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Defining and Measuring the Spatial Dimension of Accessibility

by
Nairne Cameron

*A thesis
presented to the University of Ottawa
in fulfillment of the requirements
for the degree of Master of the Arts
in Geography
Supervisor: Dr. B. Wellar*

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Abstract

This study combines a literature search and review with a real-world survey to identify, compare, and contrast techniques of measuring accessibility in conceptual and operational terms. An hypothesis-based approach is employed to ascertain how these techniques are used in the public and private sectors. With emphasis on the spatial dimension of accessibility, the thesis examines the definition of accessibility, the relative use of different accessibility measurement techniques, and the units used to measure spatial separation. The thesis also explores barriers to accessibility, the criteria and relative importance of spatial and aspatial factors in making location, network and routing decisions, and the use of GIS to implement accessibility measurement techniques. Results suggest that, despite differences in goals and/or objectives, there are similarities between the public and private sectors in both the conceptual and operational aspects of accessibility measurement, the criteria used to make location and transportation network decisions, and the limited use of Geographic Information Systems (GIS) to implement accessibility measurement techniques.

Résumé

Cette étude joint une recherche de la littérature et un sondage afin d'identifier, de comparer, et de mettre en contraste les diverses techniques utilisées pour mesurer l'accessibilité en termes conceptuels et opérationnels. La vérification des hypothèses permettait d'établir comment les secteurs privé et publique se servent des ces techniques. En mettant l'emphase sur la dimension spatiale de l'accessibilité, la thèse examine la définition de l'accessibilité, le niveau d'utilisation relatif aux différentes techniques de mesure, et les unités utilisées pour mesurer la séparation spatiale. La thèse sonde aussi les barrières à l'accessibilité, les critères et l'importance relative des divers facteurs spatiaux et non-spatiaux dans les questions de localisation, d'itinéraire et de placement dans un réseau, et l'utilité des SIG dans le mesurage de l'accessibilité. Les resultats semblent indiquer que, malgré les différents objectifs visés, il y a des similitudes entre les secteurs publique et privé dans les aspects conceptuels et operationnels du mesurage d'accessibilité, dans les critères operationnels du mesurage d'accessibilité, dans les critères décisionnels de localisation et de conception de réseaux de transports, et dans l'utilisation limitée des systèmes d'information géographiques (SIG) pour mesurer l'accessibilité.

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September, 1995

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1. Introduction and Statement of Research Problem

1.1 *Accessibility as a Research Concern*

Several quotes from the literature on accessibility combine to illustrate its relevance as a topic of research and practical application in the field of geography. The term *accessibility* is defined as "...a combination of two elements: location on a surface relative to suitable destinations, and the characteristics of the transportation network or networks linking points on that surface" (Vickerman, 1974, p. 676). Accessibility measurement techniques have a practical application in "...the evaluation of alternative transport-system configurations, alternative locations for facilities, and alternative approaches for meeting the social needs of particular population groups. In such applications, accessibility measures are needed to summarise a great deal of information about the location of one household or zone in relation to the entire distribution of urban activities and to the transport system which connects them." (Wachs and Koenig, 1979, p. 698). "In the last resort, accessibility is a cost which must be borne by the community, both directly by individuals and, beyond that, socially by the entire community through its by-products such as congestion and pollution." (Vickerman, 1974, p. 675) .

For a variety of reasons there is increased interest in accessibility as a real-world concern and as a research topic. On the one hand such interest can be traced back to lack of resolution of 'the urban problem' that was identified in the 1960s and 1970s (Owen, 1966; Meyer et al., 1969; Stegman, 1969; Smith and Wellar, 1992; Wellar, 1994).

And on the other hand, concern about and interest in accessibility can be related to more recent events such as: changing demographics (an aging population), and the implications for location and transportation decisions (Marsland, 1991; Transport 2000, 1991; Transportation Association of Canada, 1993); serious fiscal/financial constraints on government's ability to expand transportation networks (Hoel, 1990; Regional Municipality of Ottawa-Carleton, 1993; Transport 2021, 1993a,b; Button and Rietveld, 1993); and, increased emphasis on cost-cutting by business and the use of 'just-in-time' and other measures to minimize transshipment, warehousing, and storage costs (Delaney, 1991; Arbeit, 1993; Wellar, 1993; Oliver, 1994; Gleckman et al., 1994).

In the next sections of the Introduction a selection of statements which further elaborate accessibility as a practical and research concern are presented. The statements involve agencies that have responsibilities with an accessibility aspect, or real-world situations wherein the need to know more about accessibility is connected to location decisions, or to decisions involving transport modes and/or networks.

1.1.1 Ontario Ministries of Transportation and Ministry of Municipal Affairs

The initial statement about accessibility as a matter of practical and research interest is taken from the 1992 report 'Transit-Supportive Land Use Planning Guidelines' which was jointly produced by the Ministry of Transportation and Ministry of Municipal Affairs, Ontario (1992). This document contains a set of guidelines showing:

"...how all forms of urban development and redevelopment can be more *accessible* by public transit...These (guidelines) include development patterns which make transit less expensive, less circuitous, more efficient and more convenient, as well as those which make *access* to the system more attractive to the potential transit user." (Ministry of Transportation and Ministry of Municipal Affairs, Ontario, 1992, p. 1)

Guideline 3.4.1 in the report (Ministry of Transportation and Ministry of Municipal Affairs, Ontario, 1992, p. 76) represents a policy based directly on an accessibility standard:

"Municipal land use policy documents should also establish goals and objectives and specific policies on the following transit-related issues...A policy indicating that a significant majority of residences, jobs, and other activities/uses should be located within 400m walking distance of a transit stop."

1.1.2 Canada Mortgage and Housing Corporation

The Canada Mortgage and Housing Corporation (CMHC) is a federal crown corporation with an interest in accessibility as it relates to housing development. In February 1993, the agency released a report entitled 'Urban Travel and Sustainable Development: The Canadian Experience' (CMHC, 1993). This paper formed part of Canada's contribution to a project on urban travel and sustainable development undertaken by the Group on Urban Affairs of the Organization for Economic Cooperation and Development.

Both elements of accessibility, according to Vickerman (1974), are taken into account: the urban form (location of points on a surface) and the characteristics of the transportation network (lines linking the points on the surface). The report states:

"In comparison to geographically smaller, older, more densely populated 'old world' countries, Canada's cities are relatively low density and often separated by great distances. Thus, there is a relatively high level of energy consumption by the transportation sector as a whole and a high level of auto-dependence and auto use within urban areas. Culturally, Canadians expect a high degree of

mobility, thinking nothing of travelling long distances for work, recreation, shopping and socializing..." (CMHC, 1993, p. ii)

Further, in regard to the evolution of Canadian cities the report notes:

"In comparison to many 'new world' cities, where central areas have been depopulated and original transit systems dismantled, core areas of Canadian cities have largely retained their vitality and a full range of functions, along with the transit systems that serve them. Canadians have also retained traditions of urban living, with more affinity for walking, bicycling, public transit and use of public spaces." (CMHC, 1993, p. ii)

And, in terms that correspond closely to the opening quotations from articles written more than 15 years ago, it is observed that:

"Large-scale, small scale, public, private and individual initiatives are needed in all areas discussed in the paper, with special emphasis on long-term change in urban form, transportation infrastructure and demand-management (particularly road pricing), and more immediate strategies for improved transit facilities and operations, traffic management, cleaner vehicle technology, institutional reform and public education and outreach." (CMHC, 1993, p. ii)

1.1.3 Regional Municipality of Ottawa-Carleton

Peter Clark, the elected Chair of the Regional Municipality of Ottawa-Carleton (RMOC), in an address at the Ottawa-Carleton Commuter Rail Conference (October 1, 1994), stated that "Region's transportation vision is for a balanced role for many modes of transportation that are safe, effective, *accessible*, and efficient." (Clark, 1994)

A second example of RMOC's concern with accessibility is seen in an environmental review of its Regional Official Plan completed in 1993:

"There is a strong relationship between the patterns of land use in the Region, the transportation systems required to service such patterns, and the environmental and social impacts created by this interaction. Any transportation or land use policy made without an appreciation of the land use, transportation, environment relationship in Ottawa-Carleton might result in unforeseen detrimental impacts on the Region's environment." (Regional Municipality of Ottawa-Carleton, 1993, p. 1)

In the following quotation accessibility is acknowledged to play a part in the land use-transportation system relationship:

"...transportation affects land use by making different parcels of land more or less *accessible* by different modes. In turn, the mix and density of land use will affect travel in terms of the number and

length of trips made, and the modes employed.” (Regional Municipality of Ottawa-Carleton, 1993, p. 3)

1.1.4 Transportation Association of Canada

The Transportation Association of Canada (TAC) is “...a national non-profit, non-partisan association of more than 550 voluntary corporate members...(in the public and private sectors). Its interests cover all modes of transportation. It acts as a neutral forum for the discussion of transportation issues and concerns...” (TAC, 1993, p. 6). In the *BRIEFING* the TAC calls for future transportation systems “...that are more *accessible* and increase mobility”. Also, “urban transportation systems will have to be very productive, efficient, cost effective and *accessible* to allow cities to generate the wealth needed for quality of life improvements, social services, infrastructure, environmental protection, and transportation itself.” (TAC, 1993, p. 1).

The *BRIEFING* proposes:

“...a generic urban transportation vision suitable for large and medium sized urban areas in Canada. The vision is supported by a series of principles or directions designed to change past trends and result in future cities that are more:

- economically competitive,
- socially desirable,
- environmentally friendly

and allow:

- greater mobility,
- *easier access* to a wider choice of transportation options

while recognizing:

- economic realities
- constraints of the existing urban structure.” (TAC, 1993, p. 2)

In addition to addressing the characteristics of the transportation network, the *BRIEFING* also makes recommendations regarding the form of urban development:

“First and foremost among these principles is the need to change land use and urban design practices...The generic urban transportation vision...is based on the belief that a more compact form of urban development is more desirable than a less compact form in order to:

- protect and enhance the environment
- conserve natural resources including energy and land
- provide a wider and more balanced choice of *accessible* and affordable transportation services
- better respond to the needs of the majority of residents.” (TAC, 1993, p. 2)

1.1.5 Ontario Ministry of Municipal Affairs

A fifth agency with an interest in accessibility is the Ontario Government's Ministry of Municipal Affairs, which recently reformed the system of land use planning in Ontario by passing 'The Planning and Municipal Statute Law Amendment Act 1994' (Ministry of Municipal Affairs, 1994). This new legislation, which is based on the work of the Commission on Planning and Development Reform in Ontario, and is outlined in 'New Planning for Ontario, Final Report' (Commission on Planning and Development Reform in Ontario, 1993), incorporates several accessibility considerations.

Very importantly, from an accessibility perspective and at the general principles level, the Planning Act has been amended to **require** that the distribution, and hence general location of public facilities and employment opportunities be considered in the planning process:

"...The council of every municipality, every local board or authority, every minister of the Crown and every ministry, board, commission or agency of the government...shall have regard to...

(i) the adequate provision and equitable distribution of educational, health, social and recreational facilities and programs;

(k) the adequate provision and distribution of employment opportunities." (Commission on Planning and Development Reform in Ontario, 1993, p. 9)

Further at a more detailed but widely distributed level the Community Development and Infrastructure section of the document explicitly addresses the matter of accessibility:

"2. Public streets and places used by the public will be planned to meet the needs of pedestrians and be designed to be safe, vibrant, and *accessible* to all, including the disabled.

5. Communities will be planned to minimize the consumption of land, promote the efficient use of infrastructure and public service facilities, and, where transit systems exist or may be introduced in the future, promote the use of public transit." (Commission on Planning and Development Reform in Ontario, 1993, p. 31)

Finally, the Conservation Policies section states:

"3. Patterns of land use and development will be planned and modified to encourage the most efficient modes of transportation and to reduce the need for private automobile use in daily life."
(Commission on Planning and Development Reform in Ontario, 1993, p. 33)

These recent statements contained in reports of the Ontario Ministries of Transportation and Municipal Affairs (1992), Canada Mortgage and Housing (1993), Regional Municipality of Ottawa-Carleton (1993), Transportation

Association of Canada (1993), and the Ontario Ministry of Municipal Affairs (1994) confirm that accessibility as it relates to urban and regional development, location decisions, and to decisions involving transport modes and/or networks is currently a relevant and significant research and application topic.

1.2 General and Research Hypotheses

A preliminary search of the learned literature yielded numerous academic studies of accessibility measurement techniques (Dalvi and Martin, 1976; Davidson, 1977; Morris et al., 1979; Nutley, 1984; Pacione, 1989; Pirie, 1979; Vickerman, 1974; and White, 1979).

However, only one study was located (Polus and Kumove, 1979) which surveys the usage, definition and form of accessibility measurement techniques in the *real world* by practitioners. In their work, Polus and Kumove (1979) review the concept of accessibility and measurement used in several disciplines: traffic engineering, transportation planning, environmental planning, urban economics, and comprehensive urban planning.

Given the broad, real-world relevance of accessibility as indicated by Polus and Kumove, and by the agencies referred to in Section 1.1, a question logically arises. Why is the literature so 'rich' with academic studies, and so 'poor', to the point of being poverty-stricken, in terms of reports on the real-world usage of accessibility measurement techniques?

