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# Accessibility Measures:

## Overview and

## Practical Applications


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**Impacts of Transit Led Development**

**In a New Rail Corridor**


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# 1 Introduction

The purpose of this review is to provide an overview of the various ways in which accessibility has been measured. Specifically, the review supports a current research project studying the impacts of transit led development in a new rail corridor. The review was undertaken to provide a context for publications arising from the research and also to provide 'how to' instructions for the research team to enable them to measure the accessibility of and from each station precinct.

This review covers a total of 41 papers published during the past five years through conference proceedings or in academic journals. Materials for this review were sourced primarily from electronic journals (Appendix 1). A list of academic journals which dealt explicitly with travel accessibility was compiled, a search schedule created and each journal searched issue by issue for relevant article titles from the last 5 years. This list was supplemented with other literature as relevant.

# 2 Defining Accessibility

The concept of accessibility has been developed, and cast into measurable indicators, in parallel with the concept of mobility. Bhat et al (2000) credit Hansen (1959) with the first significant scholarly work on the subject. While mobility is concerned with the performance of transport systems in their own right, accessibility adds the interplay of transport systems and land use patterns as a further layer of analysis. Accessibility measures are thus capable of assessing feedback effects between transport infrastructure and modal participation on the one hand, and urban form and the spatial distribution of activities on the other hand. Some accessibility measures also include behavioural determinants for activity patterns in space and time, and the responses of transport users to physical conditions.

Litman (2003) points out that traffic and mobility planning have traditionally been concerned primarily with the movement of motor vehicles (traffic) or people and goods in general (mobility), while accessibility explicitly takes on board the land use-transport connection and handles trip numbers and travel time as indicators. There are a number of inherent conflicts or trade-offs between mobility or traffic and accessibility: for example, roads designed for maximum mobility or traffic throughput usually have poor accessibility for adjacent land uses, while precincts where (multi-modal) accessibility has been maximised may experience road traffic congestion and parking constraints.

Geurs and van Eck (2001) define accessibility as

> ‘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).’

In contrast, Bhat et al (2000) use the following definition:

> '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.'

It is notable that Geurs and van Eck (2001) make specific reference to land use and transport, thus implying that accessibility is intricately linked to, and primarily determined or 'enabled' by transport infrastructure and urbanisation patterns, whereas this spatial dimension is not at all emphasised, though still implicit, in Bhat's et al (2000) definition. Geurs and van Wee (2004) make a further differentiation in clarifying the terminology:

> 'Access is used when talking about a person's perspective, accessibility when using a location's perspective.' (p 128)

Bertolini, LeClercq and Kapoen (2005) define accessibility as

> 'the amount and diversity of places that can be reached within a given travel time and/or cost' (p209),

and sustainable accessibility as accessibility

> 'with as little as possible use of non-renewable, or difficult to renew, resources, including land and infrastructure' (p 212).

In Geurs' and van Eck's (2001) understanding, accessibility consists of four components. The *transport component* is concerned with measures such as travel time, cost and effort of movement in space. The *land use component* measures the spatial distribution of activities or opportunities, and contains an assessment of the competitive nature of demand for activities at destinations, and of supply of potential users. The *temporal component* examines the time constraints users experience for their activity patterns, and the availability of activities or opportunities according to the time of the day, week or year. The *individual component* investigates the needs, abilities and opportunities of transport users and thus takes in socio-economic and demographic factors.

Both Bhat et al (2000) and Geurs and van Eck (2001) identify several common types of accessibility measures, and discuss the suitable range and limitations of their application. Geurs and van Eck (2001) distinguish between infrastructure-based, activity-based and utility-based accessibility indicators and maintain that while the infrastructure-based type is easiest to measure and interpret, it is also the most limited when it comes to capturing the interplay of land use and transport infrastructure. Conversely, the activity-based indicator type includes the land use component from the outset, but tends to be more complex and sometimes suffers from poorer legibility. The utility-based indicator type crosses over into economic and social disciplines as well as land use and transport, and is characterised by Geurs and van Eck (2001) as an emerging model still requiring substantial research and development. Hence, accessibility is a multifaceted concept, not readily packaged into a one-size-fits-all indicator or index. In Litman's (2003) words, 'there is no single way to measure transportation performance that is both convenient and comprehensive.' (p 32). However, Geurs and van Wee (2004) produced a checklist of recommendations of how any accessibility measure should behave, regardless of its perspective (or combinations thereof):

1. Accessibility should relate to changes in travel opportunities, their quality and impediment: 'If the service level (travel time, cost, effort) of any transport mode in an area increases (decreases), accessibility should increase (decrease) to any activity in that area, or from any point within that area.' (p130)

2. Accessibility should relate to changes in land use: 'If the number of opportunities for an activity increases (decreases) anywhere, accessibility to that activity should increase (decrease) from any place.' (p130)

3. Accessibility should relate to changes in constraints on demand for activities: 'If the demand for opportunities for an activity with certain

capacity restrictions increases (decreases), accessibility to that activity should decrease (increase).' (p130)

4. Accessibility should relate to personal capabilities and constraints: 'An increase of the number of opportunities for an activity at any location should not alter the accessibility to that activity for an individual (or groups of individuals) not able to participate in that activity given the time budget.' (p130)

5. Accessibility should relate to personal access to travel and land use opportunities: 'Improvements in one transport mode or an increase of the number of opportunities for an activity should not alter the accessibility to any individual (or groups of individuals) with insufficient abilities or capacities (eg. drivers licence, education level) to use that mode or participate in that activity.' (p130)

Bertolini et al (2005) discuss the balancing act that is the development of suitable indicators for accessibility, not merely in an academic context, but also with regard to their application in practical policy making:

> 'In order to be useful for practical planning purposes, an accessibility measure must meet two basic requirements: it must be consistent with the uses and perceptions of the residents, workers and visitors of an area, and it must be understandable to those taking part in the plan-making process.' (p 210)
>
> 'A major methodological challenge […] is finding the right balance between a measure that is theoretically and empirically sound and one that is sufficiently plain to be usefully employed in interactive, creative plan-making processes where participants typically have different degrees and types of expertise.' (p 218).

It is the participants, however, who make or break successful accessibility assessment and its capacity to inform decision making, as integral communicators within the process. A transparent and legible approach is thus critical in the view of Bertolini et al (2005),

> ‘not just because of a generic democratic concern, but also because of the importance of mobilising the (tacit) knowledge of different participants in the identification of problems and the search for solutions.’ (p 218)

# 3 Accessibility Indicators - Categories

The section above outlines the range of methodological approaches to accessibility measures: the work of both Bhat et al (2000) and Geurs and van Eck (2001) are particularly relevant. Baradaran and Ramjerdi (2001) classify accessibility measures into five categories: travel-cost approach, gravity or opportunities approach, constraints-based approach, utility-based surplus approach, composite approach. The gravity or opportunities approach summarises the contour/cumulative opportunity and gravity models. The constraint-based approach is equivalent to time-space measures, while the utility-based surplus approach parallels the utility measures discussed above, though with a greater focus on individual behaviour and decision-making. Composite approaches attempt to combine time-space and utility indicators into a common model. While overcoming the methodological shortfalls of the former two indicator types, this approach is characterised by vast data requirements and the need to tailor it towards its specific application. The authors show in their work on the accessibility of European cities that where different research questions inform this composite approach, significant variations in outcome are recorded. This paper attempts to consolidate the range of accessibility measures, Table 1 shows our seven-fold classification.

**Table 1: Accessibility Measures – an Overview**

| | Methodological Category | Approach / Measure | Pros & Cons |
|---|---|---|---|
| 1) SPATIAL SEPARATION MEASURES | **Spatial Separation Model** (Bhat et al, 2000)<br><br>**Infrastructure Measures** (Geurs & van Eck, 2001)<br><br>**Travel Cost Approach** (Baradaran & Ramjerdi, 2001) | Measures **travel impediment** or **resistance** between origin and destination, or between nodes.<br><br>Travel impediment measures can include:<br><br>**Physical** (Euclidean) **Distance**<br><br>**Network Distance** (by mode)<br><br>**Travel Time** (by mode)<br><br>**Travel Time** (by network status – congestion, free-flow etc)<br><br>**Travel Cost** (variable user cost or total social cost)<br><br>**Service Quality** (eg. public transport frequency) | Data is generally easily available from digital mapping material and other public sources.<br><br>No consideration of land use patterns and spatial distribution of opportunities.<br><br>See Box 1 for a detailed discussion. |
| 2) CONTOUR MEASURES | **Contour Measures** (Geurs & van Eck, 2001)<br><br>**Cumulative Opportunity Model** (Bhat et al, 2000) | Defines catchment areas by drawing one or more **travel time contours** around a node, and measures the number of opportunities within each contour (jobs, employees, customers etc). | Incorporates land use and attends to infrastructure constraints by using travel time as indicator for impediment.<br><br>Definition of travel time contours may be arbitrary and does not differentiate between activities and travel purposes.<br><br>Methodology cannot capture variation in accessibility between activities within the same contour. |

| | Methodological Category | Approach / Measure | Pros & Cons |
|---|---|---|---|
| 3) GRAVITY MEASURES | **Gravity Model** (Bhat et al, 2000)<br>**Potential Accessibility Measure** (Geurs & van Eck, 2001) | Defines catchment areas by measuring travel impediment on a **continuous scale**. | More accurate representation of travel resistance than in contour measure, but tends to be less legible.<br>Does not differentiate between travel purposes and individual drivers for travel. |
| 4) COMPETITION MEASURES | **Competition Measures** (van Wee, Hagoort and Annema 2001)<br>**Joseph & Bantock Measure** (1982)<br>**Inverse Balancing Factor Model** (Geurs & van Eck, 2001) | Incorporates **capacity constraints of activities and users** into accessibility measure.<br>May make use of any of the preceding three models. | Provides a regional perspective on accessibility. |
| 5) TIME-SPACE MEASURES | **Time-Space Measures** (Bhat et al, 2000 and Geurs & van Eck, 2001)<br>**Person-Based Measures** (Geurs & van Wee, 2004) | Measures travel opportunities within **pre-defined time constraints**. | Well-suited to examine trip chaining and spatial clustering of activities.<br>Usually requires project-specific user surveys, limiting the geographical range and compatibility of data. |
| 6) UTILITY MEASURES | **Utility Measures** (Bhat et al, 2000 and Geurs & van Eck, 2001)<br>**Utility Surplus Approach** (Baradaran & Ramjerdi, 2001) | Measures **individual or societal benefits** of accessibility.<br>Indicators can include:<br>**Economic utility** (to the individual, or to the community)<br>**Social or environmental benefits** (eg. social inclusion, greenhouse effects) | The empirical link between infrastructure provision and economic performance is tenuous and contested. |

| | Methodological Category | Approach / Measure | Pros & Cons |
|---|---|---|---|
| | | **Individual motivations** of travel (by activity or travel purpose)<br>**Option** and **non-user benefits** of transport infrastructure | The indicator can analyse existing motivations of travel, but cannot anticipate feedback effects between land use and travel patterns, or future behaviour patterns of users. |
| 7) NETWORK MEASURES | **Network Measures: Multiple Centrality Assessment** (Porta et al 2006a, 2006b) | Measures **centrality** across entire movement networks.<br>Networks can be represented by: | |
| | | the **primal approach** (networks are understood as intersections connected by route segments) | More intuitive, and allows for the incorporation of a travel impediment measure in the network analysis. |
| | | the **dual approach** (networks are understood as route segments connected by intersections) | Clearly captures the topological form of a network, and can be used to assess its spatial legibility |

