastructure

Accessibility metrics	Pros	Cons
Reliability of modes Safety, e.g. accident rate Travel time door to door – home to desired destination (mins) Time taken to park –cars, bikes etc. Relative speed of modes of transport Cost door to door (€) Opportunity to move – by each mode of transport Measures to improve access, e.g. e-tickets Active mobility indicators, e.g. length of walkways and cycleways Micro-level metrics, e.g. walkability of urban environment (pavement and surface steps) Accessibility for impaired (incl. children, elderly) Metrics relating to physical access to public transport,	Infrastructure metrics are often: Easily quantifiable Easy to measure Able to compare between cities Used to inform transport planning	Not all infrastructure related metrics are relevant when making comparisons between cities Optimising one aspect often has negative implications for another Risk of not incorporating all costs or benefits Data collection is often not harmonised /collected in the same way Difficult to derive / change solutions (e.g. cost, scale of changes required etc.) Not equally relevant to all groups (e.g. level of congestion irrelevant for non-car users)

e.g. presence of ramps, % of low-floor vehicles Number of nodes/interconnections, indicating co-modality Number of multi-modal trips (an assumption that multimodal trips more efficient)		

Table A4-2: Summary of responses – Location-based accessibility metrics

Accessibility metrics	Pros	Cons
Space usage – Infrastructure redivision and public space Emissions – noise, PM etc. Information / websites Number of modes Intermodal interpretation Availability of transportation nearby – bus/train stop within X minutes Functional diversity of districts – GIS Spatial, distributional and destinations Logistics sprawl – calculation of optimal location of logistic facilities with regards to accessibility issues No of public transport stops within a certain range Time to a given destination Number of destinations reachable within a given time No of people within x minutes of a given destination	Location-based metrics often available at the European level Can inform city planning and long term strategic decisions Allows for demand management Location-based metrics can link people to opportunities Good combination of personal dimensions and quantitative measurement	Often difficult to make comparisons between cities External factors can play a role (not related to transport, land use etc.) There are often different perceptions of space usage It can be difficult to prioritise e.g. which locations are measured

Table A4-3: Summary of responses – Person-based accessibility metrics

Accessibility metrics	Pros	Cons
Aspects that are likely to affect accessibility: Perceptions of accessibility – satisfaction, ease of access, comfort/pleasure (obtained via interview) Affordability (monetary cost, willingness to pay €) Safety and security – perception, chance of being robbed, exposure rate of crime Health – health benefits of walking and cycling Accessibility for impaired people – to measure their access Personal travel time to work (and other key destinations) Outcome based measures – number of people who can get to jobs (as a result of accessibility)	Can inform policy on behaviour change Allows for looking at specific segments of the population	Often very hard to quantify Many of the individual-based metrics would need to be obtained via surveys This would need to be validated with 'hard' data Therefore very subjective Difficult to achieve behaviour change Difficult to measure and extract statements that are true for every individual/for the general population

Table A4-4: Summary of responses – Utility-based accessibility metrics

Accessibility metrics	Pros	Cons
Measurement of congestion Intermodal integration Occupancy rate of various modes Travel time / time of day Urban density – in terms of merging of activities Cost by mode to destinations Land value around transport access points versus land value in unconnected areas	Utility-based metrics allow the highest level of detail – allows for targets measures for individual persons	Very difficult to measure at a large scale Difficult to find measures that please large numbers of people, unless one can create an average of their individual needs Often difficult to understand/interpret

DATA AND MODELLING TECHNIQUES

Charlotte Brannigan (Ricardo Energy & Environment) gave an overview of work undertaken to date on Task 1: State of the Art Review of Urban Accessibility, focusing on potential data and modelling techniques that may be used when assessing accessibility of urban areas (see PowerPoint). Discussions followed which focussed on which data and modelling techniques might be readily available across cities in Europe to enable a common approach. Contributions are summarised below, which the study team will follow up on in updating the State of the Art Review (Task 1).

- The **TRACC Study– TRansport ACCessibility at regional/local scale and patterns in Europe** (EPSON, 2012) used a European-wide accessibility model. Data from cities included secondary schools, hospitals, surgeries etc. Case studies were produced at the regional level. The study considered land use patterns in Europe. However, it found that there were discrepancies between levels of 'potential accessibility' – differences noticed in terms accessibility that was being experienced – not real world constraints. Twenty-seven indicators were developed for the study covering a range of spatial levels. They considered cumulative opportunities, e.g. no. of secondary schools within a given time. The levels included within the study are:
- Global level – access to global cities (e.g. New York);
- Regional – no harmonisation in available data. Mixed situation – availability; and
- Local
- **Sustainable Mobility Project** (WBCSD, 2013-15) Study involving a number of case study cities. Identifying clusters of cities based on categories, development of sustainable mobility indicators. Data was collected for each of the 6 case study cities. It was found that data related to accessibility/mobility is often available - however, cities themselves don't know where to look/obtain it from. Analysis of the data available to them was then undertaken. It should be noted that resources are required in order to identify/obtain the data.
- JRC report on **Measuring Access to Public Transport in European Cities** (Poelman and Dijkstra, 2015). The report considers the distribution of people within a city and considers comparable accessibility between cities.
- Harmonising the definitions of 'cities' is required across Europe.
- Need to better understand commuting patterns of city residents and how they differ.
- Also need to take into consideration the density of the population and functionality of the urban areas. Political barriers may exist
- Publically available data on public transport can be used. Will need to consider the effects of public transport on accessibility (transport operators).
- **GTFS-exchange** – encourages other operators to make timetable data/information available - http://www.gtfs-data-exchange.com/.
- **'NODES' project – New tools for design and operation of urban interchanges** (UITP, recently concluded in 2015). This study considers the design and operation of interchanges/hubs. It has developed a tool based around stations. It identifies locations where improvements can be made to connections between modes. UITP have also been involved in the NODES study, specifically regarding the quality of hubs, with a focus on optimising interchange at a station/node. The city hub project takes a passenger point of view.
- Urban Mobility Database and Millennium Cities Database are potential sources of data (UITP).
- **The Future of Urban Mobility 2.0** (Arthur D Little, 2013) – study should be reviewed for SOA review.

