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To cite this report: Saleem Karou, Angela Hull (2012) Accessibility Measures and Instruments, in Angela Hull, Cecília Silva and Luca Bertolini (Eds.) Accessibility Instruments for Planning Practice. COST Office, pp. 1-19.

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There has been a growth of interest in the concept of accessibility in recent decades, with many accessibility studies published in the academic press discussing how to measure accessibility, the implementation of the concept of accessibility in urban planning and transport and the contribution such decision support tools might have. This interest in accessibility, more recently, has broadened such that there is a multitude of approaches used in the consideration of the development of accessibility instruments (or tools) and the contribution they could make to urban planning practice to inform land use and transport decision-making. This report focuses on these new approaches to accessibility modelling and aims to help practitioners choose the most appropriate accessibility instrument based on the urban management problem.

This chapter, however, seeks to provide a benchmark to these later instruments by categorising the 'first wave' of accessibility instruments developed using the descriptions of these instruments in the academic press. This documentary review is limited to the accessibility-based planning instruments in the English language academic press and seeks to explain early conceptualisations of accessibility and how the concept is measured and incorporated in the instrument.

The chapter has the following structure: the first section presents the categorisation and components of accessibility-based planning instruments that have been widely reported in the literature. The second section describes the aspects and dimensions of accessibility instruments while the third focuses on accessibility modelling in a GIS environment. The fourth section takes a more thematic approach to the categorisation of accessibility instruments developed for urban planning practice using some of the most common accessibility instruments developed in Europe. This section explains the themes or approaches to accessibility, the concept(s) incorporated in the instrument and what is measured as well as further relevant technical issues of accessibility modelling including input and output data. Finally, the fifth section presents what can be seen as some of the omissions in the 'first wave' of accessibility instruments suggesting that that tool developers should address these omissions if accessibility instruments are to have wider application in urban management.

Categorisation and Components of Accessibility Instruments

The concept of accessibility is about movement and, in particular, about the ease of getting around from place to place. One can categorise the different derivations of accessibility into two broad families (Hull, 2011), The first, is focussed on mobility or the ability to travel and is derived from classical location theory which hypothesises that there is a direct correlation between changes in the transport system (e.g. transport costs) and journey length (Banister, 2002; Ney, 2001; Geurs and van Wee, 2006). This conception has held the attention of geographers and transport engineers interested in the geography of flows and the movement patterns between origins and destinations noting the average speeds and predicting the direct costs of travel.

From this conceptualisation has grown another derivation of accessibility which focuses more on the 'ease of reaching' a number of daily activities at different destinations. This conceptualisation is, therefore, interested in the ability of social groups to reach destinations where they can carry out a given activity as well as the transport network (Bhat et al, 2000; SEU, 2003). This conceptualisation of how efficiently the spatial distribution of services and facilities is connected/ integrated with the transport infrastructure creates a new challenge for tool developers and urban managers.

The academic literature deals more thoroughly with the first conceptualisation of accessibility than the second. Whilst this Action is more concerned with the second conceptualisation, it is important to understand the antecedents of the current wave of accessibility instruments. This section, therefore, examines earlier published work to identify and compare the use of accessibility components and how these are incorporated in the measurement of accessibility (see Martin and Dalvi, 1976; Geurs and Ritsema van Eck (2001); Jones et al, 2005). According to Martin and Dalvi (1976), there are three equally important components in modelling accessibility. These are people's preferences and choice groups, existing opportunities, and the degree or intensity of the transport service provided to tackle distances. Handy and Niemeier (1997) identified four key components of accessibility measures: the level and type of spatial separation, representation of origins and destinations, size of travel deterrence and size of attractiveness. In the study by Reneland (1998), accessibility indictors can be split into four groups by defining four aspects of accessibility: origins and destinations, time of day, available transport modes and the characteristics of passengers including gender, age, physical condition, and type of job. Geurs and Ritsema van Eck (2001) defined four types of components important in the measurement of accessibility including land use, transport, individual and temporal components. Further, Geurs and Ritsema van Eck show that these components may be affected by accessibility through feedback mechanisms.

Based on the authors above, in general three key elements have been commonly considered in the scientific academic literature to characterise accessibility measures: (1) a determined geographical "origin" location or category of people or freight that is being considered for accessibility, (2) a set of relevant destinations that might be weighted by the size or quality of associated opportunities, and (3) a measure of physical separation between (1) and (2) that is usually expressed in terms of time, distance or generalised cost.