### *1. Spatial Separation Measures*

The spatial separation model identified by Bhat et al (2000) can be categorised as an infrastructure-based measure in Geurs' and van Eck's (2001) terms. It only uses the physical distance between infrastructure elements as input (see figure one) and is thus suitable for the analysis of nodes and network structures (Leake and Huzayyin 1979). It is easy to understand and calculate and requires minimal, easy-to-obtain data input (Baradaran and Ramjerdi 2001). However, there is no reference to land use patterns, spatial distribution of opportunities, or to network constraints to do with travel speed or other sources of resistance. Critically, spatial separation measures do not take into account behavioural aspects of travel choices, particularly the variable attraction of activities and the variable value of time to different groups of trip-makers (ibid).

A step towards greater complexity for spatial separation measures is raised by Baradaran and Ramjerdi (2001) who refer to this indicator type as the travel cost approach. Separation between locations does not need to be measured by geographical distance alone; instead or additionally, other categories of travel cost or impediment can be employed. Examples include travel time, user cost of transport, travel reliability, frequency of travel opportunities, or a combination thereof. Scheurer and Porta (2006) point out that the analysis of accessibility for public transport in particular is not well served by a travel cost measure based on physical distance, since travel time and user cost are rarely proportional to distance in public transport networks. Geurs and van Wee (2004) raise the significance of travel time reliability from the user perspective in this context (reflecting on Bates 2001), and make the observation that the disutility of travel time may not be constant across all modes and trip purposes (discussed in Blayac and Causse 2001, and Redmond and Mokhtarian 2001).

Spatial separation measures can be employed to assess the ease of access to station areas using different indicators for travel disutility (particularly distance, time, cost and service quality). This data can be used as input for the other categories of accessibility indicators.

**Box 1: Measuring Travel Impediment**

The disutility or impediment of a journey can be measured in various categories, and each category is subject to a range of further considerations in order to arrive at valid figures.

The simplest way of representing *distance* is to measure the Euclidean distance between origin and destination. However, since it is rarely possible to travel around a built environment as the crow would fly across it, this procedure invariably leads to a significant underestimation of actual distance travelled. Options for overcoming this shortfall include the incorporation of a flat deviation factor, taking into account the character of the movement network for different modes (see below), or the actual measurement of network distance. If mapping material of the transport network is available in a digital format, this can be done relatively straightforwardly using GIS software. A further qualification emerges, however, when considering the likely fact that the shortest network distance is not necessarily the preferred travel route. In multioptional networks, motorists may revert to roads that allow for faster movement and/or avoid roads that are prone to congestion, while public transport users may opt for a superior mode (such as rail) for as large a portion of the journey as possible, or alternatively for a direct (transfer-free) connection between origin and destination, even where this increases the travel distance. Pedestrians and cyclists, on the other hand, do not always confine their choice of route to the road network, but use shortcuts through open spaces or even buildings that are commonly not represented in digital maps, but have an obvious influence on travel distance.

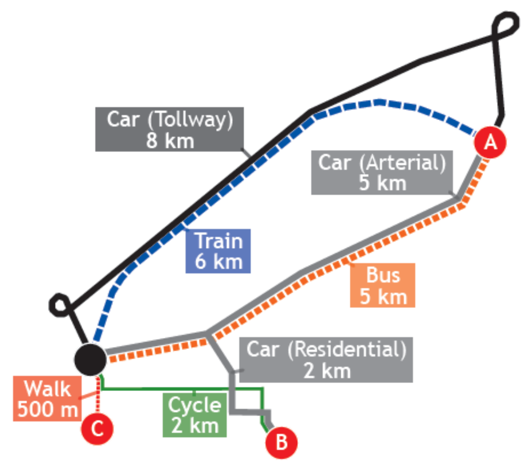
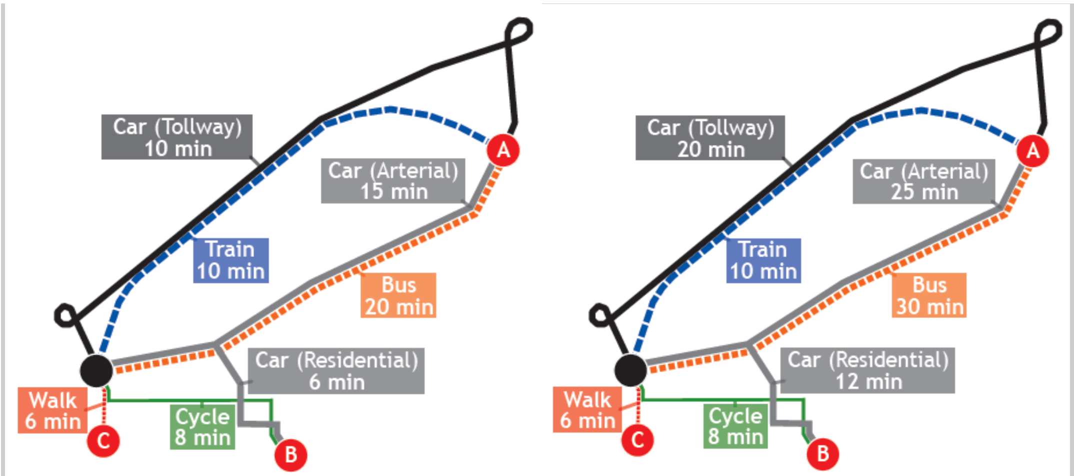



**Figure 1:**
**Travel impediment measures from origin (black dot) to various destinations (A, B and C), using metric network distance.**

Some of these problems can be resolved by employing measures other than distance to quantify travel impediment, with *travel time* possibly the most commonly used. For motorists and public transport users, travel time usually represents a more accurate predictor for the choice of route than metric distance. Sophisticated GIS applications can model such preferred routes on the basis of average speed per route segment; however, they do not necessarily take into account the effect of traffic congestion (for motorists) and the individual disposition to accept transfers (for public transport users). For pedestrians and cyclists, travel time in built-up areas is strongly influenced by traffic management features such as traffic lights, and the extent to which these are observed or disregarded.

In addition, the duration of a journey can be defined in different ways. For example, ‘kerb-to-kerb’ travel time is commonly understood as the time which a motorist, public transport user, cyclist or pedestrian spends within the publicly accessible infrastructure of the mode; thus, access times to stations or bus stops, time spent cruising for a parking space etc. are discounted. ‘Door-to-door’ travel time takes these secondary effects into account, but adds a layer of complexity to the analysis that cannot always be supported by available data. In the case of public transport, various methods are used to capture waiting time at stations and stops; a common approach is to count half the service frequency as average waiting time at system access and during transfers. However, where low frequencies (eg. more than every 15 minutes) and a reasonable level of timetable reliability prevail, allowances for waiting time can be reduced as most passengers can be expected to take scheduled departure times into account when appearing at the station or stop. Similarly, where connecting services are coordinated, transfer times can reflect the actual timetable rather than half the service frequency.




**Figures 2, 3: Travel impediment measures from origin (black dot) to various destinations (A, B and C), using kerb-to-kerb travel time under free-flow conditions (left), and during congestion (right).**

*Travel cost* is another possible indicator for travel impediment and can be measured in various ways. The simplest method is to consider only the variable user costs per trip, such as petrol and parking cost and possible road tolls for motorists, and fares for public transport users. In such a model, walking and cycling are usually considered free of cost. Insofar as cost influences the choice of mode and the decision whether or not to make a particular trip, variable user costs probably come closest to representing an individual's considerations in this respect, but they clearly only capture part of the total cost of travelling. Thus, more complexity can be added to this measure by factoring in the fixed cost of car (or bicycle) purchase, registration and maintenance, or even external costs to the public such as infrastructure provision, financial subsidies or tax breaks to public transport operators and vehicle owners, health and environmental effects etc, borne by the trip maker in his or her role as taxpayer. In this context, the physical speed of different modes of transport, informing the travel time measure described above, can be modified into a 'social speed' (Seifried 1990, Tranter 2006) that considers the time individuals spend on tasks associated with vehicle ownership, and on earning the income required to afford it.