This inquiry is concerned with part of that large question, and focusses on expanding what is known about the real-world usage of accessibility measures.

The general hypothesis underlying the research is that accessibility measurement techniques are in fact widely used for decision-making in real world settings. The basis for this assertion is that on their face accessibility measurement techniques are central to location development choices and infrastructure programs. If accessibility measurement techniques are central to decisions involving location and development choices and infrastructure programs, then it follows that accessibility measurement techniques are widely used for decision-making regardless of the lack of publications on the accessibility topic.

The implication of the general hypothesis, as it relates to the publication record which does not support the general hypothesis, may be summarized as:

1. Yes, accessibility measurement techniques are in fact widely used, but their usage is only infrequently reported in the learned literature; or
2. No, they are not widely used, their apparent relevance notwithstanding, which accounts for the infrequent reports in the literature on the day-to-day usage of accessibility measurement techniques in real-world settings.

The question of why there is an apparent paucity of literature on the *real world* usage of accessibility measurement techniques is therefore taken to represent an opportunity and need for research.

The **research hypothesis**, following from the general hypothesis, is that in real world settings public and private organizations use similar accessibility measurement techniques. The research hypothesis follows from previous findings that both public and private organizations must select locations for facilities, plan routes and delineate service areas (Parr, 1992; Wellar, 1993; Landis, 1993; Arbeit, 1993; Dangermond, 1993)

There is, of course, a major difference in the mission or objective of the two sectors in regard to accessibility. The difference may be briefly illustrated as follows.

Public sector agencies could seek to maximize efficiency by minimizing cost. However, the reality is that efficiency objectives are often compromised in the pursuit of other competing goals such as:

- a) equity,
- b) health, well-being and safety of the public, and,
- c) protection of pristine areas

in the provision of goods and services to the public.

The private sector, on the other hand, which is accountable to owners and/or shareholders is not constrained by provision of goods and services in the public interest. More specifically, the private sector focuses on “the bottom line” so the application of accessibility measurement techniques can be dedicated to the efficiency objective. For example, minimum travel time, distance, and cost are all legitimate targets of the private sector, and need not be compromised by non-efficiency considerations.

Clearly, then, accessibility measurement techniques could be the means to very different public or private ends. Further, in regard to means and ends, both sectors use accessibility-type criteria for terms of reference when planning and development initiatives and issues are debated, and choices are to be made about what land use activities are to be located where (Kalinski and Xiang, 1993; Landis, 1993; Wellar, 1993).

A central goal of the research, therefore, is to ascertain whether similar accessibility measurement techniques are used by the public and private sectors to guide these common location/route and associated development decisions.

1.3 Research Objective and Design

The primary objective of this research is to identify, compare and contrast techniques of measuring accessibility in conceptual and operational terms, and to ascertain if and how these techniques are currently being used in the public and private sectors. The key point of issue is that the public and private sectors are concerned with facility locations, route-planning, and the extent and form of service areas, and yet a detailed search of the academic literature yielded only one

review of the use of accessibility measures in the *real world* by practitioners. As noted above, the increased interest in accessibility on the one hand, and the lack of reporting on the real world usage of accessibility on the other, points to the need for this research. Figure 1 outlines the research design adopted for the investigation.

As illustrated by Figure 1, for the first part of the research a literature review of accessibility concepts, tasks and measurement techniques is presented. In addition to theses and dissertations, journal articles, books, bulletins, departmental and research institute reports, conference proceedings papers, and government, business organization and consulting company reports are examined for their contributions to defining accessibility and measurement terms and concepts. Following this section, a classification of techniques for accessibility measurement is presented.

Next, the spatial dimension of the concept of accessibility is explored, followed by a discussion of the spatial considerations involved in measuring accessibility. The final chapter in the first part of the thesis examines the relationship between accessibility and location decisions, and the relationship between accessibility and transportation network decisions. The goals which drive public and private sector location and transportation network decisions are compared and contrasted.

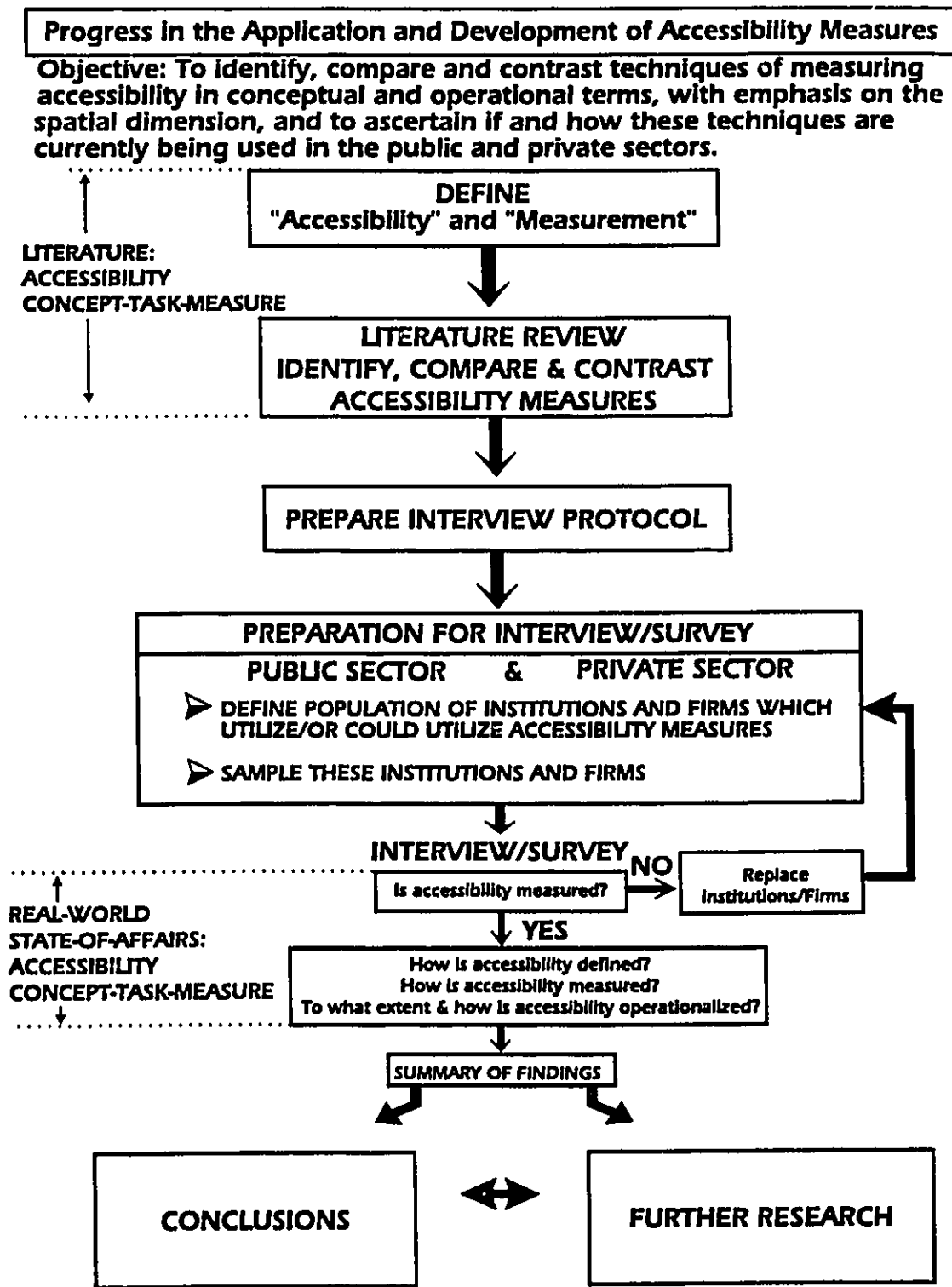
In the final phase of the literature review, the implementation of accessibility concepts and measurement techniques in real world or applications environments is examined. Specifically, this section surveys the literature for emphasis, evidence, findings, and opinions on: techniques of measuring accessibility as opposed to applications of techniques; types of applications; relative use of different types of accessibility measures; and, implementation of accessibility measurement techniques or programs by means of geographic information systems (GIS). For the second phase of the research, a field study is undertaken. This phase consists of interviews with public and private sector institutions and firms to establish their conceptual definition of accessibility, and the means by which it is operationalized.

To conclude this text of the Introduction, several questions and a brief comment on the case studies underlying the research are presented to illustrate what this line of inquiry is intended to investigate.

The kinds of questions of interest include the following. Since both public and private organizations select locations for facilities, plan routes and delineate service areas, do they use similar accessibility measurement techniques? If so, what types of measures? Is a GIS used to implement the measures? Also, is there a consensus on recommendations of pertinent literature that is used to guide the accessibility measurement process?

The National Capital Region is the primary study location, with additional interviews conducted in Toronto and Vancouver. It is appropriate to conduct the interviews in urban centres since this is where much of Canada's land use and transportation planning decision-making occurs. The 'New Planning for Ontario: the Final Report of the Commission on Planning and Development Reform in Ontario' (Commission on Planning and Development Reform in Ontario, 1993)

Figure 1: Flowchart of Research Design



confirms that land use and transportation planning is taking place in upper-tier government (urban centres, such as the Regional Municipality of Ottawa Carleton) in Ontario, and not at provincial or local-municipal levels.

“Environmental issues, general questions of economic and social change, and transportation and infrastructure planning all require a broad approach to planning. It is important that this broad planning perspective be located within a governmental structure that has the capacity to undertake and follow through on it..Good planning requires skilled practitioners and an appropriate administrative support structure. The pooling of resources from individual municipalities helps counties and regions create a strong administrative support framework. Combined with the broad planning approach, this pooling permits counties and regions to take over many approval functions now exercised by the province.” (Commission on Planning and Development Reform in Ontario, 1993, p. 61)

The National Capital Region is chosen as the main site in order to minimize time and travel costs associated with multiple interviews and site visits. Vancouver is selected because of the spatial constraints it is experiencing as a result of rapid population growth, restrictive geographic features (mountains and sea), and air pollution problems (Globe and Mail, 1995, p. 1) emphasizing the need for location and transportation network decisions which utilize space efficiently and reduce vehicle air emissions.

The third site, Toronto, is chosen because of its status as Canada’s largest city (population: Greater Toronto Area, 1991, 4.2 million (Metropolitan Toronto Planning Department, 1993)) and as such has been faced with coordinating land-use and transportation infrastructure on a large scale. A second reason for selecting Toronto is that its size attracts the head offices of nation-wide consulting firms (e.g. IBI Group), which presents an opportunity to contact a number of private sector firms for interviews.

1.4 Summary

The term *accessibility* is defined as “...a combination of two elements: location on a surface relative to suitable destinations, and the characteristics of the transportation network or networks linking points on that surface.” (Vickerman, 1974, p. 676)

Currently, accessibility is a significant factor in location and transportation network decisions as evidenced in recent reports from Ontario Ministries of Transportation and Municipal Affairs (1992), Canada Mortgage and Housing (1993), Regional Municipality of Ottawa-Carleton (1993), Transportation Association of Canada (1993), and the Ontario Ministry of Municipal Affairs (1994).

Accessibility measurement techniques can be used to evaluate transportation systems, urban and regional structure, and locations for facilities. The general hypothesis underlying the research is that accessibility measurement techniques are widely used for decision-making in real world settings.

Since public and private organizations must both select locations for facilities, plan routes and delineate service areas a logical research question arises: Do they use similar accessibility measurement techniques to assist decision-making? In order to empirically respond to the basic research question, interviews with public and private sector firms are conducted to establish their conceptual definition of accessibility, and the means by which it is operationalized. (Parr, 1992; Wellar, 1993; Landis, 1993; Arbeit, 1993; Dangermond, 1993) The specific objective of this research is to identify, compare and contrast techniques of measuring accessibility in conceptual and operational terms, and to ascertain if and how these techniques are currently being used in the public and private sectors.

There are two parts to the research: a literature review of concepts, tasks and measures, and a field study using an interview technique. The first part, a literature review, examines a wide variety of sources for their contributions to several thesis tasks: defining key accessibility and measurement terms and concepts; classifying techniques of measuring accessibility; elaborating the spatial dimension of accessibility; exploring the relationship between accessibility and location/network decisions; and, implementing and examining the why's and how's of accessibility measurement techniques in applications environments.

The second part of the research is based on a series of interviews with public and private sector organizations to establish their conceptual definition of accessibility, and the means by which it is operationalized in the real-world.

2. Literature Search and Review

In the literature review, theses and dissertations, as well as: journal articles, books, bulletins, departmental and research institute reports, conference proceedings papers, government, business organization and consulting company reports are examined for their theoretical and empirical contributions to:

- 1) defining key accessibility concepts and terms;
- 2) classifying accessibility measures;
- 3) elaborating the spatial dimension of accessibility;
- 4) understanding the relationship(s) between location decisions and accessibility;
- 5) understanding the relationship(s) between transportation network decisions and accessibility; and,
- 6) implementing accessibility concepts and measures in real world applications environments.