Some accessibility instruments focus on origins or people, some on opportunities, and some on the connection. Accessibility instruments and models have been categorised in different ways (see Spiekermann and Neubauer, 2002; Transport Scotland, 2003; DHC, 2007). Scottish Transport Appraisal Guidance (STAG) used the objective of developing the indicators of local accessibility, by cycling and walking and the coverage of public transport network, as a basis for the categorisation of instruments (Transport Scotland, 2003). In this respect, three major categories have been presented as follows:

- Category 1- Accessibility instruments analysing walk times to public transport services or to local facilities. In these instruments, public transport systems are classified according to types of desired destination, frequency, mode, and time of day while local facilities are classified by an associated function. For example, Glasgow City Council Bus Network Coverage Model, and PTALS Models (e.g. Hammersmith and Fulham), etc.;
- Category 2 - Accessibility instruments analysing travel times using public transport systems and motorised vehicles through the motorway network. In these instruments, public transport networks are described in terms of journey planning techniques and destinations are expressed as opportunities, activities or places (e.g. CBD). For example, SONATA (Steer Davis Gleave), ACCMAP (MVA), APTT (Halcrow), ABRA (Colin Buchanan and Partners);
- Category 3 – Instruments or models that are not specifically developed to measure accessibility that, however, involve the process of accessibility modelling. These incorporate: land use models that describe the spatial interaction in terms of accessibility (e.g. DELTA, MEPLAN, LILT, TRANUS, etc.); demand models that measure accessibility change for input to an economic appraisal; and activity based models that estimate behaviour according to accessibility to opportunities. For example, four stage models used in conjunction with accessibility analysis processors - e.g. ACCALC (Derek Halden Consultancy), CSTM3, TMfS, SITM used in conjunction with the SPT accessibility model;

In the same context, Derek Halden Consultancy (2007) split the accessibility instruments available internationally into three categories based on their functionality. First, catchment instruments that are used by service providers such as public transport operators and retailers. These instruments help providers to plan suitably for residents/customers to enable access to their facilities based on the analysis of the local population and output information on potential customers within the catchment area. The second category of accessibility instruments is that obtained from public transport or road journey planners. These instruments usually focus only on calculation of the time required to reach desired destinations. The third category includes land use and transport models which are more complex compared with the catchment or journey planning instruments. These can incorporate information on different features such as the type of opportunity and traveller behaviour that can be connected with separate accessibility models to produce a better quality accessibility calculation.

This chapter takes the categorisation types used by the Scottish Transport Appraisal Guidance (see above) to illustrate the different approaches taken by tool developers in the first wave of accessibility instrument development. This categorisation connects well with the application of accessibility instruments in urban planning practice which is the main concern of this Action.

Dimensions of Accessibility

Accessibility instruments can be sensitive to a range of various dimensions or aspects which characterise the functionality and capability of the instrument. This section introduces several dimensions of accessibility modelling derived from the documentary review of the academic literature covering the last two decades. These aspects include:

1. Spatial separation (deterrence) factor: The spatial separation factor represents one or more attributes of the links between areas that separate places and people from the opportunities. These can be distance (crow-fly or network distance), travel time, travel cost, reliability, information, convenience, safety or other attribute that acts as a deterrent or constraint to access.
2. Type of accessibility indicator and the measurement of spatial separation: In many studies accessibility indicators have been split into different types based on different criteria. Geurs and Ritsema van Eck's categorisation is one of the most commonly referenced and has therefore been selected for this study. Geurs and Ritsema van Eck (2001) differentiated between infrastructure-based, activity-based and utility-based accessibility measures. Further, the activity-based measures were broken down into distance, contour potential accessibility, inverse balancing factors and space-time measures.
3. Origins: Accessibility can be measured from the point of view of different population groups (e.g. age, gender or social groups) or types of economic actors (e.g. firms or industries) in the area, or people using the area (e.g. tourists or travellers). The origins may be locations (location-based measures) or people such as economic actors (person-based measures).
4. Destinations, type of associated opportunities and measurement of their attractiveness: Accessibility to the location of an area can be measured with regard to activities, opportunities and assets; for example, population, business activities, universities, health services, shopping facilities or tourist attractions. The attractiveness of these opportunities can be measured in different dimensions such as population; number of employees, students, patients or facilities; the total gross floor area of facilities; volume of sales; percentage of gross domestic product; etc.
5. Input data and parameters: These incorporate all the data required to carry out accessibility planning and modelling which, according to Titheridge (2004), can be classified into three groups including data on transport infrastructure and operations, data on people and data on facilities and amenities.
6. Output of accessibility modelling: Modelling outputs vary according to the functionality and objective of the accessibility instrument.
7. Dimension of accessibility values: Most of the indicators that have been used in accessibility instruments present the accessibility of locations as non-dimensional values which are not comparable with each other. This complicates the output interpretation and assessment of infrastructure improvements. Ranking is a useful method that has been widely used by accessibility modellers for comparison of different accessibility measures (Baradaran and Ramjerdi, 2001).
8. Spatial detail and geographical scale: Accessibility analysis may be applied at a continental, transnational, interregional, regional, municipality or neighbourhood scale. The selection of detail and level of the analysis is based on the scale of the issues considered and the detail that needs to be understood. Every spatial scale requires data of different spatial resolution with regard to area size and network representation; transfer time; and intra-area access and intra-node terminal.
9. Type of transport: Accessibility analysis might consider only personal travel or freight transport, or both.
10. Travel modes and mode choice: Accessibility might be measured for only one transport mode such as walking, bicycle, car, bus, rail, ferry, air, or bespoke services (i.e. patient transport or school transport). An accessibility model also might be run for a multi-modal transport system in which the choice between the modes is being considered based on particular criteria or where travel modes are specified by the model user.
11. Route choice: Accessibility might be measured taking into account the ability to make a choice between routes, for example minimum cost, minimum time, shortest distance, least amount of walking, route via a location or locations, route avoiding a location, include or exclude modes, etc (DHC, 2007).
12. Interchange options: Interchange options might be considered in accessibility analysis, for example minimum number of interchanges, minimum time for interchange, availability of guaranteed connections, through or avoiding a particular interchange.
13. Interchange points by facilities available: Accessibility analysis might consider the availability of facilities and services at interchange points; for example information, shelter, porters/ staff, CCTV, luggage trolleys, etc (DHC, 2007).
14. Scheduling: An accessibility instrument might be able to calculate accessibility taking into account target arrival or departure time or both, arrival or departure during a specified period, depart after, and arrive before (DHC, 2007).