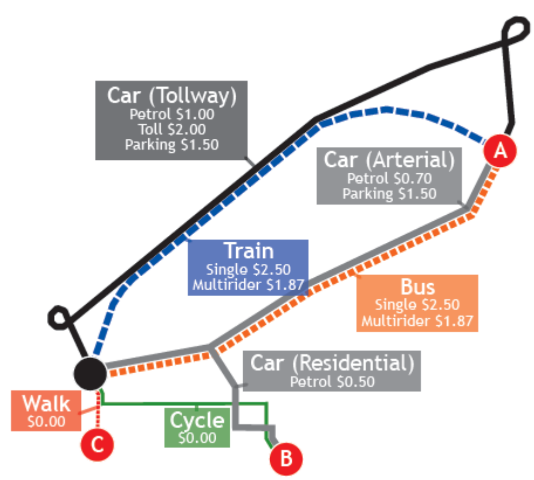


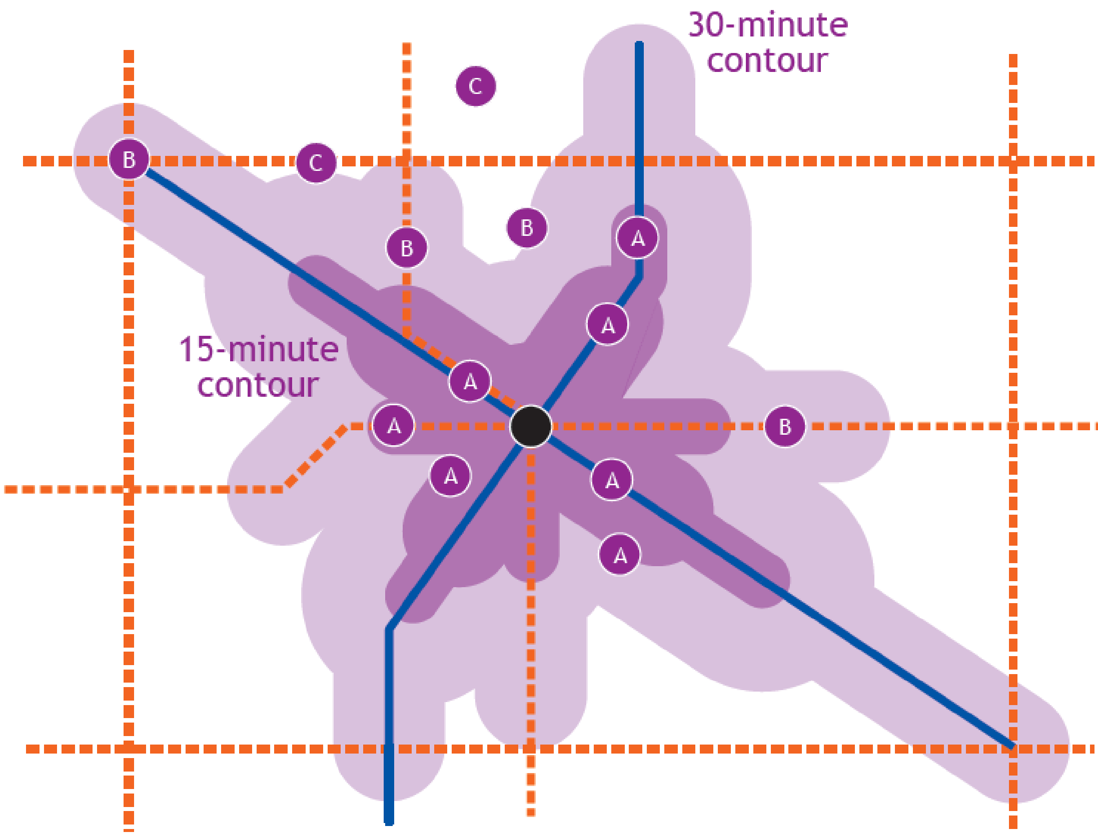

**Figure 4: Travel impediment measures from origin (black dot) to various destinations (A, B and C), using variable user cost.**

## *2. Contour Measures*

The contour measure in the terminology of Geurs and van Eck (2001), or the cumulative opportunity model in Bhat et al (2000), prominently uses the element of travel time in the composition of the indicator, and defines thresholds of maximum desirable travel times for different types of activities: catchment areas of jobs, employees, customers, visitors and other members of the travelling public are mapped out as contours for each node under consideration (Figure 5).

This approach incorporates land use patterns as well as infrastructure constraints. However, in applying a rigid boundary to the catchment area identified, this indicator is not capable of differentiating between opportunities inside this area, despite the fact that actual travel times obviously vary among activities within the same contour bracket (or isochrone). The indicator also treats activities as equal regardless of their cost or desirability for users. Critically, the contour brackets chosen for each type of activity are almost invariably arbitrary, not necessarily reflecting the real drivers of trip making from a user perspective, unless dedicated research is conducted on this component. Thus this indicator is highly sensitive to the choice of demarcation area (Baradaran and Ramjerdi 2001). Bertolini et al (2005) also recognise the weakness of a potentially arbitrary travel cost or time contour (isochrone), yet they make a strong plea for considering a 30-minute time limit where journeys to work are concerned, and recommend this measure to be taken separately for each mode and for different network conditions (car-free flow, car-congestion, public transport, cycling, walking). This is supported by statistical evidence in the Netherlands, where the average one-way commuting time is 28 minutes, with 80% of commuters spending 30 minutes or less on the trip from home to work, as well as from findings by Marchetti (1994) who established a global constant that people do not spend more than one hour travelling per day, Prud'homme and Lee (1999) for Paris and Wiel (2002) for Europe.

**Figure 5: Contour Measure. Opportunities (purple dots) are classified by travel time zones (A = up to 15 minutes, B = 15 to 30 minutes, C = over 30 minutes) from the point of reference (black dot).**




Bertolini et al (2005) then identify the way in which this can be used as a diagnostic tool. They highlight two approaches to improve the strength of public transport in a given settlement context: (a) by expanding the isochrones through insertion of new infrastructure/services and/or speed improvements on existing ones, and (b) by increasing land use densities and functional diversity within the existing public transport isochrones to augment the number of activities found there. However, three qualifications are identified. Firstly, there are manifold barriers to infrastructure development in public transport, rendering the prospect of isochrone expansion inherently uncertain and slow. Secondly, there is a continued, articulated coexistence of public transport and car modes in urban and regional mobility, necessitating the development of indicator tools taking multimodal access into account. And thirdly, the importance of local access to and from public transport and for short-distance trips calls for the inclusion of pedestrian and cycling accessibility into any tool looking at motorised travel.

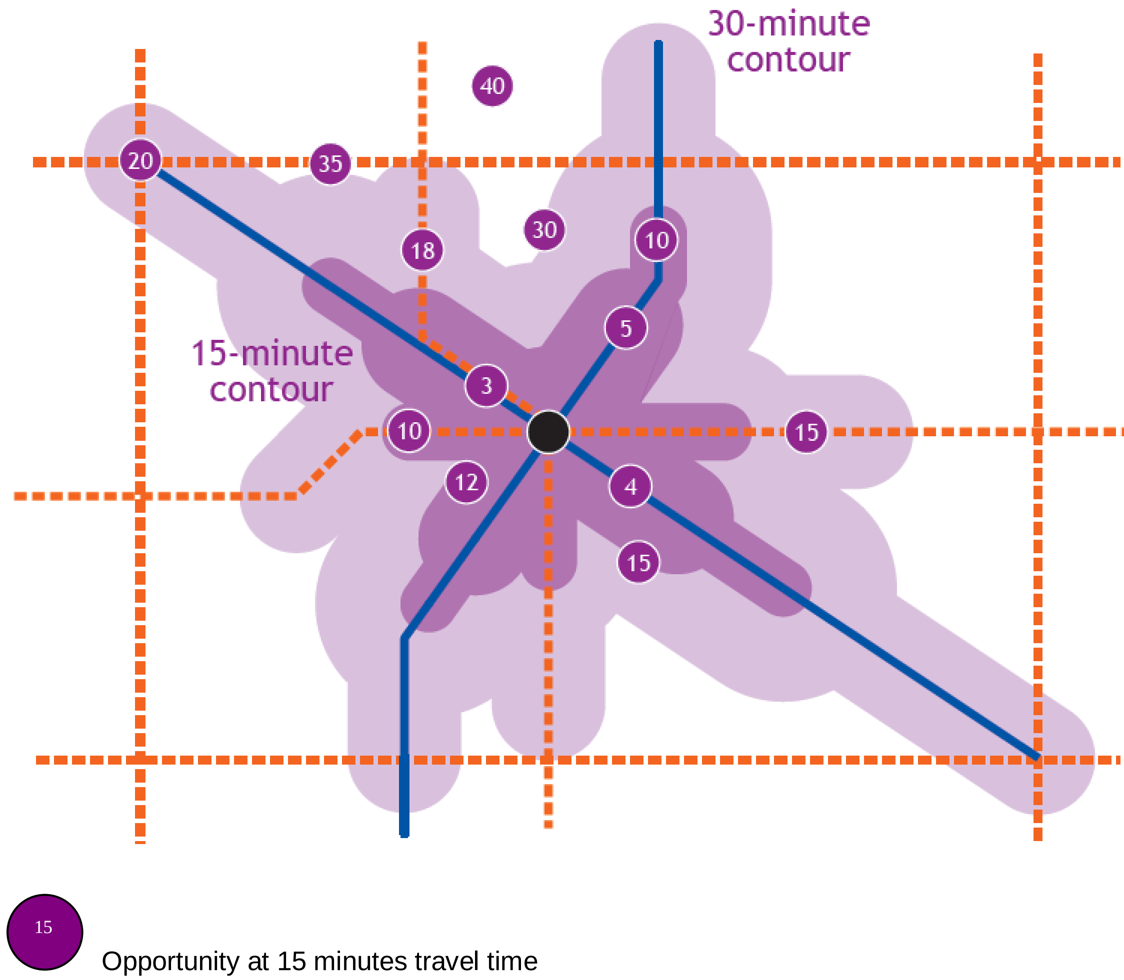
Contour measures are well-suited to assess pedsheds and cycle-sheds for station area precincts, based on assumptions of 5-minute or 10-minute access by each mode (see Curtis, 2005 for an explanation of the rationale for these assumptions).

### *3. Gravity Measures*

The gravity model in the categorisation of Bhat et al (2000), somewhat related to potential accessibility measures discussed by Geurs' and van Eck (2001), sets out to overcome the shortfall of rigid and/or arbitrary contour brackets by treating opportunities differently along a continuum of time and distance. In most cases, this is done by identifying the actual travel time for each opportunity and using a relatively generic distance decay function as a proxy for the disutility experienced by transport users with increasing travel time, cost or effort (Geurs and van Wee 2004). The model, however, still treats every transport user within the study area equally and disregards variations in individual preferences in relation to the desirability of activities (Baradaran and Ramjerdi 2001).