2.1 Procedure for Selection and Review of Pertinent Literature

A research population consists of all units about which a researcher would like to make scientific statements as illustrated in Figure 2. In this report the research population is all extant (publicly available) publications which discuss quantitative accessibility measurement techniques. This population is sampled in a two-pronged approach. The first step involves designing a procedure for selecting a sample of pertinent theses and dissertations to review. And, in the second step, a similar procedure is needed to detail a sample of pertinent journal articles, books, bulletins, departmental and research institute reports, conference proceedings papers, government, business and consulting company reports for review.

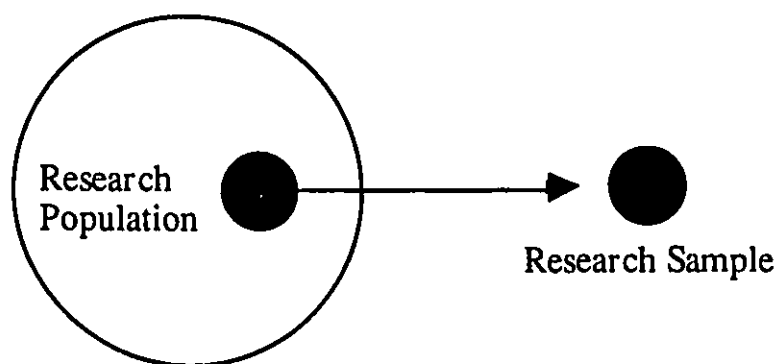
In view of the potentially large body of literature to search and review, it is necessary that the selection procedure be both effective and efficient. To that end the procedure must first identify all the material that is relevant to the research objective, and then enable identification of those materials that are most pertinent to the research objective, and then enable identification of those materials that are most pertinent to the research operations under study.

The procedure adopted for the thesis is modelled after one used in a previous, related inquiry in which the writer participated.

In the earlier study a keyword-based procedure was used to search and review the literature on scientific inquiry, quantitative procedures, and GIS (Wellar, Cameron, and Sawada, 1994). That literature search and review procedure developed sets of synonyms for article selection, and proved to be an effective and efficient means for both the electronic and manual segments of the search and review. It is

therefore employed as the basis for this study since the research objectives and literature search and review tasks are similar.

Figure 2: Research Population and Sample



Source: Adapted from Walizer and Wienir (1978, p. 427)

2.1.1 Theses and Dissertations: Search and Selection

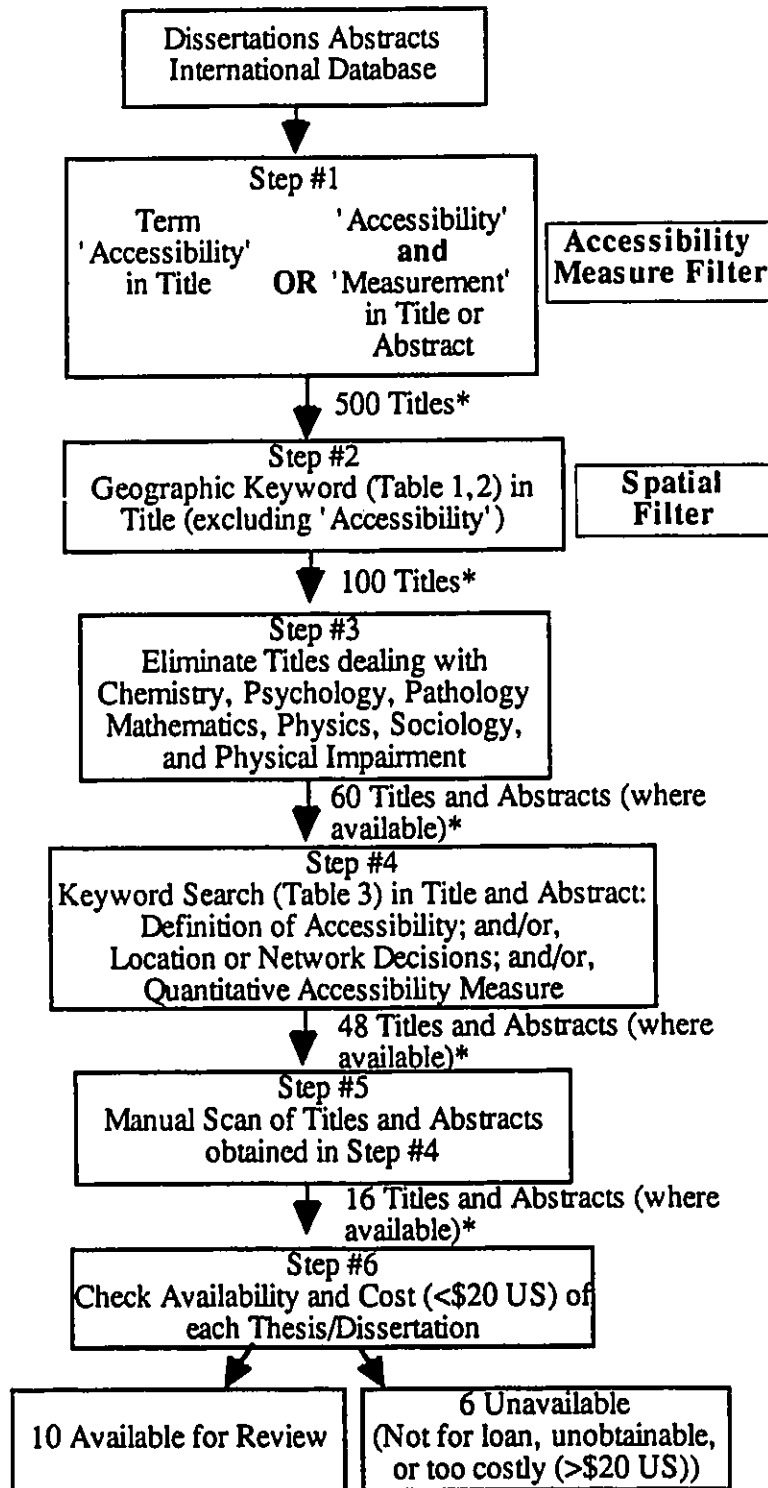
The theses selected for detailed examination are derived by means of *purposive* sampling. The six main steps involved in the sampling procedure are illustrated in Figure 3. In brief, purposive sampling is defined as an umbrella term which includes quota and availability sampling (Walizer and Wienir, 1978; Ackoff, 1953). This procedure is appropriate for this literature search because not all of the theses are available for loan, obtainable, or of a reasonable cost. Ackoff (1953, p. 118-119) provides support for use of purposive sampling:

“...practical considerations seem to preclude the use of probability sampling, and the researcher looks for a representative sample by other means. That is, he looks for a sub-group which is typical of the population as a whole. This subgroup is used as a ‘barometer’ of the population.”

Since the outcome of the research is very much affected by the literature selection, an overview of the literature search procedure is presented first, followed by a detailed description of the specific steps taken to obtain the sample of theses and dissertations.

A digital keyword search of the Dissertations Abstracts International (1994) database is conducted to identify potentially pertinent Master’s theses and Doctoral dissertations. The theses fulfilling this criteria constitute a quota sample. A quota sample is used “whenever a researcher desires to have a certain number of elements that have some characteristic in a sample.” (Walizer and Wienir, 1978, p. 437). The set of theses and dissertations selected to receive detailed study represents an availability sample, in that among the eligible candidates those

Figure 3: Procedure for Selecting Theses and Dissertations for Intensive Examination



* Refers to Titles and/or Abstracts of Theses and Dissertations

reviewed are those which are available. "An availability sample is one where elements are sampled on the basis that they are easily accessible to the researcher." (Walizer and Wienir, 1978, p. 437)

The specific steps of the literature search procedure follow the flowchart in Figure 3. First, the Dissertations Abstracts International database is searched for all Master's and Doctoral titles containing the keyword *accessibility* in the title, OR the keywords *accessibility* and *measur** (measure and its variants: measures, measured, measuring, measurement, measurable) in the title or abstract. A total of 500 titles are produced by the search.

In the second step, the 500 titles are scanned manually for titles containing a geographic keyword (Table 1 and Table 2) other than accessibility. This step ensures that the theses and dissertations selected have an emphasis on spatial factors.

The approach adopted for specifying keywords to represent the spatial is the use of point, line and polygon synonyms to represent the locations of real world phenomena (Wellar, 1993). Points represent sites and any location that can be assigned x-y coordinates, lines are connections or links between points, while polygons represent areas contained within lines (Wellar, 1993). The respective point, line and polygon synonyms for the keyword-based search are presented in Table 1.

Table 1: Keyword Search for Theses that Focus on the Spatial Dimension of Accessibility through Incorporating References to Points, Lines and Polygons

<i>POINT SYNONYMS</i>	<i>LINE SYNONYMS</i>	<i>POLYGON SYNONYMS</i>
cent(er)(re)	barrier*	area*
facilit*	boundar*	field*
hub*	grid*	neighbourhood
intersection*	lattice*	polygon*
location*	line*	region*
node*	maze*	spa*
point*	path*	sphere*
place*	ring*	surface*
sit*	rout*	zon*
termin*	scalar*	
vert*	spoke*	
	tributar*	

(NOTE: The location of the * denotes any prefix or suffix)

In addition, accessibility, adjacency, connectivity, and distribution synonyms detailed in Table 2 also represent geographical concepts which report on the combinations of and relationships between and among points, lines, and polygons.

It is important to point out that titles and not abstracts are examined, because many of the theses' and dissertations' listings do not include an abstract. As a result

of considering only the titles in all cases, all theses are treated in the same way and all have the same opportunity of selection.

Table 2: Keyword Search for Theses that Focus on the Spatial Dimension of Accessibility Through Incorporating References to Accessibility, Adjacency, Connectivity, and Distribution

ACCESSIBILITY SYNONYMS	ADJACENCY SYNONYMS	CONNECTIVITY SYNONYMS	DISTRIBUTION SYNONYMS
accessibility close convenient distan* far least-cost least-time	adjacen* buffer* contiguous edge* margin* near* neighbour* proxim* spill-over	connect* link* network*	allocation agglom* cluster* concentrat* densit* diffusion* dispers* distribut* heterogeneous homogeneous pattern* scatter* geogr*

(NOTE: The location of the * denotes any prefix or suffix)

Third, the selected titles are scanned manually and titles that deal with the subjects of chemistry, psychology, mathematics, physics, sociology, and physical impairment are rejected on the basis that they are unlikely to deal directly with the spatial accessibility aspect of location and transportation network decisions.

In the fourth step, theses' and dissertations' titles are chosen on the basis that their titles and abstracts (where available) show evidence of defining accessibility; and/or measuring accessibility quantitatively; and/or using accessibility for location or network decision-making. These criteria are consistent with the objectives of the literature search outlined at the beginning of this chapter, that is:

- 1) defining key accessibility concepts and terms;
- 2) classifying accessibility measures; and,
- 3) understanding the relationship(s) between accessibility and location/transportation network decisions.

Specific keywords used to direct this step are listed in Table 3.

Fifth, the 'surviving' titles and abstracts (where available) are manually scanned to further reduce the number of theses and dissertations - removing those not of direct interest, yielding 16 theses and dissertations. These 16 theses, which satisfy

the criteria outlined in Figure 3, represent a quota sample of theses and dissertations selected for those which are pertinent to this study.

Table 3: Keyword Search for Theses that Define or Measure Accessibility, Examine Logic of Location or Network Decisions, and/or Study the Use of Quantitative Accessibility Measurement Techniques

<i>DEFINING SYNONYMS</i>	<i>LOCATION AND NETWORK SYNONYMS</i>	<i>ACCESSIBILITY MEASUREMENT SYNONYMS</i>
defin* component* dimension* theoretical	site rout* location* network*	gravity cumulative time-space topological graph theor* potential index indices accessibility profile* distance

(NOTE: The location of the * denotes any prefix or suffix)

The sixth and final step yields an availability sample of 10 documents (Table 4), since 6 out of the 16 theses and dissertations are not available for loan, cannot be obtained or are too costly (more than \$20 American dollars (\$U.S.) in price) to borrow or purchase.

At this point it is acknowledged that since an availability sample is a non-probability sample, it is not appropriate to use the results to statistically test the null hypothesis. It remains, however, that examination of the selected theses and dissertations may yield insights that contribute to an assessment of the research hypothesis, or may contribute to the understanding and interpretation of findings from the search of the research journal literature.

Furthermore, in support of the quota sample-availability sample approach, its usefulness was recently demonstrated by Wellar (1994). In his empirical study of the development and adoption of Intelligent Vehicle Highways Systems (IVHS) by Canadian municipalities, a similar approach was adopted for the sampling design.

Table 4: Theses Examined

Author	Date	Thesis Title
C.C. Kissling	1967	Transportation networks, accessibility and urban functions; an empirical and theoretical analysis.
M.J. Hodgson	1973	Highway network development and optimal accessibility change in the Toronto centered region.
J.E. Daccarett	1975	A measure of regional an opportunity sets, market areas, and transportation network structure.
D.B. Cates	1976	Short-run airline network degeneration and accessibility change.
L.D. Burns	1978	A methodological study of the transportation, temporal and spatial components of accessibility.
D.I. Wilson	1978	An empirical study of the effect of transportation networks, travel functions and zoning systems upon accessibility-development relationships.
A.S. Fotheringham	1980	Spatial structure, spatial interaction, and distance-decay parameters.
C.O.E. Enoch	1981	Spatial inequalities, spatial inequities and spatial integration in the socio-economic development of the cross-river state of Nigeria.
A. Peiravi	1984	Path determination and connectivity of utility networks.
C. Liu	1986	Social welfare maximization on capacitated networks.
W.P. Gallimore	1993	Measuring relative accessibility differential of discount department stores using Geographic Information Systems.