15. Travel costs and fares: Accessibility analysis might consider travel cards and concessions, season tickets option, fares restricted by quota and time of day restrictions (DHC, 2007).
16. Walking time and waiting time (for public transport): Calculating accessibility by public transport should consider the total travel time of the journey including the walk access time to the public transport service, waiting time, in-vehicle time and interchange time. However, some accessibility instruments do not have the capability to consider all these details and calculate only in-vehicle travel time rather than the total time. Also, time of travel by public transport can be measured in different ways. Accessibility instruments might estimate it using service frequencies, actual service schedules for a specified time of day and day of the week, or based on speed limits and journey distance.
17. Real time updates and reliability: This reflects the instrument's capability to take into account the change in journey time due to roadwork, congestion, delays, etc.
18. Type of vehicle: Accessibility analysis might consider the physical characteristics of vehicles such as luggage carrying capability, low floor bus, etc.
19. Day of the week, seasonal variations: An accessibility instrument might be able to calculate the difference between accessibility during week days and the weekend. Also, seasonal variations might be considered in an accessibility calculation.
20. Time of day: An accessibility instrument might be able to consider the calculation of accessibility in different times of the day, for example peak time or off-peak time.
21. Environmental impact: Accessibility instruments might provide some environmental information, for example, on the amount of emissions resulting from a journey.
22. Health impact: Some health information might be also provided by the accessibility instrument such as an amount of calories burnt off to carry out the journey.
23. Safety and security information: Accessibility instruments might consider safety and security issues during the journey including real and perceived safety, speed limits, presence of road crossing facilities and travel during darkness (e.g. lack of street lighting) (Halden, 2010).
24. Physical features: Accessibility can be measured whilst taking into account the physical features during the journey that, according to Halden (2010), are categorised into three groups including steep hills and topographic constraints, kerbs and physical obstructions, and surfacing and maintenance.
25. Non-spatial barriers: In addition to spatial constraints, the accessibility instrument might consider the non-spatial barriers between areas such as economical, political, cultural, legal or linguistic barriers. Non-spatial linkages between areas (e.g. complementary industrial composition) might be considered as well (Spiekermann and Neubauer, 2002).
26. Quality and environment of journey: Accessibility analysis may consider the quality and environment of travel that can be expressed in five features: opportunities for rest points and for shelter from weather, aesthetics and attractiveness of journey routes, comfort of vehicles and waiting places, support services during journey (e.g. catering), and help and assistance from public transport staff (Halden, 2010).
27. Information and booking: This may be considered in accessibility analysis by taking account of the availability of information needed to plan the journey, time spent for planning and booking the journey, and the availability of information during the journey itself.
28. Equity: Accessibility instruments may be developed to calculate accessibility for particular areas or groups in order to find out inequities in accessibility between poor and rich, urban and rural, central and peripheral, or nodal and interstitial areas.
29. Dynamics: Accessibility instruments may be developed to calculate accessibility for different points in time in order to identify changes in accessibility due to investmentin transport infrastructure or the impacts of other transport policies (Spiekermann and Neubauer, 2002).
30. Land use analysis: Accessibility instruments may be developed to identify how changes in land use patterns and location choice affect accessibility.
31. Modelling programme: Most of the accessibility instruments have been developed to be run under a Geographic Information System (GIS) environment while some instruments rely more heavily on bespoke programming with a direct or indirect link with a GIS database.