- Rupperecht Consult have undertaken studies on monitoring/evaluating performance indicators. The work differentiates between indicators, e.g. performance indicators and output indicators. They found that data availability is often very poor for freight performance and inland shipping.
- Need to consider the availability of destination. When you have an out of town supermarket, access via car is often considered. However, for the individuals without a car, they think about local grocery shopping instead and how they might reach it. By thinking about the potential destinations it may affect what different countries consider to be destinations
    - New technologies are generating new/more data – need to consider how this can be used/accessed. Best Metropolis model was for Paris, Berlin and Warsaw see: http://www.espon.eu/main/Menu_Projects/Menu_TargetedAnalyses/bestmetropolises.html
    - There are issues relating to boundaries when we consider urban accessibility. For example, there is the accessibility within urban area versus accessibility of getting to urban areas. This study primarily considers the former.
    - The point on boundaries related to the above – what are spatial definition are we using when we talk about urban accessibility.

CONGESTION

Davide Fiorello (TRT) gave an overview of work undertaken to date on Task 2: Estimation of European Road Congestion Costs. Comments/clarifications made following the presentation are summarised below.

- Demand curve – considering car transport
- 2 x highway and local roads
- Peak and off peak
- The time span of peak was confirmed to be 2-3 hours in both the morning and evening.
- The main inputs to the estimation of congestion come from indices from Inrix and TomTom.
- Population is based on NUTS3/cities
- Information is used from data on size of population, population using cars, and car occupancy rate.
- It was confirmed that there are 130 indexes.
- The study team have undertaken some comparisons between Inrix and TomTom indices. There are some differences in the definitions used by both.
- The report will not specifically consider how accessibility may increase/decrease as a result of congestion. However, it will be taken into consideration in the recommendations
- Interurban added to urban congestion – would like messages on accessibility in spite of congestion.
- There will be a need to consider mobility vs. accessibility.
- It was suggested that monitoring of congestion in different years of the Inrix/TomTom data could be undertaken to determine whether there were differences - currently using one year of data.
- It was suggested that the results of this task could feed into other work DG MOVE is doing – e.g. congestion costs and costs of using roads.
- The value of time was calculated in 2007.

- The final results will focus on wasted time AND deadweight – likely to be min/max ranges.

Breakout Exercise 2 – Identifying potential measures to improve accessibility
Participants were asked to identify potential accessibility improvement measures in relation to each of the dimensions of accessibility: land use, transport, individual and temporal. They were also asked to identify where EU policies could support the improvement of accessibility (possibly through the measures identified already). Response are summarised below.

Accessibility measures - Land use

- Creation of an economic development plan or Vision for the city
- Availability and provision of finance and funding (EU)
- Continuative collaboration between urban (land use) planners and transport planners - Take an integrated approach
- Consultation with key stakeholders and transparency
- Ensuring denser cities/neighbourhoods, better spatial planning (reducing need to travel/distances involved, residential areas close to key services and jobs, reduction of potential accessibility barriers).
- Provision of appropriate links and connections to create a useable network.
- Ensuring exchange of best practice/guidance (EU)
- Improvements to some public transport modes, which in turn may provide relief for car users (those who have to use cars to access destinations – reduced congestion etc.)
- Introduce restrictions for cars, e.g. close city centres to cars, or limit parking etc.
- Invest in park and ride facilities – ensuring that those travelling by car can still get to urban centres where restrictions are in place, but also removing some of the perceived barriers for pedestrians/cyclists etc.
- Consideration of the effects of new infrastructure on other modes of transport.
- Provision of priority bus lanes, opening them up to other modes, such as 2-wheelers / low emission vehicles (LEVs)
- Sharing systems including prohibition taxi use
- Provision of bike rental stations across urban areas – providing alternative options
- Combine parking and public transport tickets

Accessibility measures - Transport
The majority of suggestions for transport accessibility measure relate to attempting to reduce the existing barriers to accessibility that individuals face when using (or try to use) various transport modes to access destinations.