The findings from Wellar's study applied explicitly to the selected sample of large, metropolitan centres, and implicitly to the much larger number of smaller centres that are less (electronically) advanced. It is reasonable to expect, therefore, that the theses which met the criteria for selection will contain messages to apply to the theses that did not 'survive the cut' in this study.

Finally, in regard to the ten theses selected for review via the keyword search procedure, *Measuring Relative Retail Accessibility Differential of Discount Department Stores using Geographic Information Systems* by Gallimore (1993), is also examined along with the 10 yielded from the literature search procedure (Table 4).

This Master's thesis fulfills the criteria described above, but has not yet been incorporated into the Dissertations Abstracts database. The thesis was obtained from the author, W.P. Gallimore, at the GIS in Business '93 Conference in Boston, Massachusetts, U.S. (March, 1993).

2.1.2 Other Publications: Journal Articles, Books, Bulletins, Research Reports, Proceedings Papers, Government and Business Reports: Search and Selection

Publications consisting of journal articles, books, bulletins, departmental and research institute reports, conference proceedings papers, reports of governments, business organizations, and consulting companies are obtained through four different ways, as illustrated in Figure 4.

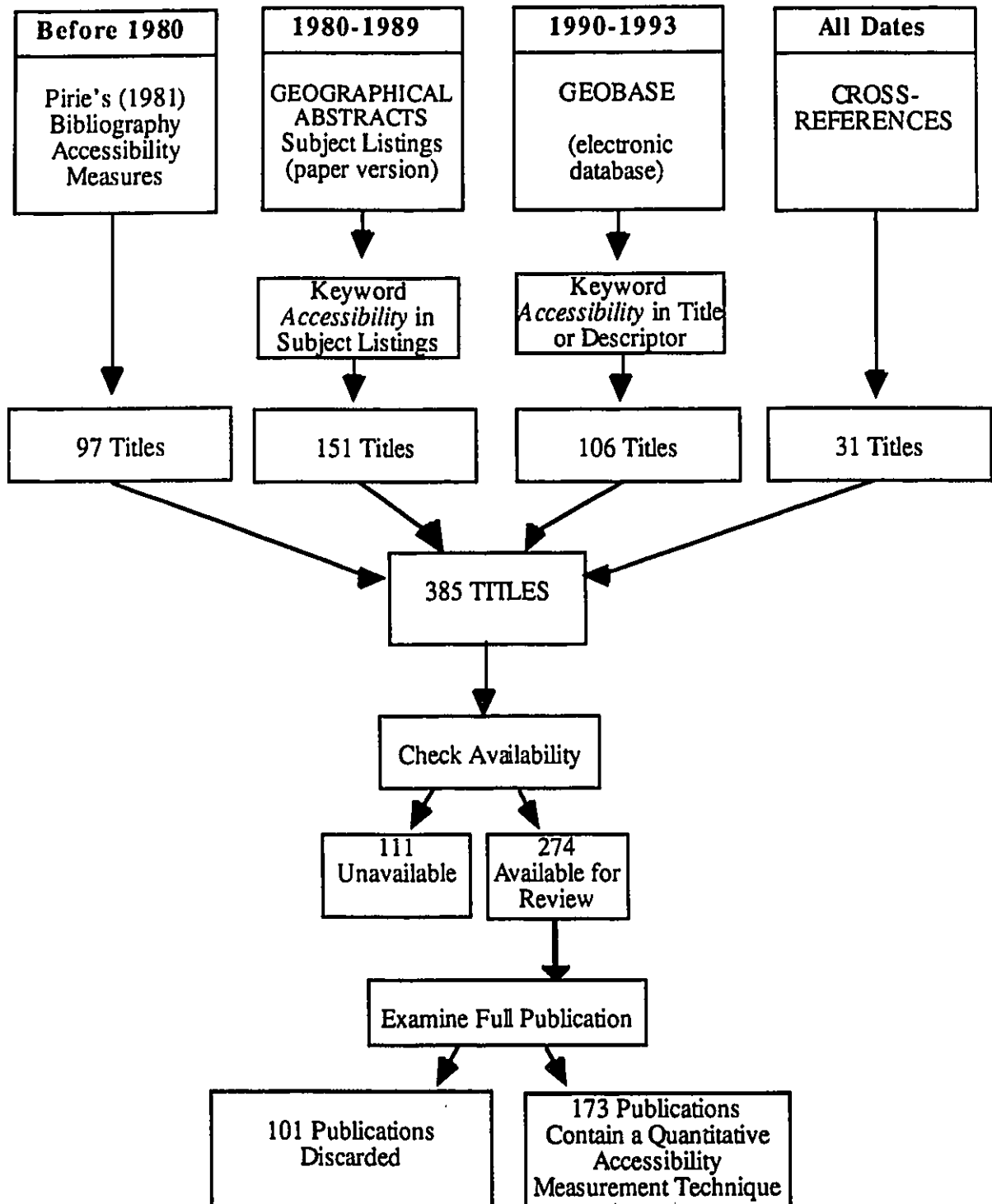
The publications are drawn from four different channels, for the following reasons:

- Before 1980, "*Measurement of geographic accessibility*" (Pirie, 1981). This bibliography only covers literature up until 1981.
- 1980 - 1989, *Geographical Abstracts Index* (Geo Abstracts Ltd., 1980-1989) subject listings for the keyword *accessibility*. The paper version of this database is used since a CD-ROM version is not available locally.
- 1990 - 1993, 'GEOBASE' (Geo Abstracts Ltd., 1990-1993). The CD-ROM version of the Geographical Abstracts, is used in conjunction with the keyword *accessibility* in the title or assigned descriptor of each publication. 'GEOBASE' is the ideal search tool, however, only the time period 1990-1993 is readily available.
- All Dates, *Cross References*. Titles of publications not selected by the above 3 search procedures (Pirie, Geographical Abstracts Index, and 'GEOBASE') are obtained by cross-referencing from other publications.

Combination of these 4 sources yields 385 titles of publications.

Next, the availability of these publications is checked at local libraries (Carleton University and University of Ottawa). A total of 274 publications which are available for review are scanned manually for evidence of use of a quantitative accessibility measurement technique. In this step, 101 publications are discarded because they fail to adequately satisfy the driving criterion for selection. By way of clarification, 66 of the discarded papers contain some reference to accessibility, but do not incorporate quantitative measures. The remaining (35) discarded papers are duplicates, off-topic, written in a language other than French or English, or deal with physical impairment issues. This final step yields 173 'surviving' publications for intensive review, which are then classified according to the type of quantitative measurement technique utilized.

Figure 4: Procedure for Selecting Journal Articles



2.2 Summary

The literature review selects theses and dissertations, and publications consisting of: journal articles, books, bulletins, departmental and research institute reports, conference proceedings papers, government, business organization and consulting company reports for their theoretical and empirical contributions to:

- 1) defining key accessibility terms and concepts;
- 2) classifying accessibility measures;
- 3) elaborating the spatial dimension of accessibility;
- 4) understanding the relationship(s) between location decisions and accessibility;
- 5) understanding the relationship(s) between transportation network decisions and accessibility; and,
- 6) implementing accessibility concepts and measures in real world or applications environments.

The research 'population', consisting of all publications focussing on quantitative accessibility measures, is sampled in a two-pronged fashion. In the first step, Master's theses and Doctoral dissertations are the subject of attention. And, the second step involves drawing pertinent publications from among the extant body of journal articles, books, bulletins, departmental and research institute reports, conference proceedings papers, and government, business organizations and consulting company reports.

Theses and dissertations identified for potential examination are selected through a combination of two types of purposive sampling --quota and availability. Titles dealing with accessibility measurement are extracted from the Dissertations Abstracts Database. Further filtering yields 16 theses and dissertations which represent a quota sample fulfilling the criteria of emphasis on:

- 1) spatial issues; and,
- 2) a) focus on defining accessibility; and/or,
b) location or transportation network decision-making; and/or,
c) measuring accessibility quantitatively.

The final 11 theses and dissertations selected for actual review represent an availability sample in that they are available for review.

Journal articles, books, bulletins, departmental and research institute reports, conference proceedings papers, government, business organizations and consulting company reports are drawn from four sources. These four sources are: Pirie's (1981) Bibliography on Accessibility Measures; Geographical Abstracts Inc. Subject Listings (1980-1989); 'GEOBASE' (CD-ROM version of Geographical Abstracts) (1990-1993); and cross-references which are combined to produce 385

titles. Of these 385 titles, 274 are available for review. A total of 173 of the available publications measure accessibility quantitatively.

3. Accessibility Defined: Terms and Concepts

Many of the articles encountered in the 'accessibility literature' use the terms *accessible, accessibility, barriers to accessibility, availability, unavailability, access, barriers to access, convenience, mobility, and level of service* interchangeably. Unfortunately, however, there is often little apparent agreement as to what the various terms are actually intended to connote or denote.

That situation is not unique to the transportation accessibility field, of course, nor is it a recent event. By way of illustration, the lack of definitional rigour involving the terms *measure, indicator, and index* interchangeably was identified more than 20 years ago as a major constraint on progress in social change, research, including that aspect related to accessibility (Wellar, 1973).

Although established references have been used where possible, some interpretation has been required to differentiate between the terms due to the lack of clarity in the literature. The general structure of the chapter is outlined as follows:

- 1) First, some pertinent basic terms --*opportunity, travel route, transportation network, line-haul route, transport mode, trip, origin, destination, activity, transportation network infrastructure, and routing*-- which are used throughout the thesis are discussed.
- 2) Next, the terms closely associated with accessibility --*accessible, accessibility, barriers to accessibility, availability, unavailability, access and barriers to access*-- are defined.
- 3) Finally, three terms: *convenience, mobility, and level of service* which are frequently used interchangeably with the term *accessibility* are reviewed.

3.1 Basic Terms

In the context of location and transportation network decisions, the focus of this thesis is on three fundamental terms.

- a) **Location:** the siting of *opportunities*, that is, the point or place where there is an opportunity for spatial interaction;
- b) **Network:** the location of *travel routes*, and the spatial characteristics of transportation networks (which are composed of travel routes); and,
- c) **Routing:** the spatial strategy, plan, logic, algorithm, or other kind of reasoning by which *transport modes* (e.g. road vehicles) navigate transportation networks (e.g. a regional road system).

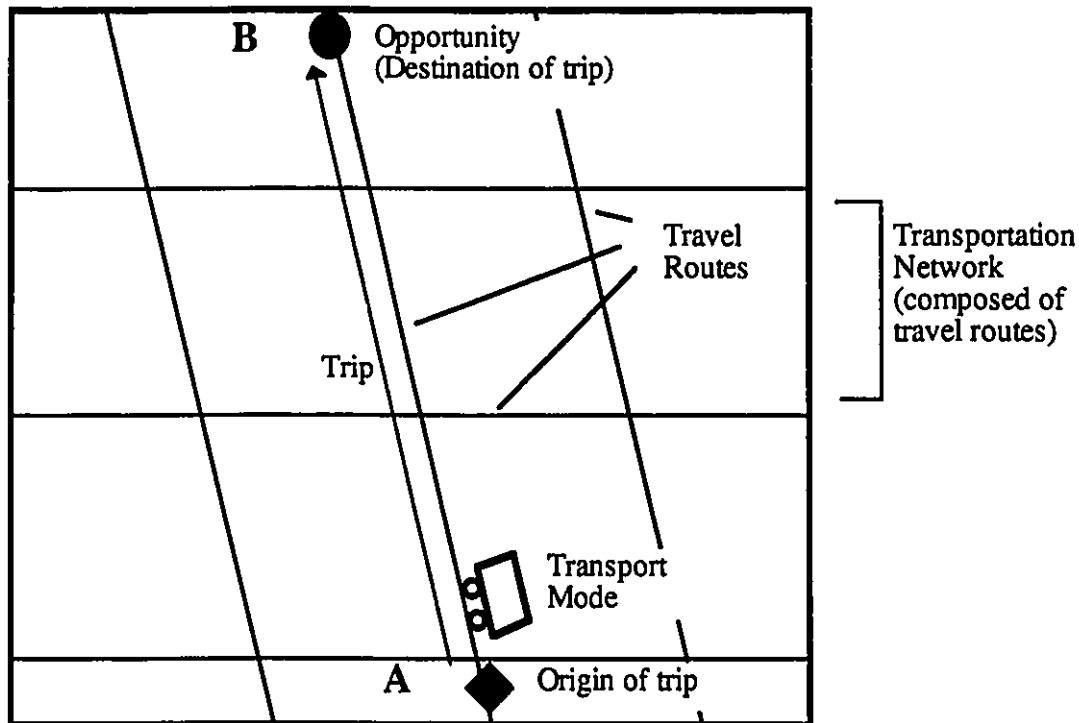
Thus, the main components of interest are:

- opportunities;

- travel routes; and,
- transport modes.