Accessibility Modelling in a GIS Environment

With the rapid increase in computer power and availability of a wide range of electronic data sets, the dependence on GIS techniques for accessibility analysis has significantly risen in the last decade. GIS is well-known for its capability to analyse, model and visualise geographical data such as transport and socio-economic data. It facilitates the utilisation of quantitative geographical approaches within a digital environment. A GIS map can incorporate many and various layers of information that are accompanied with a linked database and which can demonstrate them in innovative ways (Grid, 3-D, thematic maps, etc.) to ease data interpretation (Wu and Hine, 2003).

In the past, GIS users used to analyse accessibility by using "buffer" and "overlay" tools. The main drawback of these conventional tools was their inability to consider the transport network. Accessibility was being measured based on crow-fly or Euclidean distances rather than using actual distances on the network. Furthermore, all the locations within the computed buffer zones were equally weighted which means the nearest location to the desired destination or service is as equivalent as the furthest one to the same destination (de Jong and van Eck, 1996; Geertman *et al.*, 2004).

In 1991, Geertman and Bosveld used potential measures based upon a real world transport network for the first time in GIS-based accessibility analysis (de Jong and van Eck, 1996). The analysis overcame the drawbacks of "buffer" and "overlay" functions, dividing the study area into many hexagonal tiles that are equal in size. The new GIS-based accessibility analysis usually uses accessibility measures that are especially designed in a way that can be integrated in a separate modelling programme with a direct or indirect link with the GIS database. An integrated GIS tool, ACCESS, was developed by Liu and Zhu, 2004, within the ArcView 3.2 offering flexible and interactive GIS environment that supports accessibility analysis for many planning and decision making applications on a whole urban area or region. Accessibility Analyst is another new ArcView extension which was also created by Liu and Zhu working with the other ArcView extensions such as Network Analyst, Spatial Analyst, Patch Analyst and 3D Analyst in order to run advanced potential models in addition to the usual potential and contour models.

Recently, a software package named Flowmap designed to analyse and display interaction or flow data between two different geographical locations was developed at the Faculty of Geosciences of the Utrecht University in the Netherlands (Utrecht University, 2011). Since most thematic mapping and GIS packages have little functionality for handling this type of information, Flowmap fills this gap in GIS packages by dealing with:

- Storage, visualisation and analysis of spatial flow patterns (e.g. trade flows and commuter journeys);
- Computing travel times, distances, or transport costs using a transport network map;
- Modelling the market areas of current or programmed services.

It presents some unique and practical graphical measures including catchment profile, location profile and proximity profile. All these abilities make Flowmap a very efficient technique that can be integrated in planning support systems especially in terms of facility and service location planning (Geertman *et al.*, 2003). However, since it is developed as an extension for a particular spatial analysis that is difficult to run in GIS packages, data management, network analysis and mapping functions in Flowmap are further behind those provided in GIS packages (Liu and Zhu, 2004).

Another main tool that can be linked to GIS to improve its analysis capability of developing transport models is ACCMAP. It is a trip access and travel time mapping package which provides an accessibility calculation from and to any point using travel costs through highway and public transport networks (Citilabs, a). ACCMAP is able to show the impact of network changes on the transport system by overlaying accessibility mapping on any background map. Also, the tool facilitates the generation of Public Transport Accessibility Level (PTAL) indices for different time periods using public transport services (Wu and Hine, 2003). Lately, a considerable development has been executed in the ACCMAP package by MVA and Citilabs on behalf of the UK Department for Transport (DfT) to build a new tool named Accession. This tool is able to measure accessibility using many more origin and destination combinations and to produce different types of indicators (Citilabs, a

Accessibility-based Planning Instruments

This section compares the different approaches to accessibility instrument development using the three-fold categorisation of instruments employed by Transport for Scotland in their Scottish Transport Appraisal Guidance (STAG). This categorisation is used to illustrate the different approaches to the access indicators used (see section above - Categorisation and Components of Accessibility Instruments). The STAG categorisation is used here because it is consistent with the classifications articulated in the state of the art scientific literature (Handy and Niemeyer (1997), Geurts and vanWee (2006), and Silva (2008)) and at the same time relates easily with the context in which practitioners apply ideas on accessibility. As noted earlier, this English language review is heavily dependent on accessibility instruments developed in the United Kingdom.

Category 1: Accessibility by Public Transport

This first category includes accessibility instruments that examine the accessibility by public transport incorporating analysis of the walk times to public transport services or to local facilities.

Within this category are instruments that measure access to the public transport network at a geographical point without measuring the separation or interaction between places. One example of this approach is PTAL (Public Transport Accessibility Levels) which has been developed by the London Borough of Hammersmith and Fulham. PTAL deals only with the origin or destination of a journey using a set formula to measure the intensity of public transport provision at different points (bus stop or train station) within easy walking distance of each area or site (Jones *et al.*, 2005). This formula takes account of walk time to nearby public transport services, the number of services available, service reliability and average waiting time in order to score each location on a six-point scale (Halden *et al.* 2005). The main datasets required are the public transport network including locations of public transport stops, delineation of routes and schedule frequency in order produce the PTAL indices (Wu and Hine, 2003). The ACCMAP software has been used to facilitate the production of these indices for different time periods of public transport service. The output of the PTAL's analysis, expressed as a set of Accessibility Indices for a range of locations, is classified into six-value ranges and spatially mapped, and then defined in terms of Accessibility Levels.