Gravity measures can be used in station precincts to use an alternative model for pedestrian and cycling access, taking into account that the 5-minute or 10-minute contours for pedsheds or cycle-sheds may be arbitrary and disputable. Opportunities are represented by actual travel time in minutes from the point of reference.  This means that the destinations are now identified by actual travel times as opposed to category (eg. A, B C) as shown in the contour measure example.  Different opportunities can then be listed by actual travel time and so compared.

**Figure 6: Gravity Measure. Opportunities (purple dots) are represented by actual travel time in minutes from the point of reference (black dot).**




## *4. Competition Measures*

The Joseph and Bantock measure (Joseph and Bantock 1982), and the inverse balancing factor model discussed by Geurs and van Eck (2001) consider the presence of competition factors in accessibility. In the first measure, the capacity of (for instance) medical facilities poses an upper limit to the number of potential users, and similarly, an abundant number of potential employees may compete for a limited number of jobs available in a given location. Conversely however, competition may also (and simultaneously) occur between employers for suitably skilled workers, generating two-way constraints to theoretical accessibility. This is captured in the double-constrained spatial interaction model, credited in Geurs and Van Wee (2004) to Wilson (1971).

Competition effects in accessibility measures are discussed in more detail in van Wee, Hagoort and Annema (2001) and Shen (1998). In the view of van Wee et al, contour and potential accessibility measures lead to a bias favouring centralisation of activities, that is, the locations with the highest accessibility scores are necessarily the ones with the highest degree of centrality in the transport network. However, the centralisation of activities in transport nodes can reach a point beyond which their accessibility at a regional scale actually declines: for example, once the number of jobs concentrated there exceeds the number of potential employees within a reasonable commute.

To include competition effects in an accessibility measure, van Wee et al (2001) propose the introduction of an additional dimension, or extension, to the indicator. Not only is a location zone assessed for the number of activities within a given travel time (or other travel impediment factor): each of the destination zones is further assessed for its capacity of a given activity and relative to activity choices in adjoining zones, and the results factored into the measure of the original zone. This procedure can be repeated for the destination zones, adding a further extension, and so forth – however, the model is subject to diminishing returns with growing distance from the original location.

Testing the model in a practical application in the Netherlands, the authors conclude that accessibility values change by up to 10% if competition effects are included. However, their next argument acknowledges the weakness of the approach: what exactly does a 10% increase or reduction in accessibility mean? The geographical complexity of the model limits its legibility, and it is recommended to use index values (eg. base case = 100) to make it more understandable. Further complicating factors are links to the economic cycle, changes to land values and travel costs, and the observation that the labour market (for which the model was generated) is far from homogenous. It is also noted that employees vary in elasticity to choose their job location, depending on income, family status, housing situation and other factors.

Competition measures are relevant to station areas where they also accommodate activity centres, and where it is intended to assess the attractiveness of these activities in comparison to established alternatives for a broader user group, or where there is a need to assess a potential catchment area for regional facilities (health, education, sports etc).

**Figure 7 SCENARIOS A-D: COMPETITION MEASURES.**

**Figure 7A – Scenario A – 'The Base Case' where facility size and patrons are equal. The diagram below shows capacities of facilities ('office') with their accessible catchment areas (pale circles) that are proportional to the geographical distribution of patrons (small dots).**

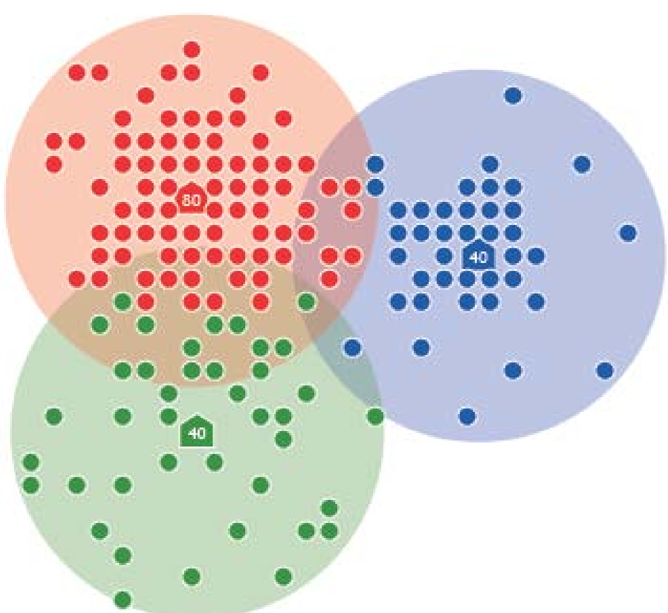


**Figure 7B – Scenario B – 'Constrained Facilities'. The diagram below shows the distribution of patrons for each facility where capacity constraints exist – for example, only 68% of those living in the red catchment are served by any of the three catchments, while the remaining 32% do not get any service at all.**

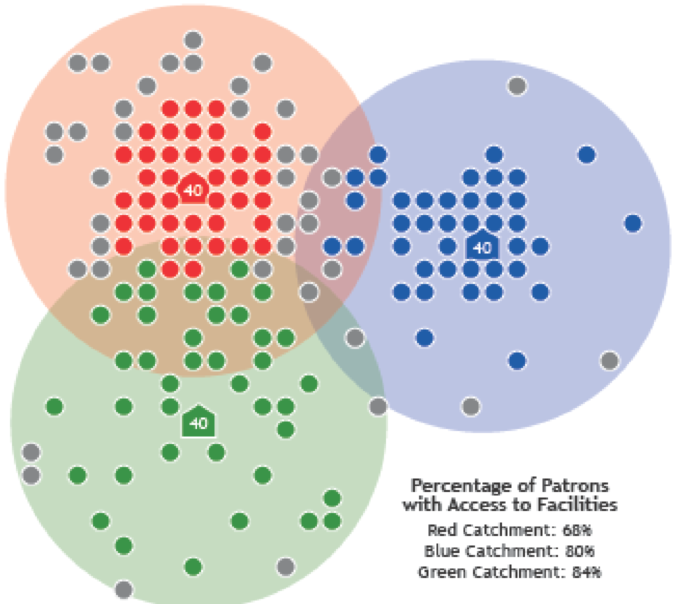



**Figure 7C – Scenario C – 'Unconstrained Facilities'. The diagram below shows the distribution where facilities with generous capacity compete for a limited number of patrons. For example, the blue and green catchments are operating below full capacity because the red catchment is capitalising on the demand constraint. It is assumed in these diagrams that accessibility of the facilities decreases gradually from the centre to the perimeter of each catchment area (gravity model).**

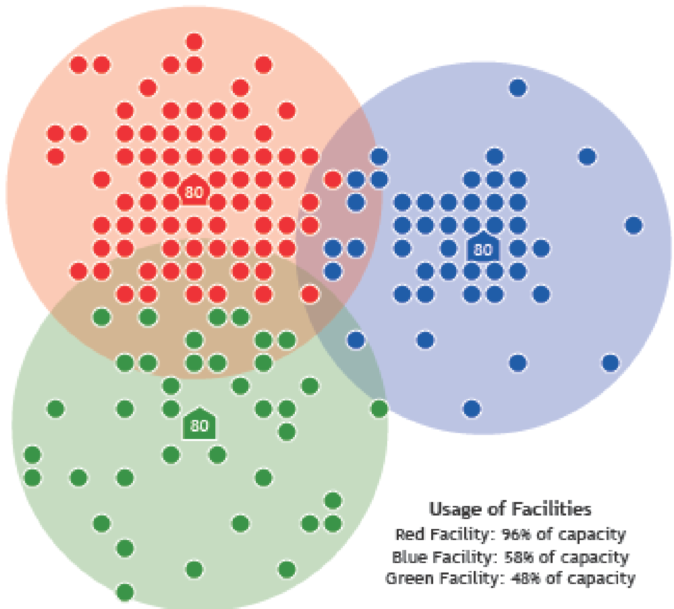
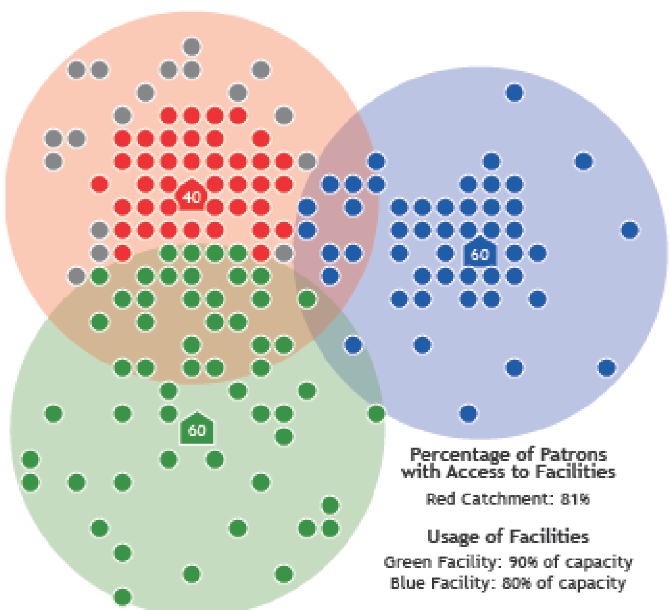