These components are defined in detail in the following paragraphs. Figure 5 illustrates basic trip and transportation terms.

Figure 5: Trip and Transportation Terms



An *opportunity* refers to an "opportunit(y) for spatial interaction...(and) may concern employment places, day nurseries, doctors, shops, parks, etc." (Weibull, 1980, p. 54)

A *travel route* is "...a regularly travelled path or line of communication between different places. Travel or movement may be by road, rail, air, water, pipeline or some other means. Intersecting routes form a *network*." (Goodall, 1987, p. 416)

A more detailed description of a *network* is given by Vickerman (1974, p. 676): "The starting point is an assumption of a planar surface and a *network* in the form of a planar graph. Points where *links* of the network cross are called *nodes* or *vertices*, all links are counted equally."

A *line-haul route* is a type of travel route "...along which people and goods are moved in bulk to a distribution point near their destination." (Goodall, 1987, p. 416)

A *transport mode* is a “type of transport” (Goodall, 1987, p. 479), such as pedestrian, bicycle, car, bus or boat. In Figure 5 a transport mode is used to move between point A and point B.

A *trip*, (represented by an arrow →), is “...a one-way movement between a point of origin and a point of destination.” (Goodall, 1987, p. 482) In this case, a trip = movement from point A to point B.

The *origin* of a trip is where movement originates (point A) and the *destination* is the termination point of the trip (point B). “There is a specific *origin* in geographic space...as well as a specific *destination* some distance away from the origin. There is a path connecting these two points. Movement between *origin* and *destination* requires the expenditure of both time and effort.” (Lowe and Moryadas, 1975, p. 1)

Three additional terms: *activity*, *transportation network infrastructure*, and *routing* although not illustrated, are also defined.

An *activity* “...means what actually takes place on a parcel of land...consist(ing) of observable relationships among persons, goods, and vehicles.” (Guttenberg, 1993, p. 247) Examples of activities are office activity, school activity, and pedestrian movement.

Transportation network infrastructure is:

- “1) the transport facilities needed for all forms of economic and social activities; and,
- 2) fixed transport installations, such as networks of roads, railways and canals, as well as terminals, including airports and docks, and associated sites, buildings and equipment.” (Goodall, 1987, p. 479)

The strategy, plan, logic, algorithm, or other kind of reasoning by which transport modes (through their operators) navigate the transportation network is called *routing*. “Routing involves ‘legal’ travel from one point to another along a designated transportation network. Used in this context, legal means making only allowable turns or transfers.” (Landis, 1993, p. 33)

Opportunity, *travel route*, *transportation network*, *line-haul route*, *transport mode*, *trip*, *origin*, *destination*, *activity*, *transportation network infrastructure*, and *routing* are basic terms used throughout the thesis, and are essential to the discussion of terms related to accessibility and measurement. In the interests of coherency and consistency, the terms are used in the remainder of the text as presented above in Section 3.1.

3.2 Accessibility Terms and Concepts

As explained previously, there is considerable difference of opinion in the ‘accessibility literature’ (publications, and theses and dissertations) over accessibility terms and concepts. In this section, various authors’ definitions and uses of *accessible*, *accessibility*, *barriers to accessibility*, *availability*, *unavailability*, *access*,

barriers to access are presented and discussed. Then, three terms –*convenience*, *mobility*, and *level of service*– which are used interchangeably with *accessibility* are reviewed.

3.2.1 Accessible

In examining the ‘accessibility literature’, two distinct definitions of *accessible* emerge.

The first form of the definition is given by Savigear (1967, p. 64) who notes that “whether or not a place is *accessible* depends on whether or not it can be reached.” A similar definition is quoted by Daccarett (1975, p. 9). “The term *accessible* when applied to some potential spatial destination, implies a certain capacity of being reached. It also implies the ability to reach or gain *access* to some distant objective.” These definitions imply that *accessible* is a binary condition; a place is either accessible or inaccessible and the ease of travel is not a consideration. Thus, according to these definitions, within a defined area, an opportunity is *accessible* to an individual if all of the following conditions are met:

- a) an opportunity is available;
- b) there is access to this opportunity;
- c) a travel route is available;
- d) there is access to this travel route;
- e) a mode of transport is available;
- f) there is access to this mode of transport;

Accessible as defined in this manner is particularly applicable to assessing the possibility of obtaining necessary services in remote and isolated settlements. Moseley (1979, p. 55) explains “...in the rural context, the duration of the trip...is a relatively small consideration; much more important is whether the trip is possible at all.”

The second form of the definition for *accessible* is interpreted as the ease of travel. “When we talk about something being *accessible* we are referring...to the degree to which it is get-at-able.” (Moseley, 1979, p. 56) Similarly, the Joint Working Group of the United Kingdom Transport and Road Research Laboratory and Gwent County (1981, p. 2) define *accessible* in the following way: “a place is said to be accessible if it is easy to get to and inaccessible if it is difficult or impossible to reach.”

A third example of this interpretation is given by Knox and Agnew (1989, p. 65). “All locations are not equal, even on an isotropic plain. Some are *more accessible* than others. Usually this means that they are easier to travel to or are more central.”

3.2.2 Accessibility

Restated in numerous articles is a statement by Gould (1969, p. 64)

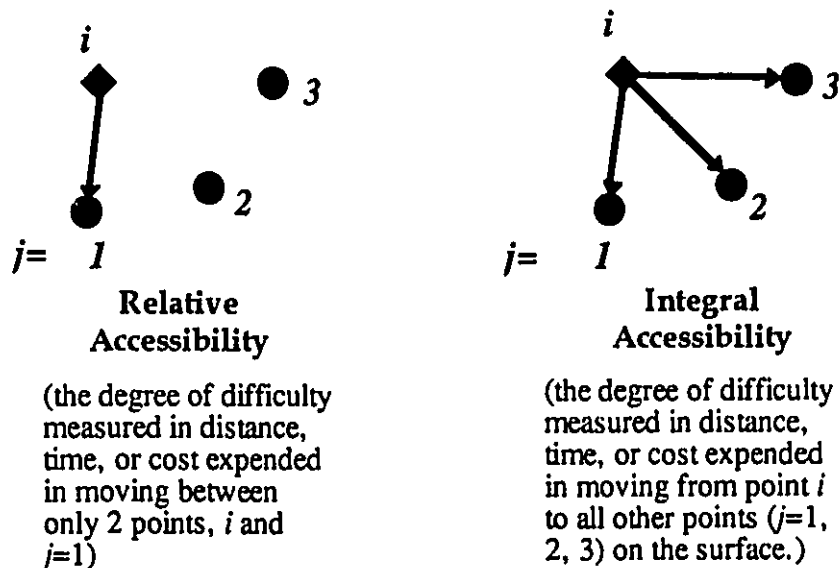
"Accessibility...is a slippery notion...one of those common terms that everyone uses until faced with the problem of defining and measuring it."

Daccarett (1975, p. 9) also notes that "...the concept behind the term (accessibility) has eluded precise and generally accepted definition." However, the one point upon which the majority of the definitions of accessibility agree upon is that "accessibility measures are based on the premise that space constrains the number of opportunities available. Beyond this point, definitions of the concept differ widely. There is considerable variation in the other elements which may be included and in how they are measured and combined." (Morris, Dumble and Wigan, 1979, p. 92)

3.2.2.1 Relative and Integral Accessibility

The terms *relative* and *integral accessibility* represent important concepts in visualizing accessibility. *Relative accessibility* is defined by Ingram (1971) as the degree (which refers to the degree of difficulty or effort measured in distance, time, or cost) by which two places (or points) on the same surface are connected. On the other hand, *integral accessibility*, is defined as the degree of interconnection for a given point with all other points on the same surface. Figure 6 illustrates relative and integral accessibility.

Figure 6: Relative and Integral Accessibility



3.2.2.2 *Place and Personal Accessibility*

Place and *personal* accessibility are variations of integral accessibility.

“Accessibility can relate to place or person. *Place accessibility* reflects the spatial arrangement of land use and transport facilities, giving an objective measure of supply conditions. *Personal accessibility* of an individual represents a combination of place accessibilities associated with the person’s location.” (Hensher, 1979, p. 120)

Bach (1980, p. 304-305) defines *accessibility* synonymously with Hensher’s (1979) definition of *place accessibility*, as “the locational quality of a central facility with respect to the locations of users.” *Access opportunity* is used by Bach (1980, p. 304-305) to refer to *person accessibility* “the locational quality of the locations of users with respect to a central facility.”

The focus of this thesis is on *place accessibility*, since location and transportation network decision-making of *organizations* is being investigated and not that of *individuals*.

3.2.2.3 *Key Elements in Definitions of Accessibility*

In Table 5 the main elements of various authors’ stated definitions of accessibility are summarized in the light grey areas, while sub-elements appear in the clear areas. It is emphasized that the authors’ stated definitions don’t necessarily correspond to the manner in which accessibility is actually measured in the articles. For example, an author’s stated definition may state define accessibility as level-of-service, but then fail to include level-of-service in the measurement of accessibility. In general, then, the authors’ definitions contain one (or more) of the following key elements:

- 1) characteristics of the transportation network;
- 2) spatial relation or degree of connection between one location and others;
- 3) supply/availability of opportunities;
- 4) attractiveness of opportunities;
- 5) freedom of individuals to decide whether or not to participate in different activities; and,
- 6) individuals assign a utility to each of their travel alternatives, and take the choice associated with the maximum utility.

As illustrated by Table 5, these six elements of accessibility definitions can be recognized as *connection*, *supply*, or *demand* related. *Connection* definitions consider the transportation network connecting supply with demand. *Supply* definitions concentrate on the presence and attractiveness of opportunities, while *demand* definitions focus on individuals which make up the demand for travel and opportunities.

Table 5: Main Elements in Definitions of Accessibility

CONNECTION (of supply to demand):

1) Characteristics of the transportation network (Vickerman, 1974)

a) effort (distance, time, cost, etc.) required to traverse a travel route (Morris, Dumble and Wigan, 1979; Zakaria, 1974; Hall, 1983; Allen, Liu and Singer, 1993; Taylor, 1976; Dalvi and Martin, 1976; Richardson and Young, 1982; Wilson, 1978; Daccarett, 1975)

b) convenience (Zakaria, 1974; Dalvi and Martin, 1976; Stone, 1973)

c) comfort (Hall, 1983; Zakaria, 1974; Dalvi and Martin, 1976; Stone, 1973)

d) reliability (Hall, 1983)

e) safety (Hall, 1983)

f) speed (Zakaria, 1974);

g) level of service (Black and Conroy, 1977)

2) "Spatial relation between one location and others, or the degree of connection between that location and all others in a region" (Al-Sahili and Aboul-Ella 1992, p. 3)(Black and Conroy, 1977; de Lannoy and Van Oudheusden, 1978; Stone, 1973; Vickerman, 1974; Daccarett, 1975)

SUPPLY (of opportunities):

3) Supply/availability of opportunities (Stone, 1973; Breheny, 1978)

4) Attractiveness of opportunities (Dalvi and Martin, 1976; Hensher, 1979; Carrothers, 1956; Wilson, 1978; Daccarett, 1975)

DEMAND (for opportunities):

5) "Freedom of individuals to decide whether or not to participate in different activities" (Burns, 1979, p. 1)(Hagerstrand, 1970; Weibull, 1980)

6) Individuals assign a utility to each of their travel alternatives, and take the choice associated with the maximum utility (Koenig, 1980)

Characteristics of the transportation network, as illustrated in Table 5, consists of several sub-elements. The most widely recognized is the effort required to traverse a travel route (also termed 'relative' accessibility). Other performance characteristics such as convenience, comfort, reliability, safety, speed and level of service are included in some authors' definitions.

The second element, spatial relation or degree of connection between one location and others, is also a common element in authors' definitions of accessibility.

Morris, Dumble and Wigan (1979, p. 96) note that "...when services have administratively defined catchment areas the 'choice' of destination is not an issue, and accessibility may be more meaningfully measured by the 'effort' involved in reaching the prescribed activity centre." This means that in a situation where there is only one destination, the spatial relationship between the specified location and the destination is no longer an issue. Instead, the 'relative accessibility' determines the ease of making the trip.

The third element, supply/availability of opportunities is combined with the first element, characteristics of the transportation network to form the definition given by Stone (1973, p. 253):

"Accessibility can be defined in two ways. First, it is the cost, time taken, comfort and convenience of making a journey, usually from the home to a particular facility, which depend on the mode of transport and its relationship with the origin and destination of the journey. Secondly it can be defined in terms of the opportunity to use facilities after journeys of various lengths."