Another examples of this category, which incorporates more robust measures of the perceived walk access times to bus stops and rail transport, is WALC (Weighted Access for Local Catchments) developed by the Transport Studies Group (TSG) at the University of Westminster. This is a walk access instrument based on a very detailed representation of the local walking network, covering pedestrian only routes, alleyways and short cuts. WALC calculates walk access times for different groups of people taking account of several limitations that accompany the local environment. These limitations include: the local terrain (e.g. steep hills); the lack of provision of a shelter and seating at bus stops; low levels of street lighting; and difficulties in crossing busy roads because of heavy traffic volumes, speeding traffic, barriers (e.g. guard railing) preventing crossing at convenient points and lack of safe crossing points (Jones et al, 2005). WALC aims to demonstrate how the consideration of the hindrances to walking (physical obstacles and individual limitations) will change and shrink the shape of standard catchment areas.

The instrument uses the catchment (contour) measure based on different walk speeds and maximum acceptable walk times to different public transport nodes, and with regard to the concerns of various population groups. Weighted values for lack of bus stop facilities (e.g. shelter and/or seating), steep gradients (=>1:5), low levels of street lighting, and absence of formal pedestrian crossing arrangements are used to produce the catchment areas. Several different types of data are required for calculating each catchment; these include (Jones et al, 2005):

- A road network including a detailed pedestrian network;
- The location of bus stops (and facilities available); crossing points; steep hills; lamp posts as well as lighting levels;
- The weighted perceptions of different groups in regard to each of the limitations associated with walk access; and
- Other relevant data, including data on traffic flow data and pavement characteristics.

After applying the various weighting factors to the pedestrian network and to certain railway stations / bus stops, the outputs of WALC analysis are presented using ArcGIS as maps showing how the catchment sizes differ from each other according to the type of population group. The analysis is able to generate three different types of catchment area for each of the socially disadvantaged groups considered, to/from selected railway stations and bus stops: unadjusted walk catchments (no penalties); daytime penalties catchments; and night time penalties catchments (Jones et al, 2005).

Category 2: Accessibility by motorised vehicles through the transport system

These are instruments that focus on the flow of motorised traffic through the motorway network. Instruments cover one or more motorised modes and describe the transport network in terms of journey planning techniques with destinations expressed as opportunities, activities or places.

One application that focuses only on the bus network accessibility and buses run by the same operator is PTAM (Public Transport Accessibility Mapper) developed by West Yorkshire Passenger Transport Executive. PTAM can generate both origin and destination-based indicators and has an integrated GIS-based accessibility mapping instrument that. The instrument measures the accessibility of a location or set of locations by calculating the total travel time by bus taking account of walking time (based on straight line walking distance from and to bus stops), bus waiting time (estimated from service frequencies) and bus journey time (calculated from bus timetable database) (Halden *et al.* 2005). In order to carry out an accessibility calculation, PTAM requires the following data (Jones *et al.*, 2005):

- Bus services databases including timetables, stops and routes;
- Ordnance Survey mapping illustrating road networks, different physical features and administrative boundaries;
- Census statistics including many population characteristics;
- Employment location characteristics, and;
- Facilities databases including information on the provision of retail, education, health, and leisure services.

The output of PTAM can be presented as isochrones on an Ordnance Survey background or as tables including census statistics, employment statistics and lists of facilities associated with their attributes (Jones *et al.*, 2005).

Another application that focuses on the bus network is SONATA (SOcial Needs And Transport Accessibility) which has been used by rural local authorities in the UK to address travel needs and prioritise their expenditure on rural public transport (DfT, 2000). SONATA is a technique that was developed by Steer Davies Gleave in the late 1980s to estimate travel needs and identify gaps in the transport network across a given area (Helm, 1999). It evaluates the extent to which the existing public transport services are able to meet people's travel needs based on trip profiles estimated from maximum travel times and duration of purpose, and also test the effect of service changes and define those services that are most significant in meeting these needs (Cumbria County Council, 2002).

SONATA employs a combination of local surveys and social indicators to measure travel needs. It assigns total travel needs to particular journey purposes according to percentages obtained from travel survey data (Titheridge, 2004). The model analyses the use of bus services for work, health, senior education, leisure and shopping purposes. By applying car ownership, population and other socio-economic factors, numbers of unmet journeys can be estimated (Somerset County Council, 1997-2000).