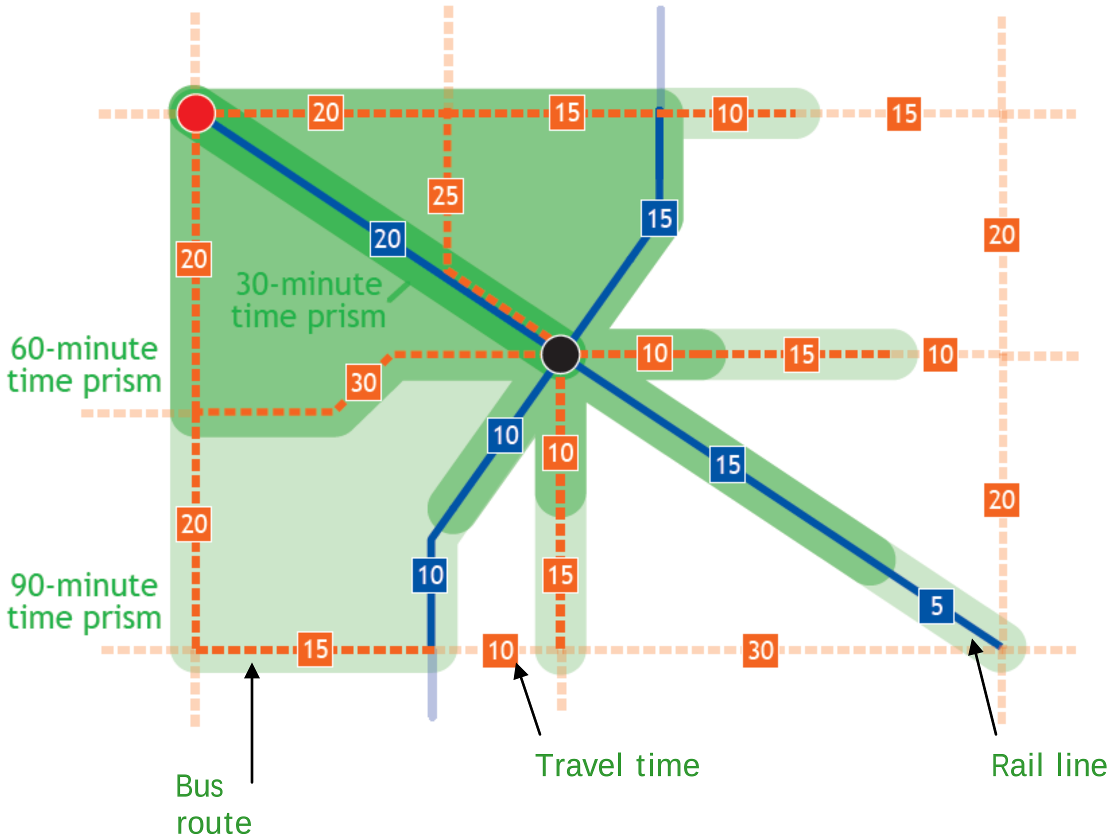

**Figure 7D – Scenario D – 'Constrained and Unconstrained Facilities'. The diagram below shows the situation where there is a spatial mismatch – one facility is constrained (the red catchment) and two are unconstrained (ie. they have spare capacity).**



## 5. Time-Space Measures

Time-space measures, discussed by both Bhat et al (2000) and Geurs and van Eck (2001), and further refined into person-based measures by Geurs and van Wee (2004), focus specifically on the time budgets, or space-time paths, of transport users. Bhat et al (2000) identify three types of time constraints in this context: capability constraints (limitations to the number of activities a person can accommodate within a given time frame); coupling constraints (the need to be in particular places at particular times); and authority constraints (the times of operation of given activities, or of components of transport infrastructure/service). This approach is highly suitable for the evaluation of trip-chaining and of spatial clustering effects of activities (Burns 1979, Hall 1983, Baradaran and Ramjerdi 2001). Both Bhat et al (2000) and Geurs and van Eck (2001) point out, however, that the information required for this approach is not usually available from standardised travel surveys and therefore often needs to be collected specifically. This limits the opportunities for data aggregation over larger areas, and the compatibility of data sets collected in different surveys. Baradaran and Ramjerdi (2001), quoting Wang (1996), further note that the recognition of time constraints alone in this approach does not yet do justice to the full spectrum of motivations for individual travel choices.

**Figure 8: Time-Space Prism. Geographical ranges available for accessing additional activities on a trip between origin (red dot) and destination (black dot) with varying travel time budgets of 30, 60 and 90 minutes. Travel times of route segments in minutes are indicated in coloured squares, and the time budget allocations make allowance for access and transfer times (5 minutes each).**




Using state-of-the-art GIS software from late 1990s, O'Sullivan, Morrison and Shearer (2000) generated isochronic maps of Glasgow's public transport accessibility. The authors note that isochronic mapping is not yet a widespread practice, despite an abundance of evidence to its usefulness in the literature. This is possibly due to the magnitude of data that needs to be computed for the purpose, a constraint that is expected to fade with further advances in GIS. In a further step, the contour measure is combined with a space-time constraint approach, and the results are visualised in maps. Space-time prisms, or representations of the travel range achievable within a constrained time window, thus become geographically identifiable areas around particular public transport network elements.

Time-space measures, projected into a geographical context, can be used in conjunction with the findings from user surveys to assess the opportunities for trip-chaining and co-location of activities in station areas.

## *6. Utility Measures*

Utility measures, identified both by Bhat et al (2000) and Geurs and van Eck (2001), are designed to capture the benefit to users from accessibility to opportunities. This can occur in monetarised form as a measure of economic utility, or as an indicator for social equity (or for other sustainability objectives). It can also be applied as a behavioural indicator, measuring the value individuals afford to the accessibility of particular activities. Geurs and van Eck (2001) point to the weakness of empirical evidence for the link between infrastructure provision and economic activity, and the relative inability of this approach to capture feedback effects between transport patterns and land use changes over time. Bhat et al (2000) highlight the inevitable bias in defining a set of choices for activities and opportunities to be included in this approach, and its inherent conservatism – it cannot predict the emergence of new choices and their effects on travel behaviour. Baradaran and Ramjerdi (2001) also mention the problematic integration of income effects in this approach. While disregarding such effects restricts the efficacy of the model, their inclusion – and consequently, the allocation of a higher utility value on activities performed by higher-income earners – raises concerns with equity (Geurs and van Eck 2001).

The social dimension of accessibility is further explored by Hine and Grieco (2003), who make a distinction between direct accessibility and indirect accessibility, taking into account the ability of personal and community networks to expand an individual’s access to activities and services:

> ‘By direct accessibility we mean the ability of individuals to plan and undertake journeys by public or private modes subject to time budget and cost. Indirect accessibility, on the other hand, refers to the extent to which individuals or groups can rely on neighbours or other support networks to access goods and facilities on their behalf subject to time and financial budgets.’ (p 300)

This is related to the density of time, which effectively turns travel time budgets into flexible items:

> ‘Density can be increased by multi-tasking and the purchase of time, by asking others to undertake certain tasks or by using [information and communication technologies]’ (Hine 2002, p 499).

Thus social capital is to some extent able to compensate for constraints in physical (direct) accessibility, which Hine and Grieco (2003) claim has a great significance for the degree of access to activities experienced by disadvantaged groups. Geurs and van Wee (2004) further point to the phenomena of option benefit and non-user benefit in the context of a utility perspective on accessibility. For example, an individual may put a value on the availability of a particular transport mode or activity even if they do not use them regularly, to cater for uncertainties (such as ‘crisis journeys’ in the terminology of Hine and Grieco 2003). Similarly, a value may be placed on facilitating accessibility for special groups, eg. disabled people, even by those who do not belong to these groups. As noted (with reference to Roson 2001), ‘option and non-user benefit motives may form an important reason for willingness-to-pay through public funds, so as to subsidise public transport services’. (p138)

Utility measures are relevant in estimating the added value afforded to activities in station areas by the addition of rail service, for example terms in economic performance, access opportunities for disadvantaged groups, greenhouse gas savings etc.

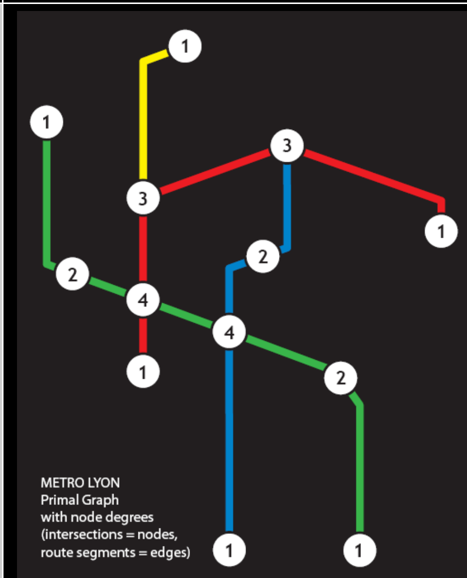
## *7. Network Measures*

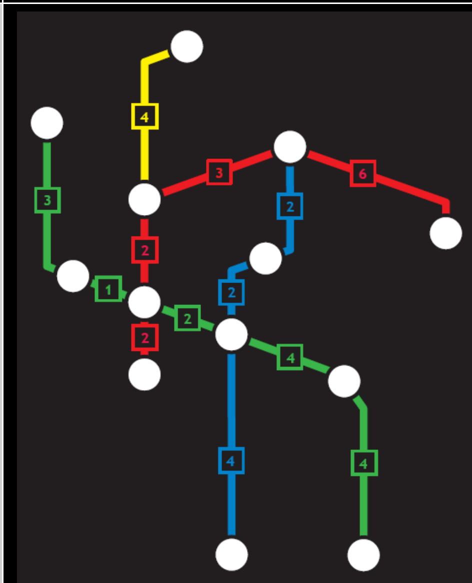
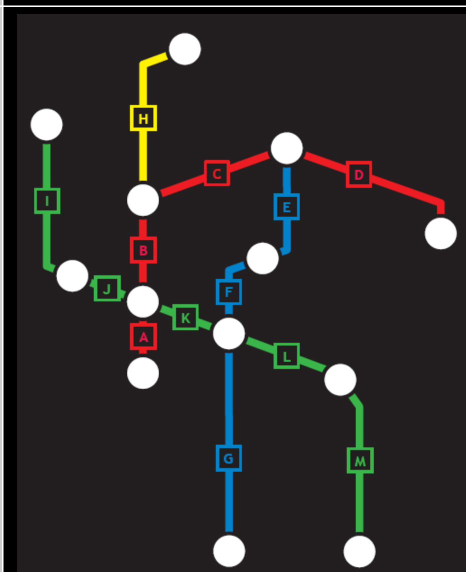
Porta, Crucitti and Latora (2006a, 2006b) take the investigation of accessibility to the level of analysing entire movement networks. Two approaches are distinguished: the primal approach and the dual approach (Figures 9 and 10). Each approach is based on the identification of nodes and edges as the twin components of any network: in the primal approach, street segments are considered as edges and street intersections are considered as nodes. In the dual approach, it is the other way around. The authors describe the primal approach as a ‘simple, intuitive representation of networks’ (2006a, p3) used in most studies on the subject, including those on non-geographical structures such as social networks. They maintain that the primal approach is most suited to capture distance, as ‘one of the most crucial components of the geographic dimension’ (2006a, p3), as it is designed to include a measure proportional to the physical distance, or other impediment, of movement paths. However, the primal approach still contains a topological measure as well, in that it identifies path lengths as numbers of edges traversed. This indicator captures a fundamental characteristic of social networks, as popularised in the seminal work of Milgram (1967) on the average ‘six degrees of separation’ between any two individuals in the US. In this example, the distance between two individuals in a social network cannot be expressed in a meaningful way by applying a quantitative measure of length to their relationship. It can, however, be measured by counting the number of direct relationships in a chain that connects any two individuals in the sample (degree of separation).