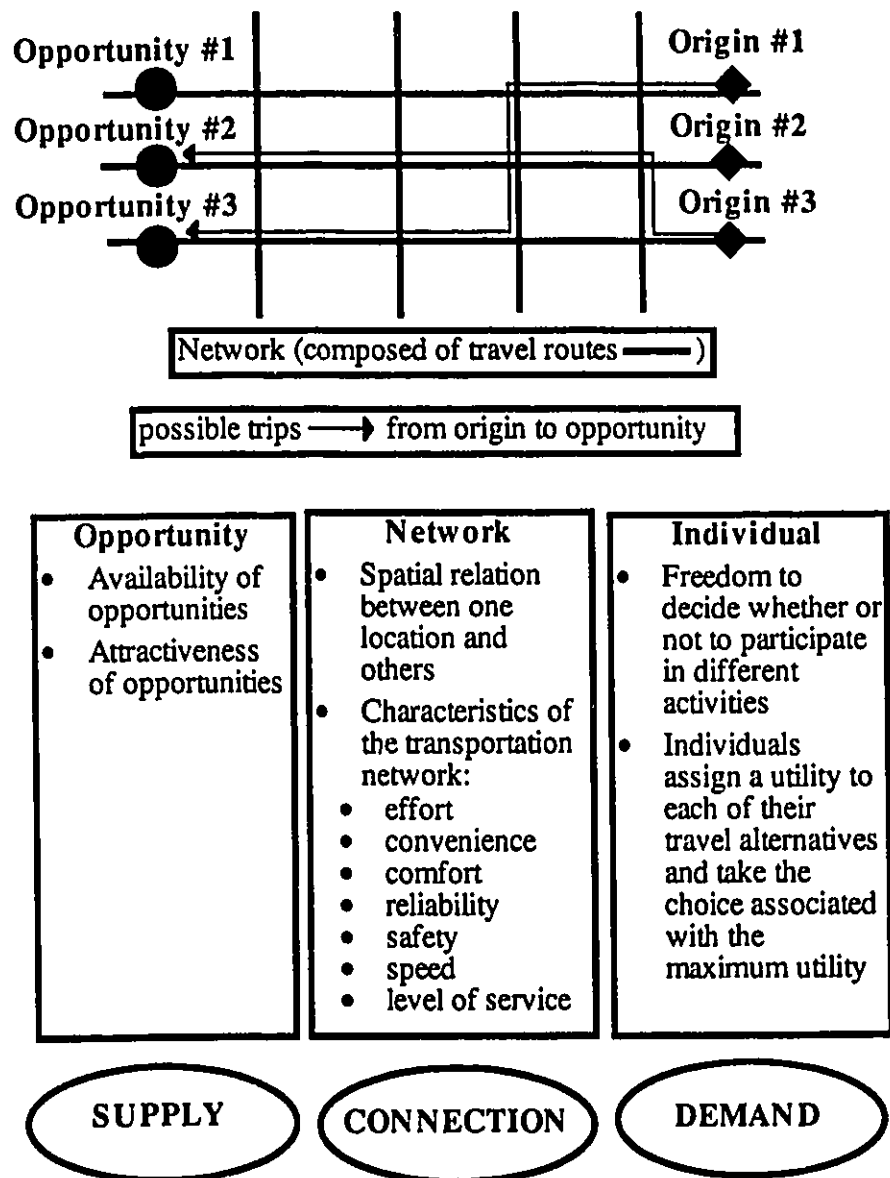
Attractiveness of opportunities, the fourth element, is less commonly incorporated into the definition of accessibility. Attractiveness of opportunities refers to characteristics of opportunities which influence the relative ability of opportunities to draw or attract customers or users. White (1979, p. 19) argues that attractiveness of opportunities should not be part of the definition of accessibility. "Facility attraction measures should be kept separate. Attraction influences the desirability of interaction but not the ability to interact or the effort involved in interaction."

The fifth element, freedom of individuals to decide whether or not to participate in activities, presented by Burns (1979), is based on Hagerstrand's (1970) time-space framework.

The sixth element, individuals assign a utility to each of their travel alternatives, and take the choice associated with the maximum utility is the prime assumption of the behavioural utility approach to accessibility. (Koenig, 1980) The utility of a place is a trade-off between the benefits of using the opportunity at that place and the cost in travelling to that place. The accessibility of a place is the "...expected value represent(ing) the average benefit derived from a trip by (an) individual...and it takes into account both the desirability of destinations and the trip cost or time required to reach them." (Koenig, 1980, p. 149)

Figure 7 illustrates the six key elements of accessibility definitions grouped according to their connection, supply, or demand emphasis. Connection definitions are the most common interpretation of accessibility, whereas supply and demand definitions have less support in the literature.

Figure 7: Elements of Various Definitions of Accessibility



3.2.2.4 Spatial Dimension of the Concept of Accessibility

There are two aspects to the spatial dimension of accessibility. The first is the effect of space/distance on the pattern of human activity, and the second is the spatial

expression of accessibility shaped by non-geographic variables. These two aspects are explained by Khan (1992, p. 276).

“Spatial access is that which is specifically conditioned by the spatial/distance variable (as a barrier or a facilitator) where the pattern it generates has the most direct geographic manifestation. In contrast, aspatial access or social access of individuals or communities is that which is conditioned by non-geographic barriers or facilitators, but may also have a geographic expression, thus revealing a spatial pattern of (social) access.”

The first aspect of the spatial dimension of accessibility, the effect of space/distance on the pattern of human activity, is captured in the connection definition of accessibility (Section 3.2.2.3, page 37). The connection definition considers the effort (time, cost, distance, etc.) required to traverse a travel path which is the relative accessibility between two points. It also includes the ‘spatial relation or interconnection between one location and others’ or the integral accessibility at a point.

Joseph and Phillips (1984, p. 116) elaborate upon the second aspect of the spatial dimension of accessibility, namely the spatial expression of accessibility which is shaped by non-geographic variables.

“Numerous non-geographical determinants of health services utilization behaviour such as social class, although it should be emphasized that these variables are ‘non-geographic’ only insofar as they can occur in almost any location. In aggregate, however, they often display regular and marked spatial variations... Therefore, even these apparently aspatial characteristics may, in their distribution, acquire important geographical influence.”

The second aspect, the spatial expression of accessibility shaped by non-geographic variables, can be influenced by:

1) Demand:

Characteristics of individuals who constitute the demand for opportunities, travel routes and transport modes:

- economic (Bailey and Phillips, 1990; Joseph and Phillips, 1984)
- legal/institutional (Hagerstrand, 1974)
- modal (Isard, 1956)
- social/demographic/cultural (Bailey and Phillips, 1990; Joseph and Phillips, 1984; Knox, 1978)

2) Supply:

Presence and characteristics of opportunities, travel routes and transport modes:

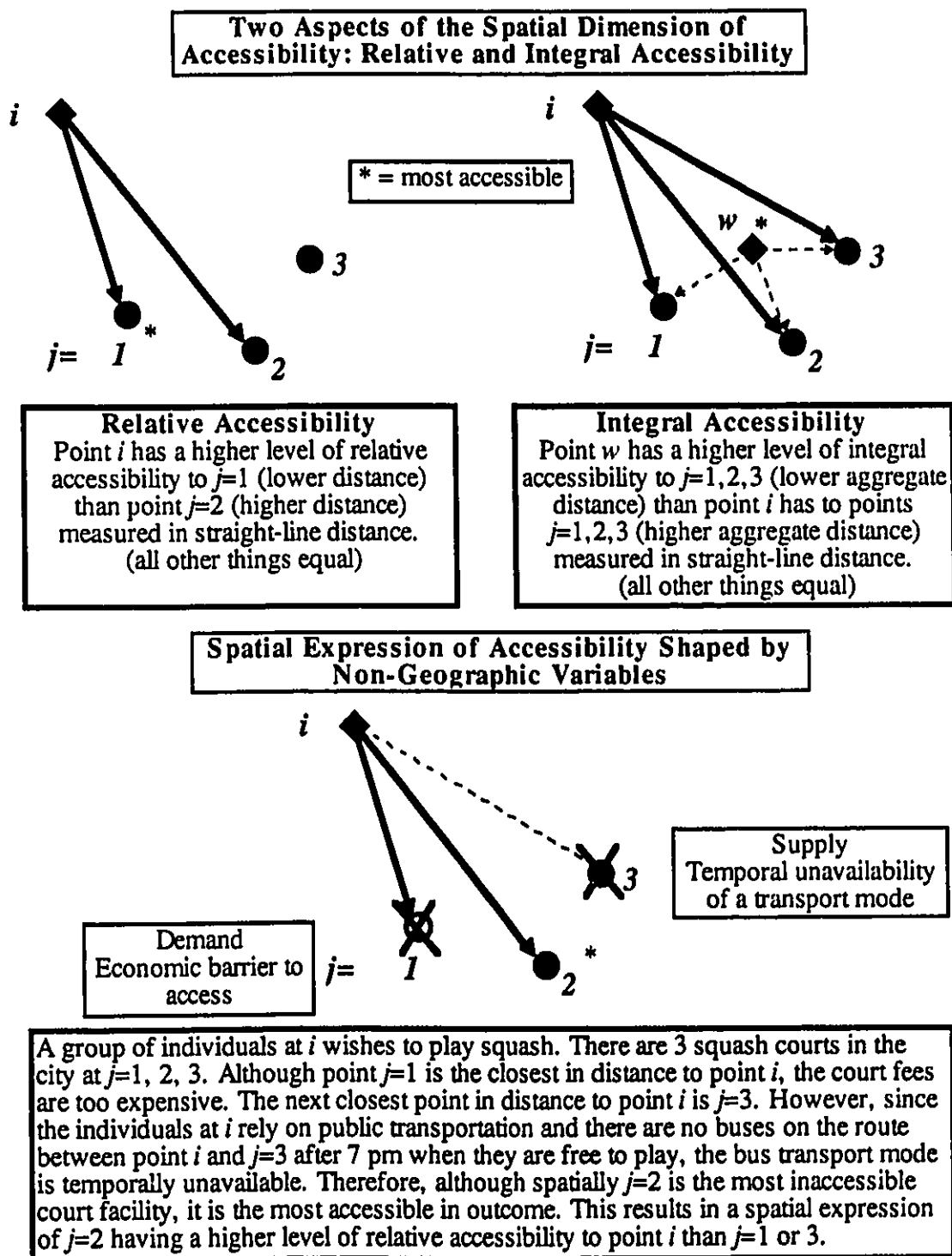
a) presence of opportunities, travel routes and transport modes:

- physical
- temporal

b) attractiveness of opportunities

A comparison between the spatial dimension of accessibility and the spatial expression of accessibility shaped by non-geographic variables is given in Figure 8.

Figure 8: Comparison between the Spatial Dimension of Accessibility and the Spatial Expression of Accessibility Shaped by Non-Geographic Variables.



3.2.2.5 Definitions of Accessibility Adopted in this Thesis

Two definitions of accessibility, from among those presented above are adopted in this thesis. The first definition is that cited by Vickerman (1974, p. 676):

“...a combination of two elements: location on a surface relative to suitable destinations, and the characteristics of the transportation network or networks linking points on that surface.”

This definition incorporates both elements of the connection-type definition outlined in Table 5, specifically, the ‘characteristics of the transportation network’ and the ‘spatial relation between one location and others or the degree of connection between that location and all others in a region’.

This ‘connection’ aspect represents the main spatial dimension of the concept of accessibility which looks at the effort (distance, time, or cost) required to traverse a travel route, and the spatial relation between one location and all others in a region.

The second definition of accessibility chosen to guide this study is that of Stone (1973, p. 253):

“Accessibility can be defined in two ways. First, it is the cost, time taken, comfort and convenience of making a journey, usually from the home to a particular facility, which depend on the mode of transport and its relationship with the origin and destination of the journey. Secondly it can be defined in terms of the opportunity to use facilities after journeys of various lengths.”

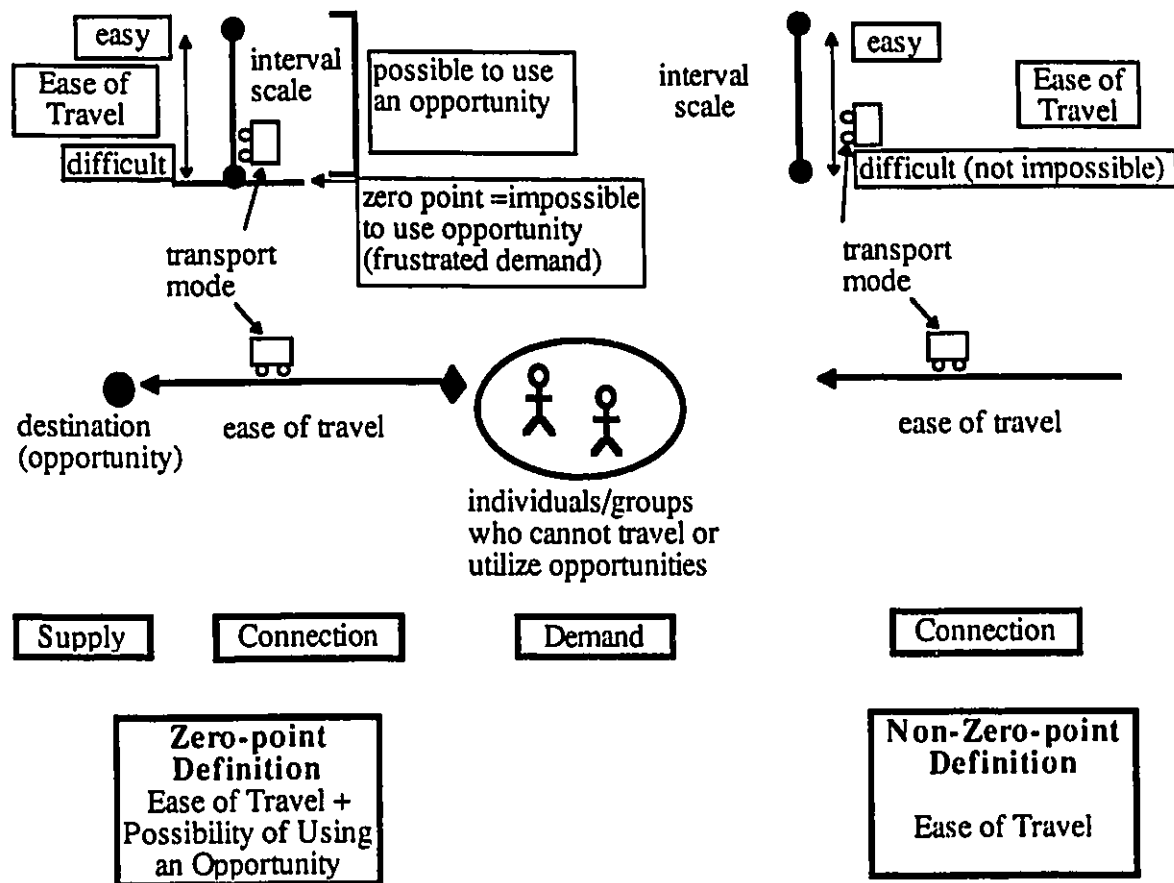
This version represents a comprehensive definition which takes into consideration both the supply (of opportunities, travel routes, and transport modes) and connection (cost, time, comfort, and convenience) aspects of accessibility.