The key output of SONATA is a prediction about the proportion of travel needs produced by each area which are met by the public transport networks. The output can be expressed in terms of need met/unmet. A mapping system has been included to present the results on a geographical base. Since SONATA measures fulfilment of different types of travel need separately, it is possible to map needs met for each journey purpose at different times of day. In addition, SONATA is able to generate a report on the number of travel needs that are met by each separate public transport service (Steer Davies Gleave, 2004).

Some instruments in this category can cover all the key features of journey time by public transport covering walking time, waiting time, in-vehicle time (actual not generalised/ weighted) and interchange time. An example of this type of instrument is CAPITAL (CalculAtor for Public Transport Accessibility in London).CAPITAL measures accessibility based on the minimum of total travel time between two zones using any combination of public transport modes in Greater London (i.e. bus, underground, Docklands Light Railway and national rail) in addition to walk access times (by assuming an average walk speed of 5km/h) to the public transport network (London Transport, 1999). However, accessibility cannot be calculated at different times of the day since data is only collected for the morning peak travel period. Furthermore, different population groups can be only considered in measuring accessibility in CAPITAL by using standard representative values for walk speeds, thresholds, etc. (Jones *et al.*, 2005).

The CAPITAL instrument combines information from Transport for London's Planning and Development Geographical Information System (PDGIS) and its public transport assignment model (RAILPLAN) (Jones *et al.*, 2005). CAPITAL relies on the Ordnance Survey Centre Alignment of Roads (OSCAR) database as a source of the road network in Greater London, containing all the major and minor roads, which has some supplementary information on walk links. RAILPLAN represents links, stops and services together with route characteristics (i.e. frequency) and uses a multi-routing assignment algorithm.

The analysis output is typically provided as shaded maps illustrating isochrones of journey travel times from and to a specific location, or set of locations using GIS mapping software. Further, the output file can be also presented as a spreadsheet where other types of analysis can be carried out (London Transport, 1999).

There are instruments in this category that support multi-modal travel including public transport, car, cycling and walking. Two examples of this approach are TRANSAM (TRANSport Accessibility Modelling) and Accession.

TRANSAM is an approach developed by Brown & Root to measure and quantify road network accessibility by competing travel modes and to analyse access changes in terms of network improvements and new public transport services. It provides the ability to make a comparison of accessibility measures for cycle, walk and public transport networks, or for a combination of these travel modes for the complete journey from origin through to destination (Robbins, 1999).

The TRANSAM model is based on a customised GIS which can create travel time contours based on the lowest generalised cost route for a range of travel modes (rail, bus, car, cycle and car) from all network nodes to the destination node. The calculation takes into account the walk time at the start and end of the public transport journey, the wait time at the bus stops and railway stations, and the on board travel time (Titheridge, 2004).

Data sets have to be set up in GIS for TRANSAM. These include the car network with the associated speed-flow relationships and observed volumetric information for each link; the public transport network (i.e. bus and rail) with the service time tables; cycle and walk networks; network nodes reflecting bus stops and railway stations; points of interest or "focal" points on the network such as transport interchanges, centres of employment and key hospitals; and other relevant statistical data (Robbins, 1999). By running TRANSAM, travel time contours will be created and then GIS can demonstrate visually the extent of travel attainable for acceptable combinations of travel modes. In this context, the output from TRANSAM is able to highlight the areas where levels of network accessibility for different travel modes are relatively low and high.

Accession is a travel access and travel time mapping package that was developed by MVA and Citilabs on behalf of the UK Department of Transport (Jones et al, 2005). It is built from a fully functional GIS with many features to help Local Authorities and their partners in: setting up strategic and action plans; the evolution and development of proposed actions; the prioritisation of resources; and the monitoring of accessibility strategies and action plans (DfT, 2004). Accession supports multi-modal travel and flexible routed and demand responsive transport modes (DfT, 2004).

The instrument measures accessibility to and from any point based on travel time, cost, distance or generalised cost through road and public transport networks (Titheridge, 2004). It is able to consider many origin and destination combinations in calculating accessibility and to generate different types of indicators (Halden *et al.* 2005). Accession offers a number of calculation methods: Threshold Hansen/ Gravity measure, Hansen/ Gravity Measure, Relative Hansen/ Gravity measure, Simple Utility or logsum measure or simple time-constrained accessibility (Citilabs, b). Access to local public transport is represented as a combination of walk time to a boarding point and the average wait time for a service. This can be calculated based on either the actual walk time or a straight-line walk time, while in-vehicle travel time is usually calculated based on scheduled arrival or departure times. The accessibility calculation can be carried out for specific catchment values of origins/ destinations, for selected modes, for particular routes/ services, and for particular days of the week and times of day (Titheridge, 2004). Moreover, other criteria can be considered in the analysis, for example road speed, maximum speed, frequency, start and end times, and delays for wheelchairs (Citilabs, b).