The dual graph approach is derived from the space syntax methodology first developed by Hillier and Hanson (1984). The motivation here is to identify the continuity of streets over a multiplicity of intersections as a key attribute of the legibility and functionality of movement networks.

Porta et al point to a number of measures to express the properties of networks. These are:

- the degree of a node $k_i$, understood as the number of edges converging in node i;
- the average degree of nodes within a network, and the distribution of degree values across all nodes in the network;
- the correlation between the degree of directly connected nodes (assortative and disassortative mixing), calculated from the average degree of nearest neighbours of all nodes within the network with the same degree k;
- the characteristic path length L(G), understood as the average distance, or degree of separation, between any two nodes i and j within the network;
- the clustering coefficient C(G), understood as the average number of edges found within the sub-network of nearest neighbours of each node, as a proportion of the total number of pairs of nodes within that sub-network;
- the global efficiency $E_g(G)$, understood as the inverse average shortest path length between any two nodes in the network;
- the local efficiency $E_l(G)$, understood as the average efficiency of all sub-networks of nearest neighbours of each node.

| | Network Property Measure | Example<br>(Metro Network of Lyon) |
|---|---|---|
| Two different ways of PORTRAYING the network measure | **1) Degree of nodes (primal graph)**<br>This indicator measures the number of route segments converging in each intersection.<br>$K(i) = \sum j$<br><br>where:<br>$j \in N(i)$ and $i \neq j$<br>**N(i) =** intersections linked to intersection i by one route segment (nearest neighbours)<br><br>**Example:** The node at the far right end of the red route has only one route segment accessing it – so is labelled '1'. The more routes converging in the node, the higher the accessibility.<br><br>**Figure 9** |  |
| | **2) Degree of nodes (dual graph)**<br>This indicator measures the number of other route segments that share an intersection with the route segment in question.<br>$K(l) = \sum m$<br><br>where:<br>$m \in G(l)$ and $l \neq m$<br>**G(l) =** route segments linked to route segment l by a common intersection<br><br>**Example:** From the yellow route segment you can reach 2 other route segments by passing through just one intersection. This measures the degree of connection and thus suggests a degree of accessibility.<br><br>**Figure 10** |  |

| | Network Property Measure | Example<br>(Metro Network of Lyon) |
|---|---|---|
| Two ways of MEASURING | **Characteristic Path Length -<br>1) metric – number of stations**<br>This indicator measures the average metric journey length between any two nodes on the network by number of stations as a proxy to travel time (in the Lyon example, the typical scheduled travel time between two adjacent stations is 1½ minutes).<br>**$L_m(G)$ = 7.5 stations**<br><br>**Example**: The figures in squares indicate the number of segments between stations (number of intermediate stations plus one) for each route segment between network nodes.<br>The idea is to measure the number of stations on a given journey – for example, there are five intermediate stations (six segments between stations) on the route segment at the far end of the red line to the right of the graph.<br><br>**Figure 11.** |  |
| | **Characteristic Path Length -<br>2) topological – number of route segments**<br>This indicator measures the average metric journey length between any two nodes on the network by number of route segments (A-M).<br>**$L_t(G)$ = 2.7 segments**<br><br>**Figure 12** |  |

<table>
<tr><th></th><th>Network Property Measure</th><th>Example<br>(Metro Network of Lyon)</th></tr>
<tr><td>Two ways of measuring efficiency</td><td>

**Global Efficiency (metric)**

This indicator measures the average inverse metric distance to all other nodes in the network.

$E_g(i) = \sum(1/d_{ij})/(N-1)$

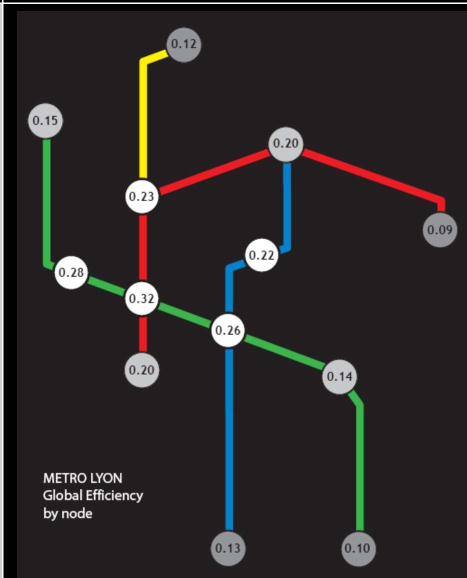
where:<br>
**$d_{ij}$ =** metric distance between nodes i and j, with $j \in N$ and $i \neq j$<br>
**N =** all nodes in the network

**Global Network Efficiency** $E_g(G) = 0.19$

**Example:** A measure of 0.32 is saying that the average distance from this node to any other node in the network is approximately 3 route segments (for example, if it is 6 route segments you invert 1/6 = 0.17). The higher the number, the more efficient (as it is showing the ability to connect to a larger number of nodes in a shorter distance).

**Figure 13**

</td><td>

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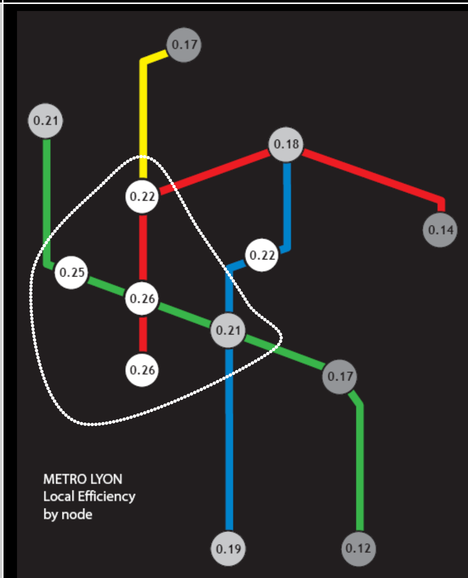
| | Network Property Measure | Example<br>(Metro Network of Lyon) |
|---|---|---|
| | **Local Efficiency (metric)**<br>This indicator measures the average inverse metric distance to all other nodes in the network within the sub-network of nearest neighbours of the node in question.<br>$\mathbf{E_l(i) = (E_g(i)+ \sum E_g(j))/(N(i)+1))}$<br><br>where:<br>**EG(i) =** global efficiency of node i<br>**EG(j) =** global efficiency of node j, with $j \in N(i)$ and $i \neq j$<br>**N(i) =** nearest neighbours of node i<br><br>**Local Network Efficiency $E_l(G)$ = 0.20**<br><br>**Example:** The local efficiency of the node where the green and red lines intersect (0.26) is the average global efficiency (Figure 13) of the five nodes within the dashed line (nearest neighbours – 0.23, 0.28, 0.32, 0.26 and 0.20).<br><br>**Figure 14** | <br> |

From these measures the following indexes for network nodes are derived:

- Degree centrality $CD_i$, defined as the proportion of nodes directly connected to node i out of all nodes (other than i) within the network;
- Closeness centrality $CC_i$, defined as the inverse average distance between node i and all nodes (other than i) within the network;
- Betweenness centrality $CB_i$, defined as the average proportion of paths between any two nodes within the network that traverse node i, out of the total number of possible paths between these two nodes.
- Efficiency centrality $CE_i$, defined as the ratio of the actual inverse average shortest path length between node i and all directly connected nodes

(other than i), to the theoretical average shortest path length (Euclidean distance) within that sample.

- Information centrality $CI_i$, defined as the relative drop in network efficiency in case node i is removed from the network.

TWO WAYS OF MEASURING CENTRALITY

**Centrality Index**

**Example**
(Metro Network of Lyon)

**Degree Centrality (transfer-free links)**

This indicator measures the proportion of other nodes within the network that are accessible by way of a *transfer-free journey.*

$$CD_{i,tf} = \sum a_{ij}/(N-1)$$

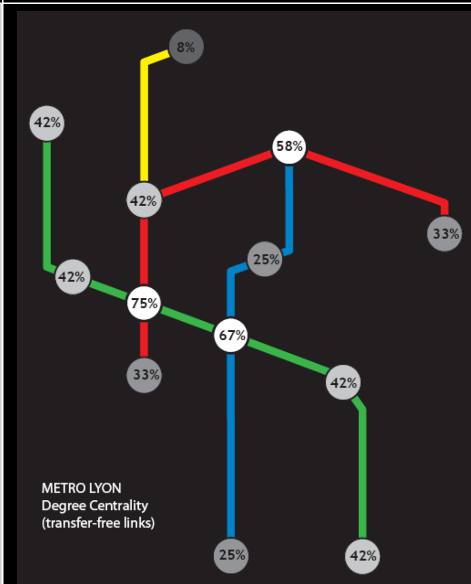
where:

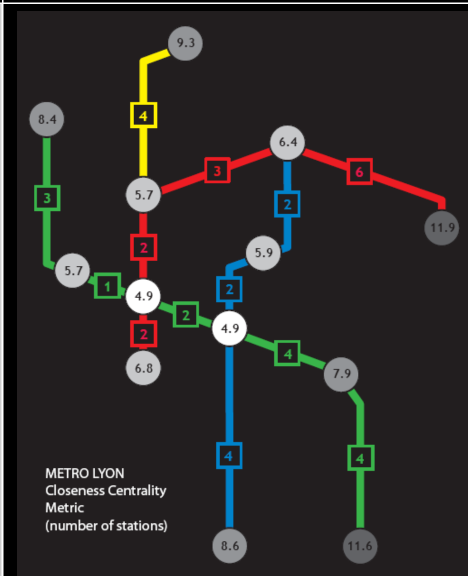
**$a_{ij}$ =** transfer-free link between nodes i and j, with $j \in N$ and $i \neq j$

**N =** all nodes in the network

**Example:** The degree centrality for the node where the green and red lines intersect (75%) is showing that from here you can get to all the nodes of the green line and all those on the red line without changing – ie. 9 nodes out of 12 (or 75%). So this shows a different view of accessibility more useful for public transport.