3.2.2.6 Ease of Travel Versus Possibility of Using an Opportunity

The definitions of *accessible* that were encountered in the literature show a divergence of thought in which some writers-researchers view *accessible* as the **ease of travel**, and others explain it as the **possibility of using an opportunity**. This dichotomy in the definition of *accessible* is also apparent in the definition of *accessibility* as discussed by Joseph and Phillips (1984). In their comment on the topic they refer to accessibility as the **ease of travel and the possibility of using an opportunity** on the one hand, and **ease of travel** on the other.

The possibility of using an opportunity is a binary condition in which an opportunity may be possible or impossible to actually use. If the possibility/impossibility of using an opportunity is considered when measuring accessibility, then the measurement scale would need to include a zero-point representing the impossibility of certain individual(s) and group(s) to use an opportunity. Values above this zero point represent the possibility of using an opportunity, and increment according to the ease of travel as illustrated in Figure 9.

Figure 9: Zero-Point Versus Non-Zero Point Measurement of Accessibility



As shown in Figure 9, the zero-point definition of accessibility has a zero point which represents those individuals/groups for which utilization of an opportunity is impossible (frustrated demand). It can be due to an unavailability of and/or barriers to access to opportunities, travel routes, and/or transport modes. For those individuals/groups for which utilization of an opportunity is possible, the ease of travel from the origin to destination can be measured on an interval scale ranging from easy to difficult. The zero point definition thus takes into account the following aspects of accessibility:

- a) **supply** (opportunities needed/desired by individuals);
- b) **demand** (from individuals for travel and opportunities); and,
- c) **connection** (or ease of travel between origin and destination)

The non-zero-point definition illustrated in Figure 9, on the other hand, simply examines the ease of travel and measures the ease on an interval scale ranging from easy to difficult ignoring the demand for travel and opportunities and the supply of opportunities. Thus, the non-zero-point definition represents the connection aspect of accessibility.

On the other hand, ease of travel does not incorporate those individuals/groups who do not/cannot travel. Instead, ease of travel focusses on the travel component and only measures the degree of effort (measured in distance, time, or cost) of a trip. Hence, it is measured on a non-zero point scale with respect to the total population of individuals who need/desire to use a particular opportunity.

The 'zero-point' measurement of accessibility, which incorporates the ease of travel and the possibility/impossibility of using an opportunity is recognized by Joseph and Phillips (1984, p. 53): "*Effective accessibility* concerns whether a facility is always available or open, whether it is socially or financially available to people and whether a person's time-space budget permits him to use the service." (Note: according to the definitional scheme in this thesis, 'socially or financially *available*' would be replaced in the preceding quote with the phrase 'social or financial *access*').

In contrast, the term *locational accessibility* which "...represent(s) physical proximity...crudely expressed in mileage terms." (Joseph and Phillips, 1984, p. 53), matches the non-zero point definition of accessibility or the ease of travel.

Ease of Travel

If *accessibility* is envisioned on a scale which does not have a 'zero point', then a destination must fulfill the requirements of being *accessible* before the ease of travel can be considered. Joseph and Phillips (1984, p. 52) support this argument. "The supply of a service is a pre-requisite for accessibility. Unless services are *available* there can be no consideration of the factors, geographical or otherwise." The requirements for an opportunity to be *accessible* are:

- a) availability of opportunity;
- b) access to opportunity;
- c) availability of a travel route;
- d) access to travel route;
- e) availability of a transport mode; and,
- f) access to transport mode.

Once these pre-requisites are fulfilled, ease of travel can be measured.

A drawback of using the 'non-zero point' measurement (or, ease of travel) is that groups in society which lack and/or lack access to transport modes, travel routes, and opportunities are not included in accessibility measurements. Moseley (1979, p. 54) addresses this issue. "The whole essence of the 'rural transport problem' is that many strongly felt desires for transport are frustrated...Often it is the non-users who are the principal sufferers of accessibility-related problems."

This is not to say that ease of travel is not an important consideration. To the contrary, ease of travel represents the connection aspect of accessibility, which is the main spatial dimension of accessibility.

Possibility of Using an Opportunity and the Ease of Travel

The 'zero-point' scale for measuring accessibility considers the possibility or impossibility of using an opportunity. Individuals/groups who need/desire to use an opportunity, but who cannot, are **directly** incorporated into the accessibility measurement. Thus, the six pre-requisites listed for the 'non-zero point' definition can be directly included in the accessibility measurement along with ease of travel.

Considering the possibility/impossibility of using an opportunity along with the ease of travel takes a broader view of accessibility than (by) solely examining the ease of travel. The zero-point scale includes the supply-aspect (availability of opportunities, travel routes, and transport modes) and demand-aspect (access to opportunities, travel routes, and transport modes) of accessibility along with the connection-aspect (ease of travel).

Overview of the Possibility of Using an Opportunity versus the Ease of Travel

The distinction between the possibility of using an opportunity and the ease of travel (definitions of accessibility) appears to depend on the application for accessibility measurement. For example, if the purpose is to identify "glaring deficiencies in the transport system" (Morris, Dumble and Wigan, 1979, p. 95) then measuring the connectivity of the transport network or the ease of travel, ignoring the destinations for travel, may be justified. Also, in instances where the requirements for an opportunity to be accessible are automatically fulfilled, then examining only the 'ease of travel' is justified. For example in routing applications where a courier has availability and access to a transport mode and simply makes deliveries as opposed to using an opportunity at the destination of the trip, the route strategy or 'ease of travel' is the single concern.

However, in making location and transportation network decisions which will impact upon a broad spectrum of individuals who seek needed activities and services, a broader view of accessibility than just the ease of travel may be taken into account. Morris, Dumble, and Wigan (1979, p. 95) comment:

"Accessibility to transport or to opportunities? Since most travel is a means to an end, an accessibility measure which reflects the distribution of activities within the city is preferable to a measure which simply describes the ease of traversing a space via a given transport system."

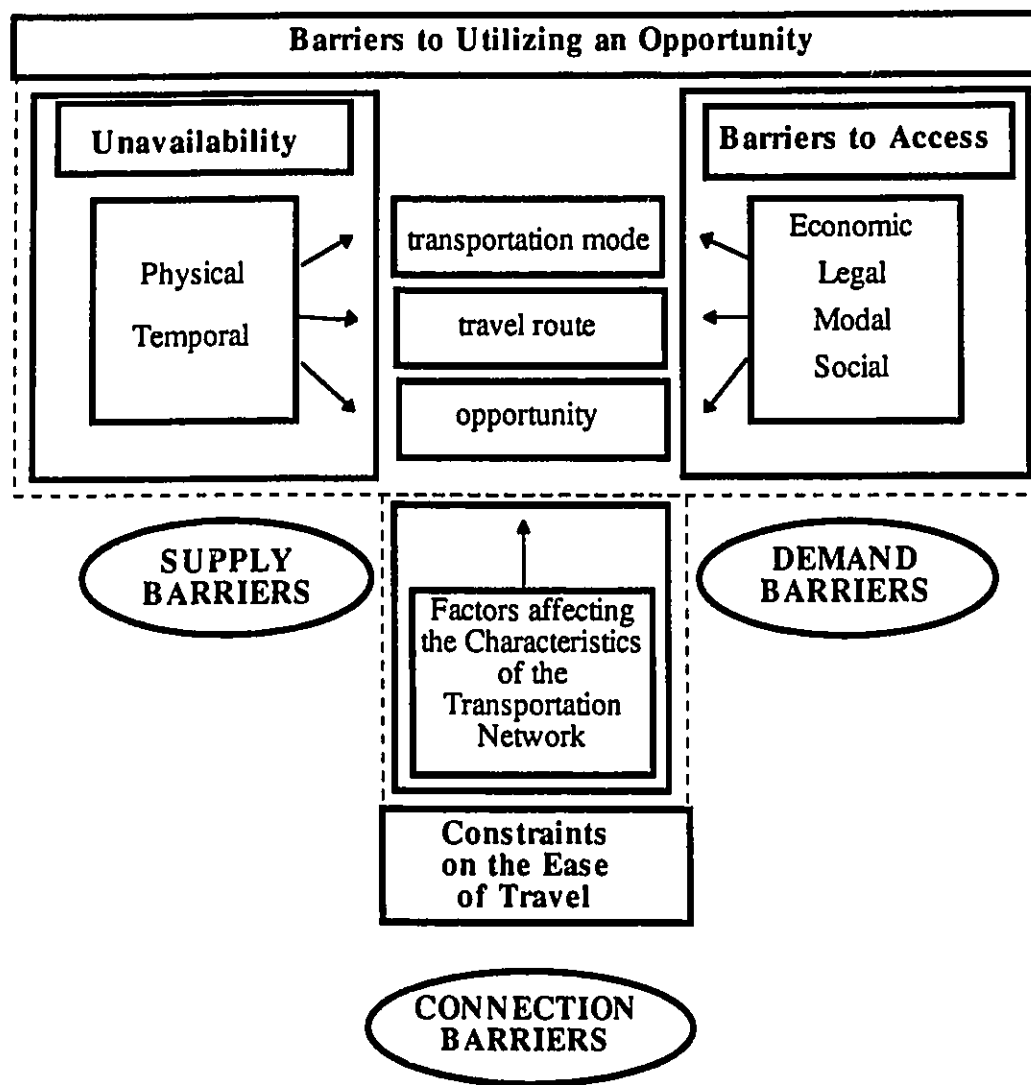
Decisions relating to public facilities and transportation network infrastructure, which are planned in such a manner to serve the public equitably, might adopt this broader view of accessibility.

3.2.3 Barriers to Accessibility

Similar to the supply, demand, and connection components of the definition of accessibility, there is a parallel structure within barriers to accessibility. Figure 10

illustrates these supply, demand, and connection components of barriers to accessibility.

Figure 10: Barriers to Accessibility



Supply barriers are restraints, constraints or other features that limit or restrict accessibility because opportunities, travel routes, or transport modes are unavailable. That is, they can be unavailable in a temporal sense (no buses after midnight), or in an absolute or physical sense (absence of a grocery store in a village).

Demand barriers are those which occur due to a characteristic of an individual or group(s) of individual(s). The characteristic, which can be economic, legal/institutional, modal, and/or social/ demographic/cultural in nature, prevents the individual or group(s) from utilizing a transport mode, travel route, or opportunity. An example of a demand barrier of the economic type is the

inability of an individual to pay for entrance to an opportunity such as a hockey game.

Connection barriers, unlike availability and barriers to access, do not prevent the utilization of an opportunity, but merely constrain the ease of travel. These barriers can increase the effort (time, cost, or distance) and decrease the convenience, comfort, reliability, safety, speed, and level of service of the trip/travel route. Examples of connection barriers are traffic congestion and multiple transfer points on a public transit journey.

3.2.4 Availability

The Concise Oxford Dictionary (Sykes, 1976, p. 64) defines *availability* as "...capable of being used; at one's disposal; within one's reach." Availability can apply to the provision of:

- a) an **opportunity** (Kissling, 1967; Pred, 1973; Joseph and Phillips, 1984) (e.g. 1 library per municipality);
- b) a **travel route** connecting two points directly or indirectly (de Souza, 1990) (e.g. presence of a road or bike path); or,
- c) a **transport mode** (Ruijgrok and Meijher, 1979) (e.g. car or public transport is available).

The terms availability and accessibility are not synonymous. Availability tends to be used to deal with the supply conditions (as illustrated in Figure 7 and Figure 10). Availability has a spatial dimension in the sense that the supply of an opportunity, travel route, or transport mode can be measured for a particular geographic area or administrative unit. That is, it is present or it is absent.