In order to measure accessibility, Accession requires a collection of data sets with regard to: public transport data (rail and bus) including boarding points and full timetables; the road network with the associated speed limits; walk and cycle links; and demographic and other data that can be disaggregated from census geography and other polygon systems onto origin points (Citilabs, b). The outputs of Accession can be presented as tables and various contours reflecting accessibility. Also, the results can be exported for mapping or analysis in other packages.

Category 3: Other models that incorporate accessibility

In this category are models and instruments that have not been developed specifically to measure accessibility that, however, incorporate some dimensions of accessibility modelling. Included in this category as examples are two land use and transport interaction models and a technique from urban space design.

GenMod

GenMod is a static multimodal transport model that was developed by the Transportation Planning Department of Amsterdam (DIVV) and the University of Amsterdam (Brömmelstroet and Bertolini, 2008). It is basically a traditional four-step model based on household surveys and mobility counts. As a by-product, GenMod can be used for measuring accessibility as it calculates travel times between 933 zones within the Amsterdam region using extensive public and car transport networks.

GenMod has been used to show the land use - transport system consequences of land use/ transport alternatives, by calculating network consequences (e.g. level of service), network opportunities (e.g. for more efficient use) and the dynamics of indicators that show the change from a baseline scenario; for example potential accessibility (e.g. the number of people or jobs accessible from each zone within acceptable travel time) and sustainability (e.g. the number of people or jobs reachable within a crow flight distance) (Brömmelstroet and Bertolini, 2008).

In order to run the model, land use data including the number of people or jobs held by zone, and road and public transport networks are required. The outputs of GenMod runs are presented as clear overviews of all the indicators used and spatial maps produced by GIS that help to define which land use - transport system choices have a negative effect on the chosen indicators and which a positive one. These can be used to build a list of appropriate land use transport choices and strategies.

TMfS (Transport Model for Scotland)

TMfS is a strategic, multi-modal demand and assignment model which was developed by MVA Consultancy, with its land-use capability developed by David Simmonds Consultancy (Transport Scotland, b).

The key objective of TMfS is to enable the Scottish Government and Local Authorities across Scotland to examine the impact of and/or interaction between major inter-urban road and public transport schemes and major transport policy options in forecast years (MVA, 2006) TMfS measures the implications of these schemes for accessibility and travel demand and, consequently, helps Local Authorities in prioritising and scheduling their transport interventions (Transport Scotland, a). Other objectives are to undertake economic, traffic and land-use assessments of proposed transport schemes and policies, and also to produce robust traffic forecasts on all Trunk Roads within the model area (Transport Scotland, b; MVA, 2006).

An accessibility analysis package is included as an add-on to the basic TMfS model. The analysis uses the output costs obtained from running the basic model along with several parameters specified by the user, and produces a number of accessibility measures. These measures can be for either destinations or origins and can be weighted by demographic and socio-economic data related to each geographical zone such as the number in employment or the number of households (Transport Scotland, b). The model takes into account the main responses of passengers to schemes or policies such as destination choice, mode choice, route choice, trip frequency and peak spreading. A wide range of data is required to run TMfS which is built using a system of zones and a transport network. The main data include (Transport Scotland, b):

- Census and travel to work data including travel diaries, roadside and public transport passenger interview data, and rail ticket data;
- Planning data forecasts that are set up by Local Authorities and focus on future development land allocations for each TMfS zone;
- National/regional economic and geo-demographic assumptions;
- Public transport service data including routes, boarding points, fares and frequencies;
- Road network details including number of lanes, link lengths, junction lay-outs, typography, signal timings and speed limits, and;
- Count data including traffic counts, public transport user counts, turning counts at junctions and car park surveys.

This is a strategic regional model that generates a variety of outputs that can be used to evaluate policy initiatives or public transport and road infrastructure schemes as well as to predict changes in both transport and land use patterns over the model area. The key outputs available from TMfS are: operational analysis; accessibility analysis (that can be performed by linking the operational analysis of the transport model with graphical and tabular analysis of land use changes); congestion mapping; accident analysis; environmental analysis; economic and financial assessment; sub-area analysis; and demographic and land-use predictions (Transport Scotland, b; MVA, 2006).

Space Syntax

Space Syntax is a technique developed by Bill Hillier, Julienne Hanson and colleagues at the Bartlett, University College London that provides a spatial analysis of aspects and structure of space and helps to describe social activities and human behaviour from a spatial configuration perspective (Jiang et al, 2000). Space Syntax has been used to estimate the connectivity and, consequently, accessibility of architectural or urban spaces (i.e. buildings, open spaces, streets and cities) (Hillier, 1996). It is also able to define movement patterns and the degree of difficulty in mobility. Moreover, the instrument can be used for other applications including land-use distribution, criminal activity, estate prices and other spatial related characteristics.

The main principle of Space Syntax is to model a spatial structure as a set of axial lines and calculate spatial indices of a space in order to estimate the relation between various parts of indoor or urban spaces (Jun et al, 2007). Axial lines are lines of unhindered movement used in measuring accessibility, and they are defined as the least number of longest straight lines. This is illustrated with a connectivity graph where axial lines are represented as nodes and line intersections as links, which reverses the terminology used in the traditional method (Abubakar and Aina, 2006).