**Figure 15**



| | Centrality Index | Example (Metro Network of Lyon) |
|---|---|---|
| | **Closeness Centrality (metric – primal graph)**<br>This indicator measures the average number of segments between stations to access the other nodes on the network, as a proxy for metric journey length.<br>$CC_{i,m} = \sum L_{ij}(m)/(N-1)$<br>where:<br>**$L_{ij}(m)$ =** number of segments between individual stations between nodes i and j, with $j \in N$ and $i \neq j$<br>**N =** all nodes in the network<br>The number of segments between stations on each network segment is marked on the graph.<br>**Example:** From the node where the green and red lines intersect (metric closeness centrality = 4.9), the average distance to the other twelve nodes in the network is 4.9 segments between stations.<br>**Figure 16** |   |

**Four ways of measuring centrality**

| Centrality Index | Example (Metro Network of Lyon) |
|---|---|

## 1) Closeness Centrality (topological – primal graph)

This indicator measures the average number of network segments to access the other nodes on the network, regardless of their metric length in number of stations.

$$CC_{i,t} = \sum L_{ij}(t)/(N-1)$$

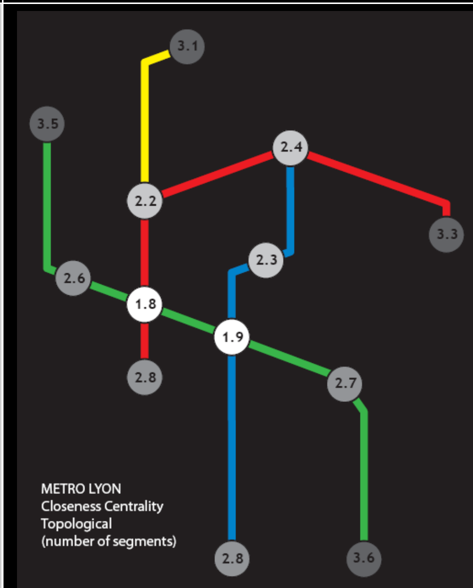
where:

**$L_{ij}(t)$ =** number of network segments between nodes i and j, with $j \in N$ and $i \neq j$

**N =** all nodes in the network

**Example:** From the node where the green and red lines intersect (topological closeness centrality = 4.9), the average distance to the other twelve nodes in the network is 1.8 network segments.

**Figure 17**




## 2) Betweenness Centrality (shortest metric distance)

This indicator measures the proportion of journeys between any two network nodes that pass through the node in question, assuming that users determine their choice of route by the shortest metric distance (number of stations).

$$CB_{k} = \sum P_{ij}(k)/(N(N-1))$$

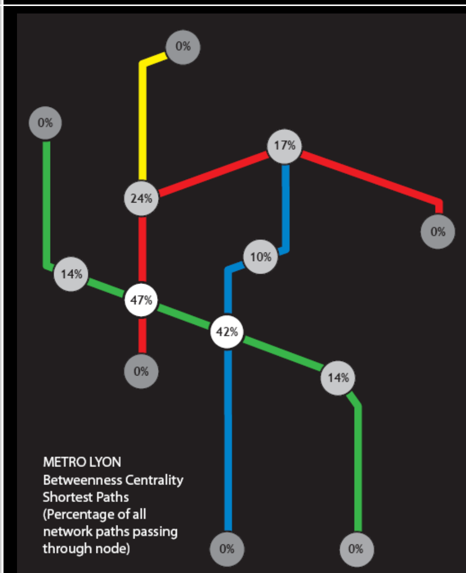
where:

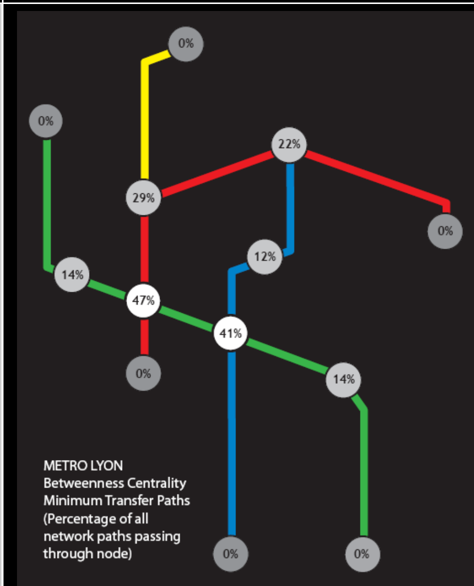
**$P_{ij}(k)$ =** paths between nodes i and j that pass through node k, for all $i,j \in N$, $i \neq j$, $i \neq k$ and $j \neq k$

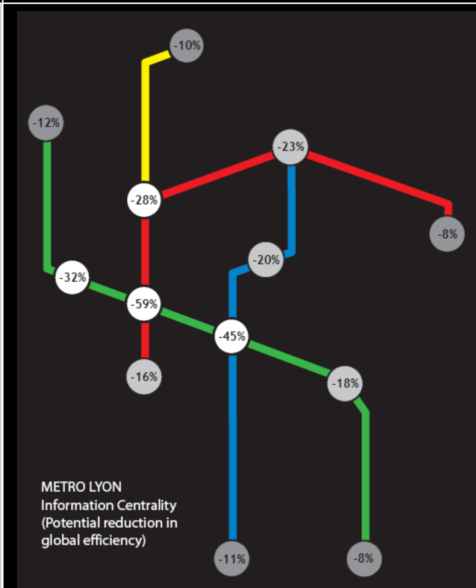
**N =** all nodes in the network

**Example:** This looks at how someone will get from one node in the network to another, using the fastest route (regardless of the number of transfers required), and counts them at all nodes other than origin and destination that they will pass on the way.

**Figure 18**



| | Centrality Index | Example (Metro Network of Lyon) |
|---|---|---|
| | **3) Betweenness Centrality (minimum number of transfers)**<br>This indicator measures the proportion of journeys between any two network nodes that pass through the node in question, assuming that users determine their choice of route by the lowest possible number of transfers.<br><br>Formula as in previous graph.<br><br>**Example:** This looks at how someone will get from one node in the network to another, using the route requiring the fewest transfers (regardless of the journey time), and counts them at all nodes other than origin and destination that they will pass on the way.<br><br>**Figure 19** |  |

| | Centrality Index | Example (Metro Network of Lyon) |
|---|---|---|
| | **Information Centrality**<br>This indicator measures the relative reduction in global efficiency if the node in question, and the route segments between this node and its nearest neighbours, were removed from the network.<br>$\Delta CI_k = -(1-\sum(1/L_{ij}(k))/\sum(1/L_{ij}))$<br><br>where:<br>**$L_{ij}$ =** metric distance (number of stations) between nodes i and j, with $i,j \in N$ and $i \neq j$<br>**$L_{ij}(k)$ =** metric distance (number of stations) between nodes i and j in case node k is removed, with $i,j \in N$ and $i \neq j$<br>**N =** all nodes in the network<br><br>**Example:** If the node where the yellow and red lines intersect were removed from the network, the global efficiency of the network would be reduced by 28%, both due to trips now requiring lengthier detours and due to trips no longer being possible at all (such as any trip involving the otherwise isolated yellow line).<br><br>**Figure 20.** Note: the distance between nodes that are no longer connected through the network after removing node k is defined as infinite, thus $1/L_{ij} = 0$. |  |

Porta et al test these indexes on a number of real-world urban street systems of different character (Ahmedabad, Venice and two examples from the Californian Bay Area) and conclude that the application of the primal approach leads to more comprehensive, objective and realistic analytical results than the dual approach. This is largely due to the greater level of abstraction inherent in the dual approach, which is only concerned with the topology of a network and disregards the metric geography of the system. The dual approach is further vulnerable to subjectivity in the definition of node (street segment) continuity. Porta et al examine three approaches – continuity of sight lines, continuity of street names, and a computerised model termed ‘Intersection Continuity Negotiation’, to arrive at significantly different outcomes in each case.

Scheurer and Porta (2006) attempt to apply this methodology to public transport networks and arrive at a different picture from the model suited to the analysis of urban streets. In particular, they define every transfer-free link between pairs of nodes on the network as a separate edge in its own right. The degree of node i is thus equivalent to the number of other nodes that can be accessed on public transport without a transfer, and the topological distance between any two nodes (degrees of separation) is equivalent to the number of segments between transfers that make up the journey. Edges are assigned an impediment factor in the primal approach that takes in travel time and frequency of service (travel opportunities per hour) rather than physical distance (which is not very relevant to public transport users, since it bears no direct relation with travel time, cost or service frequency).

The recommendation of Porta et al (2006b) for primal graphs and the use of metric distances is complemented by a third element, which the authors term ‘Multiple Centrality Assessment’. The authors maintain that out of the five centrality indexes investigated (see above), no single one is capable of capturing the multifaceted meanings of centrality; instead, they advocate for the simultaneous application of all five concepts. It is concluded that this technique does in fact make Multiple Centrality Assessment a discursive, interactive policy instrument, in that centrality, and the strengths and weaknesses of policy interventions, can be viewed from a range of perspectives. Lastly, it is emphasised that the primal approach makes use of a data format based on road centrelines between nodes (intersections), which has rapidly become a world standard of geographical information systems in recent years and is therefore easily accessible.