- Development of common accessibility indicators (EU scoreboard) (EU)
- Governance powers (city) national coordination
- Ensure that a transport plan is in place, and link with land use strategies.
- Improve or introduce appropriate traffic rules that can reduce barriers to accessibility, e.g. speed limits etc.
- Address accessibility barriers that may exist related to public transport, e.g. frequency, reliability, comfort, interchange, provision of information etc.
- Modal shift – co-modality / inter-modality

- Interoperability – local, national etc.
- Implementation of a city logistics strategy
- Implementation of smart ticketing / fares, smart road pricing (spread peak)
- Reward of active mode use – walk, cycle, LEV
- Expel coaches from city centres (tourist)

Accessibility measures - Individuals

- Introduce taxes/incentives (e.g. taxes for company cars, 2nd/3rd cars, incentives for bikes, LEVs) to reduce car use (EU)
- Implement measures that aim to raise awareness about alternative modes of transport, which may lead to travel behaviour changes (EU)
- Address perceived and real safety issues that are currently barriers to access by increasing road safety for pedestrians and cyclists (EU)
- Ensure provision of up to date and relevant travel information
- Mapping users needs to segment transport demand (individuals and freight companies)
- Incentives for social use of taxis (disabled, elderly etc.)
- Make collective transport barrier free
- Educate people/children about efficient mobility choices (EU)
- Encourage and support work from home and flexible working hours, reducing barriers related to accessing employment (EU)
- Ensure coherence of different strategies.

Accessibility measures - Temporal

Not many suggestions were made for temporal accessibility measures.

- Destinations, e.g. shops, could provide incentives for users to travel sustainably
- Congestion charging could be considered in peak hours / changing peak hours (EU)
- Peak time relief (price adaptation)
- Extend opening hours of shops/destinations will reduce temporal barriers to access (shift workers, individuals with range of other commitments etc.)
- Introducing off peak hours for deliveries (urban logistics)

Summary – Accessibility measures

Although many suggestions were made as to which accessibility improvement measures could be introduced related to the land use, individual, transport and temporal aspects of accessibility, a review of these suggestions reveals that they are in fact largely aimed at encouraging the use of sustainable transport (i.e. moving away from private car use and achieving wider environmental policy objectives). However, it was recognised that whilst the majority of these suggestions are likely to increase accessibility (and mobility) within urban areas to key services and opportunities for the majority of the population in a sustainable way, there would still be some individuals and groups (possibly the most vulnerable) whose accessibility needs would not be met, e.g. through discouraging private car use.

Wrap up and next steps

Guy Hitchcock (Ricardo Energy and Environment) thanked everyone for the active participation in the work and noted that if anyone had further thoughts following the event they should feel free to contact the project team.

The key next steps in the work were:

- Completion and reporting on the State of the Art review (task 1) by end of the year
- Completion and reporting on the costs of Urban Congestion (task 2) by the end of the year
- Work will now start on assessing the efficiency of urban transport modes (task 3) and best practice in improving urban accessibility (task 4) with reporting due Mid 2016
- The project will conclude with a stakeholder seminar to report all the finding and policy recommendation by the end of 2016.

Glossary of key terms

Term	Meaning
Accessibility	The ease of reaching goods, services, activities and destinations in urban areas. It includes factors such as mobility options, travel information, transport network connectivity, land use patterns and cost for both passengers and freight
Mobility	Movement of people and goods
Indicator	Statistics used to measure current conditions or to forecast trends
State of the art	Most recent ideas and/or methods
Congestion	Condition where vehicles travelling on road links are delayed.
Opportunities (in the context of accessibility)	Key services, activities or destinations which individuals would like to get to/access
Contour measures	Using contours to define an area including all of the places that a person could move to within a given amount of time or cost
Utility measures	Quantification of accessibility in terms of utility an individual could derive from being able to access activities or opportunities (e.g. monetary value or other selected units)
Space-time prism	All points that can be reached by an individual given a maximum possible speed from a starting point in space-time and an end point in space-time, taking into consideration their own personal constraints
Potential accessibility	Catchment areas defined by measuring travel impediment on a continuous scale
Social exclusion	What can happen when individuals or areas suffer from a combination of linked problems such as unemployment, poor skills, low incomes, poor housing, high crime environments, bad heath and family breakdown

Abbreviations

Acronym	Meaning
CIVITAS	CIty-VITAlity-Sustainability
DEFRA	[UK] Department for Environment, Food and Rural Affairs
DfT	Department for Transport (UK)
DG MOVE	Directorate General Mobility and Transport
EPSON	European Observation Network for Territorial Development and Cohesion
ERDF	European Regional Development Fund
ESF	European Social Fund
ESIFs	European Structural and Investment Funds
EC	European Commission
EU	European Union
GIS	Geographic Information System
GNI	Gross National Income
GNSS	Global Navigation Satellite System
ITS	Intelligent Transport Systems
ICT	Information Communication Technology
LAA	Local Area Agreements
PAMELA	Pedestrian Accessibility and Movement Environment Laboratory
TRACC	TRansport ACCessibility at regional/local scale and patterns in Europe

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