Three key measures using different configuration parameters can be applied in the calculation: "connectivity" which computes the degree that each space (node) is directly linked to other spaces (nodes) in the connectivity graph, "control" which computes the potential of any space to provide part of a route linking between any two spaces within a defined distance (modelling movement *through* spaces), and "integration" which computes relative depth from any space to all other spaces (modelling movement *to* spaces), and (Abubakar and Aina, 2006; Vaughan and Geddes, 2009).

In addition, three different types of distance calculation can be considered in accessibility analysis by using Space Syntax. These are metric (shortest paths), topological (fewest turns' paths) and geometric (least angle change paths). For example, when topological distance is applied, the most accessible sites are not those closest to all other sites in terms of metric distance, but rather those in terms of number of changes of direction through the journey (Hillier, Turner *et al.* 2007). The topological method, called depth-based accessibility, is commonly more significant since it assesses the complexity of routes within the defined area (Rose and Stonor, 2009). Depth of one node from another can be directly estimated by calculating the number of turns (or steps) between two nodes, while the depth of a node (or a street) in a particular step distance is measured by the number of nodes that are separated from that node by the given number of steps (Jun et al, 2007). However, the Space Syntax-based measure has a key weakness in calculating the actual journey length since it does not considertraditional travel costs such as travel time or distance (Jun et al, 2007).

In order to measure accessibility in Space Syntax, the transport network (i.e. public transport services, roads, cycle and/or walk routes) as well as the associated lengths of the network links are required to be built. The spatial indices derived from Space Syntax analysis reflect the extent to which a space (or node) is integrated and connected with other spaces (or nodes) in the studied area (Jun et al, 2007). The resulting maps can be presented in several scales of colours showing the different range of accessibility values (Vaughan and Geddes, 2009).

Recommendations for Accessibility Instruments Improvements

The review above has focused on accessibility instruments that are well described in the literature identifying some of the gaps in the coverage of accessibility. The following list summarizes a number of issues contributing to enhance the soundness of accessibility instruments.

However, it is not necessary that each accessibility instrument should consider all the recommendations listed below since the various objectives of accessibility analysis in planning practice require different considerations.

- Consider, in addition to public transport and car, other modes including walking and cycling;
- Consider all public transport networks (i.e. bus, rail, underground, ferry, air, etc) in the modelled area rather than the bus network only;
- Consider interchange options between public transport services of different operators and modes (e.g. bus, rail and underground);
- Consider interchange options based on the minimum time accepted for interchange, best route (fastest route, cheapest route or shortest distance), priority for interchange between public transport services of the same mode or operator, and/or minimum number of interchanges required to complete the journey;
- Considered the influence of specific times of day for specific days of the week (i.e. during weekday or the weekend) associated with access requirements to particular types of facility;
- Consider the declining attractiveness of potential destinations with increasing travel time (or distance) from an origin location, by using a distance decay measure (e.g. Hansen measure),
- Consider different walk access speeds according to area and type of population group;

- Consider different walk access thresholds (time or distance) to boarding point (bus stops and stations) according to area and type of population group;
- Consider real time updates due to traffic congestion, roadwork or delay;
- Consider physical features including physical obstructions, steep hills and topographic constraints, and maintenance and surfacing;
- Consider the type of vehicle to gain a better assessment of accessibility for a specific journey purpose or for some population groups. For example, a bus with luggage carrying capability for people travelling to an airport, and a bus with assigned space for a wheelchair/ pushchair for disabled people or those travelling with young children in pushchairs;
- Consider the quality and environment of the journey including opportunities for shelter from weather and for rest points; comfort of waiting areas and vehicles; attractiveness and aesthetics of walking routes; support services when travelling (e.g. catering); and assistance and helpfulness of public transport staff;
- Consider the safety and security factor during the journey including real and perceived safety whether outside or in the vehicle, speed limits, obstructions during hours of darkness (e.g. lack of street lighting), and availability of road crossing facilities;
- Give an indication of the environmental impact of the route choice, for example emissions resulting from the journey;
- Be able to identify changes in demand and in land-use patterns that might result from an improvement – or deterioration – in accessibility in an area.

Conclusion

The importance of using accessibility instruments in planning practice has recently been rising in many countries. This chapter has reviewed the way in which accessibility instruments have been categorised in the literature focusing on the conceptualisation of accessibility and the dimensions modelled in the instruments.

To illustrate the approaches used by tool developers a three-fold categorisation was used which matched well with the state of the art categorisations by leading tool developers and related to how accessibility is being articulated by practitioners. Examples of each category were demonstrated to illustrate the general issues and themes. The chapter concluded with recommendations on how to improve accessibility instruments to make them more usable for urban management practitioners.