Network measures are suited to measure the impact of local public transport infrastructure insertions and service improvements across an entire urban or regional network, to assess the comparative position of different station areas within the larger system, and to measure the competitiveness of public transport in the broader spectrum of travel choices.

# 3 Debate

There is clearly no agreement about the accessibility index that is most suitable for the assessment of urban and regional land use and movement systems. Bertolini et al (2005) recommend the use of a contour measure based on travel time and/or a travel cost measure that takes into account travel purposes, socio-demographic factors and the effects from measures such as road pricing and parking management. Conceding the limitations of a sharply defined isochrone for mapping individual travel decisions that are much more spatially and temporarily fluid in real life, they suggest the consideration of a gravity-based measure that can show a more gradual decline of attraction utility with increasing travel time and cost. Geurs and van Wee (2004), too, build a strong case for the incorporation of several perspectives on accessibility into common measurements or, failing that, the application of several accessibility measures in the same context. The authors concede, however, that 'applying the full set of criteria would imply a level of complexity and detail that can probably never be achieved in practice.' (p 130) In a discussion on feedback effects between different components of accessibility (land use, transportation, temporal, individual), it is pointed out that land use densification may result in greater traffic congestion and thus an increase in 'the disutility for an individual to cover the distance between an origin and a destination using a specific transport mode' (p 128). There is also a mention that improved travelling speed may have an impact on urban sprawl, but there is a conspicuous omission here of another well-documented feedback effect between transport and land use, that of improvements to fixed public transport as facilitators of densification around its infrastructure (Bernick and Cervero 1997, Newman and Kenworthy 1999, Dittmar and Ohland 2004).

Murray and Wu (2002) maintain that public transport accessibility is determined by two competing factors. One is the accessibility of public transport stations or stops from their catchment area (by walking, cycling or driving). The other is the geographical coverage public transport can offer to users within a given travel time budget. In practice, both aspects need to be integrated in network and route planning. A 400-metre walkable catchment for bus stops is suggested and backed by several pieces of evidence (Demetsky and Lin 1982, Levinson 1992, Federal Transit Administration 1996, Ammons 2001); however, it is also acknowledged that accessibility needs to be understood in a gradual rather than just binary sense (that is, a concentration of residents and/or jobs immediately adjacent to public transport provides a higher degree of accessibility than if these activities were indiscriminately scattered around the 400-metre catchment). However, in modelling different average stop spacings along a bus route in Columbus, Ohio, there is a conspicuous lack of reference made to the actual geography of the pedestrian network (pedsheds), and there is also no recognition that (desirable) higher travel speeds on public transport are determined by factors such as traffic priority, vehicle performance, boarding procedures etc. alongside stop spacing.

In the work of O'Sullivan et al (2000), public transport system data consists of station-specific rail timetables and average frequencies, speeds and travel times along bus routes, as well as walking access along a street network centreline database. The modelling of transfers between routes put the model under considerable stress; it is to be expected that contemporary hardware capacity and software sophistication will facilitate this over time. The authors emphasise that trains and buses require different approaches to count waiting time: while train passengers (at medium and low frequencies) are likely to know their timetables and make their way to the station accordingly, bus passengers – at least in a Glasgow context - are more likely to experience the timing of departure as arbitrary and thus just turn up at random at the bus stop.

Potential questions worthy of exploration for our research project include:

1) From here – where can I get to (places)? By what mode? How long will it take, what will it cost? The range of accessibility measures reported above can be utilised in order to enable a comparison of the three station precincts. This provides for output showing access to opportunity and on the quality of access of the different modal networks (both currently and post station opening).

2) Another perspective is gained by asking ‘Who can get to this precinct?’ and ‘How?’ This will provide information about the relative accessibility of each station precinct within the region as a whole. This offers a potentially useful devise for planning and investment in land use change and transport improvements.

3) Within this precinct what opportunities are there for local residents – is there variation in access by mode?

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# Appendices

## *Appendix 1: Search Strategy*

**Transport Policy (Science Direct)**

| | Vol. 8 (2001) | Vol. 9 (2002) | Vol. 10 (2003) | Vol. 11 (2004) | Vol. 12 (2005) | Vol. 13 (2006) |
|---|---|---|---|---|---|---|
| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 2 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 3 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 4 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 5 | | | | | ☐ | |
| Issue 6 | | | | | ☐ | |

**Transportation Research Part A: Policy and Practice (Science Direct)**

| | Vol. 35 (2001) | Vol. 36 (2002) | Vol. 37 (2003) | Vol. 38 (2004) | Vol. 39 (2005) | Vol. 40 (2006) |
|---|---|---|---|---|---|---|
| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 2 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 3 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 4 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 5 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 6 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 7 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 8 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 9 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 10 | ☐ | ☐ | ☐ | ☐ | ☐ | |

**Transportation Research Part B: Methodological (Science Direct)**

| | Vol. 35 (2001) | Vol. 36 (2002) | Vol. 37 (2003) | Vol. 38 (2004) | Vol. 39 (2005) | Vol. 40 (2006) |
|---|---|---|---|---|---|---|
| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 2 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 3 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 4 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 5 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
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| Issue 7 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 8 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 9 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 10 | ☐ | ☐ | ☐ | ☐ | ☐ | |

**Transportation Research Part D: Transport and Environment (Science Direct)**

| | Vol. 6 (2001) | Vol. 7 (2002) | Vol. 8 (2003) | Vol. 9 (2004) | Vol. 10 (2005) | Vol. 11 (2006) |
|---|---|---|---|---|---|---|
| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 2 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 3 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 4 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 5 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 6 | ☐ | ☐ | ☐ | ☐ | ☐ | |

**Transportation Research Part E: Logistics and Transportation Review (Science Direct)**

| | Vol. 37 (2001) | Vol. 38 (2002) | Vol. 39 (2003) | Vol. 40 (2004) | Vol. 41 (2005) | Vol. 42 (2006) |
|---|---|---|---|---|---|---|
| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 2 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 3 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 4 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 5 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 6 | ☐ | ☐ | ☐ | ☐ | ☐ | |

**Transport Reviews (Meta Press – Library Catalogue)**

| | Vol.21 (2001) | Vol. 22 (2002) | Vol. 23 (2003) | Vol. 24 (2004) | Vol. 25 (2005) | Vol. 26(2006) |
|---|---|---|---|---|---|---|
| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
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| Issue 3 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 4 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 5 | | | | ☐ | ☐ | |
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**Transportation (SpringerLink – Library Catalogue)**

| | Vol.28 (2001) | Vol. 29 (2002) | Vol. 30 (2003) | Vol. 31 (2004) | Vol. 32 (2005) | Vol. 33 (2006) |
|---|---|---|---|---|---|---|
| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 2 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 3 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 4 | ☐ | ☐ | ☐ | ☐ | ☐ | |
| Issue 5 | | | | | ☐ | |
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**Transportation Journal (ProQuest – Library Catalogue)**

| | Vol.40 (2001) | Vol. 41 (2002) | Vol. 42 (2003) | Vol. 43 (2004) | Vol. 44 (2005) | Vol. 45 (2006) |
|---|---|---|---|---|---|---|
| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 2 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 3 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 4 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Transportation Planning and Technology (Meta Press – Library Catalogue)**

| | N/A | Vol. 25 (2002) | Vol. 26 (2003) | Vol. 27 (2004) | Vol. 28 (2005) | |
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| Issue 1 | | ☐ | ☐ | ☐ | ☐ | |
| Issue 2 | | ☐ | ☐ | ☐ | ☐ | |
| Issue 3 | | ☐ | ☐ | ☐ | ☐ | |
| Issue 4 | | ☐ | ☐ | ☐ | ☐ | |
| Issue 5 | | | ☐ | ☐ | ☐ | |
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**Transportation Science (ProQuest – Library Catalogue)**

| | Vol. 35 (2001) | Vol. 36 (2002) | Vol. 37 (2003) | Vol. 38 (2004) | Vol. 39 (2005) |
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| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ |
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| Issue 4 | ☐ | ☐ | ☐ | ☐ | ☐ |

**Planning Practice and Research (Meta Press – Library Catalogue)**

| | Vol. 16 (2001) | Vol. 17 (2002) | Vol. 18 (2003) | Vol. 19 (2004) | Vol. 20 (2005) |
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| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ |
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| Issue 3 | ☐ | ☐ | ☐ | ☐ | |
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**World Transport Policy & Practice** [http://www.eco-logica.co.uk/WTPPhome.html](http://www.eco-logica.co.uk/WTPPhome.html)

| | Vol. 7 (2001) | Vol. 8 (2002) | Vol. 9 (2003) | Vol. 10 (2004) | Vol. 10 (2005) |
|---|---|---|---|---|---|
| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ |

**International Planning Studies (Meta Press (Taylor & Francis Group) – Library Catalogue)**

| | Vol. 6 (2001) | Vol. 7 (2002) | Vol. 8 (2003) | Vol. 9 (2004) | Vol. 10 (2005) |
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| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 2 | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 3 | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 4 | ☐ | ☐ | ☐ | ☐ | ☐ |

**Journal of Transport Geography (Science Direct – Library Catalogue)**

| | Vol. 9 (2001) | Vol. 10 (2002) | Vol. 11 (2003) | Vol. 12 (2004) | Vol. 13 (2005) | (2006) |
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| Issue 1 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 2 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 3 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Issue 4 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Urban Studies (EBSCO Publishing – Library Catalogue)**
Keyword search (too many articles to go through one by one)

**Google Scholar –** main search terms: *accessibility*, *transport access*, *transit accessibility*
**Other possible terms –** locational disadvantage, pedestrian access, -disability, -disabled access

## Conferences

**Moving through nets: The physical and social dimensions of travel**
10th International Conference on Travel Behaviour Research
http://www.ivt.baug.ethz.ch/allgemein/iatbr2003.html

**Australasian Transport Research Forum (ATRF)**
http://www.patrec.org/atrf/index.php

**PATREC Research Forum 2005**
http://www.patrec.org/atrf/index.php

**TOD Conference 2005**
http://www.patrec.org/atrf/index.php