3.2.4.1 Availability of Opportunities

Four main techniques can be used to measure the spatial availability of opportunities. All of these techniques take the form of a ratio of **supply of opportunities to demand for opportunities**. The following examples which illustrate each technique are taken from the health care industry:

- 1) *Population per opportunity ratio* (Anderson and Rosenberg, 1990) (e.g. 1 physician/750 people);
- 2) *Comparison to an absolute standard* (Anderson and Rosenberg, 1990) (e.g. 1 physician/700 people);
- 3) *Location quotient* (Anderson and Rosenberg, 1990); and, Anderson and Rosenberg (1990, p. 40) give an example showing how to calculate a location quotient.

$$LQ_i' = (GP_i' / P_i') / (\sum_i GP_i' / \sum_i P_i') \quad (1)$$

where:

LQ'_i = location quotient for region i at time t

GP'_i = # of general practitioners in region i at time t

P'_i = population of region i at time t

A location quotient >1 means that a region has its 'fair' share of general practitioners relative to its share of the population.

4) Coefficient of localization (Joseph, 1982)

The coefficient of localization is a type of gini coefficient which measures the regional concentration of opportunities relative to that base magnitude. (Lloyd and Dicken, 1968)

$$CL' = \frac{1}{2} \sum_i \left| \frac{GP'_i}{\sum_i GP'_i} - \frac{P'_i}{\sum_i P'_i} \right| \quad (2)$$

where:

CL' = coefficient of localization at time t

GP'_i = general practitioners in region i at time t

P'_i = population of region i at time t

A coefficient value of 0.0 indicates general practitioners are distributed across regions in exactly the same proportions as population. Values between 0 and 1 reflect increasing concentration of opportunities in certain areas. (Joseph and Phillips, 1984, p. 98)

The spatial dimension of availability of opportunities is important as it contributes to the spatial dimension of accessibility. This topic is addressed in more detail in Chapter 5.

3.2.4.2 Availability of Travel Routes

The availability (or supply) of travel routes can also be measured for a particular geographic area. *Network density* is calculated as the "total number of route miles or kilometers per unit area." (de Souza, 1990, p. 143)(e.g. 302 km of roads/100 km²)

The availability of travel routes is important since the supply of travel routes can affect the level of accessibility. For example,

"...the greatest concentration of surface transportation facilities appears in Western Europe, the United States and Southern Canada, Japan and in western parts of the USSR. In these regions, road and rail densities are so high that virtually no place is inaccessible." (de Souza, 1990, p. 146)

The type of travel route investigated must be matched with the appropriate mode of transport. For example, if a highway network is examined the likely modes of

concern are the motorcycle, car, truck and bus modes, and not the walk and bicycle modes.

3.2.4.3 Availability of Transport Modes

In addition to measuring the availability of opportunities and travel routes, spatial availability to a transport mode can also be assessed as the number users of a particular mode per unit area. Ruijgrok and Meijher (1979, p. 76) describe the difficulty in developing an availability measure.

“Car availability implies the possibility of uses of a car for a trip. It is a necessary condition for car usage. Car availability is not identical with car ownership; the use of a car by one person precludes its use by someone else at the same time, and from another angle, not owning a car does not rule out the possibility of borrowing one. Moreover, car availability is not the same as car usage. One can have a car available for a trip and yet use another mode of transport. Furthermore it is possible to distinguish car availability for drivers and for passengers.”

A technique for measuring the accessibility to public transportation is given by Morris, Dumble and Wigan (1979, p. 93):

$$A_i = \sum_{(y)i=1}^n \frac{\sqrt{N_{(y)i}}}{\sqrt{P_i}} \quad (3)$$

where:

$N_{(y)i}$ = frequency of public transportation services y , serving zone i

P_i = physical area of zone i (in square metres)

n = number of public transportation services, y , serving zone i

Benwell and White (1979) define 7 types of car availability on the basis of activity type and their periods of availability during a survey week. These are: weekday shopping; Saturday shopping; work/college/school; weekday daytime social/recreational; weekend daytime social/recreational; evenings, social/recreational; and, overall car availability, combining the 3 social/recreational ‘types’. These 7 types of car availability are then compared to the percentage of respondents who are a: driver always; driver sometimes; passenger always; passenger sometimes; and, ‘carless’ individual (a car is never available, as a driver or a passenger).

The availability of a transport mode and in particular the type of mode is important as it influences the level of accessibility. “The mode of transport available to individuals is a particularly vital element in calculating accessibility.” (Morris, Dumble and Wigan, 1979, p. 95). Hanson and Schwab (1988, p. 743) note that “people with many opportunities close to home make a higher proportion of their stops with non-motorized modes (on foot or by bicycle). Non-motorized modes are also more likely to be used on a journey to work by individuals having

higher work-based accessibility. Especially for those with cars, higher accessibility levels are also associated with lower levels of automobile use."

3.2.4.4 Availability Versus Accessibility

Kissling (1967, p. 15) differentiates between the terms *availability* and *accessibility*. "...*Accessibility* has a different connotation from a closely related word, namely *availability*. Goods and services may be *available* at a given location but not *accessible* to one another." That is, an opportunity (offering goods and services) may be available but a travel route or transport may not be available to reach the goods and services and/or there may not be a barrier to access to the opportunity, travel route or transport mode.

Black and Conroy (1977, p. 1017) also draw a distinction between the two terms.

"Physical *accessibility* is a useful measure that combines the location of activities and transport system services into one index that describes the urban spatial structure...However, if the main purpose is to measure residents' *accessibility* we need to distinguish the transport modes *available* to residents. This is because private transport usually gives a much better level of service to the user than does public transport... Measures of physical *accessibility* for any selected residential zone can be weighted by transport *availability* in that area."

Studies conducted by Black and Conroy (1977) and Pacione (1989) follow that the use of considering the terms jointly by incorporating transport mode availability into accessibility measurement techniques.

In view of the discussion in Chapter 1 about differences of opinion in this field, however, it comes as no surprise that the term *availability* is often used interchangeably with the term *accessibility*. For example, Black, Kuranami and Rimmer (1982) consider a calculation of facilities per capita (population per opportunity ratio, see Section 3.2.4.1) to be a measurement of *accessibility*. Similarly, Anderson and Rosenberg (1990) in studying the distribution of physicians state that a location quotient (see Section 3.2.4.1) is a measurement of *accessibility* to health care services.

These two examples might be considered to be supply-demand type accessibility measurements or spatial availability measurements in that they are simply ratios of supply to demand for an opportunity in a certain geographic area. They do not incorporate the connection aspect of accessibility, specifically the characteristics of the transportation network (Vickerman, 1974).

3.2.5 Unavailability

Burns (1979, p. 1) notes that "...different activities are not *available* at all times and at all locations." Thus, availability/unavailability can be categorized as:

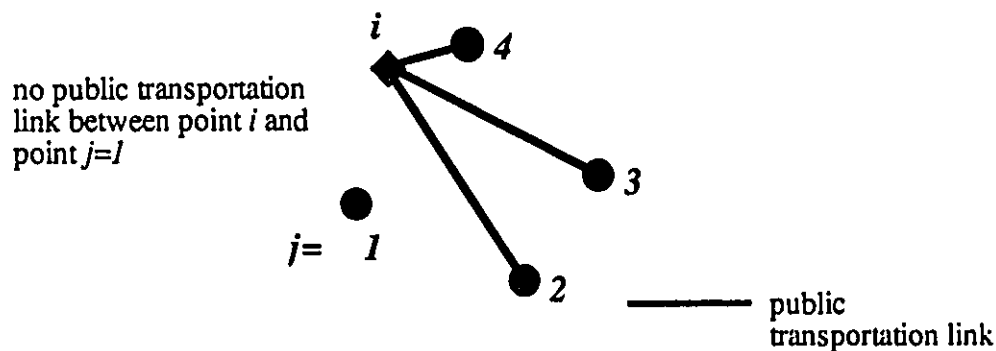
- a) physical (Joseph and Phillips, 1984) and,

b) temporal (Burns, 1979).

Physical

The *physical* dimension of availability/unavailability deals with the supply (or absence) of an opportunity, travel route or transport mode. For instance in a specified geographic area there may not be a public swimming pool, a road may not exist, or public transport is not supplied. An example of physical unavailability to a transport mode is given in Figure 11.

Figure 11: Availability/Unavailability (Physical Unavailability of a Transport Mode)



Temporal

The *temporal* dimension of availability/unavailability pertains to opportunities, travel routes and transport modes which are obtainable at certain times and not at others. For example, many shops and businesses are open Monday to Friday 9am-5pm, but not at 3am. In the case of travel routes, an example is 'ice roads' in Northern Canada which are only in existence during the winter months. Finally, there is also temporal variation in the availability of transport modes, for instance, public transit may not operate at night.

3.2.6 Access

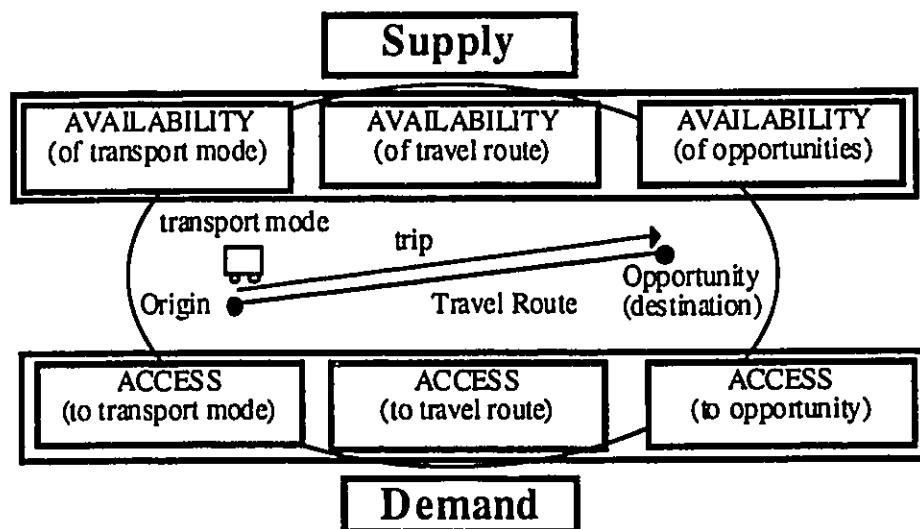
The Concise Oxford Dictionary (Sykes, 1976, p. 6) defines *access* as the "...right or means of approaching or reaching." Although the topic of *barriers to access* is frequently addressed in the literature, the specific definition for *access* is not. Combining the dictionary definition with that of 'barriers to access' yields the following definition: *access* is the ability for certain groups and individuals to gain the right to use:

- 1) an opportunity (e.g. 19 years old, attained the right to consume alcohol in a bar);

- 2) a travel route (e.g. limited access highway, no trucks); and/or,
- 3) a particular mode of transport (e.g. hold a driver's license).

Clearly, access is not inherently a spatial term. Figure 12 schematically illustrates the terms *access* and *availability* as they relate to opportunities, travel routes and modes of transport. Unlike *availability* which pertains to *supply* conditions, *access* deals with the individual or *demand* characteristics related to transport modes, travel routes and opportunities.

Figure 12: Schematic Diagram Illustrating the Differences between Terms Access and Availability



The availability or supply of an opportunity, travel route or mode of transport is a pre-requisite for the issue of *access*. *Access* holds a *gatekeeper* role determining who does and who does not gain entry to an opportunity, travel route or mode of transport.

3.2.6.1 Access Versus Accessibility

The term *access* is also confused with the term *accessibility*. Joseph and Phillips (1984, p. 2) use the term *socio-economic accessibility* to characterize what has in this thesis been termed *socio-economic access*. "*Socio-economic accessibility* involves people's ability to pay for a service, whether they feel its appropriate...or whether they are permitted to use it (organizational and institutional restrictions on accessibility)" The problem with defining accessibility in this way, however, is that it ignores the connection aspect of accessibility, specifically the characteristics of the transportation network (Vickerman, 1974). Instead, it represents the demand aspect of accessibility illustrated in Figure 12, and hence it ignores the supply aspect specifically the availability of opportunities, travel routes, and transport

modes. It also fails to address the connection aspect (ease of travel) which is the main spatial dimension of accessibility.

3.2.7 Barriers to Access

A barrier to access is a filter or selective criterion which prevents certain groups and individuals from using an opportunity, travel route, or transport mode. Returning to the health care industry for illustrative purposes, Khan's observation (1992, p. 275-276) that "utilization of services or the actual entry into the system, is dependent on barriers and facilitators that reflect dimensions of both the service system and the potential users" is instructive. That is, and drawing on that industry as an analogy, the main barriers to access in terms of location and transportation network decisions can be categorized as:

- a) **Economic:** inability to pay for entrance to an opportunity (Bailey and Phillips, 1990; Joseph and Phillips, 1984). An example is the inability to pay for a ticket to travel to a place of potential employment.
- b) **Legal/institutional:** legislation or institutional restrictions which prevent the use of an opportunity (Hagerstrand, 1974). An example of a legal barrier to access is that persons under the age of 16 are not allowed to (legally) drive a car in Ontario. An institutional barrier exists where different private bus operators providing commuter services in a metropolitan area may not have a fare-sharing agreement which results in a barrier to 'easy' travel within that area.
- c) **Modal:** mode of transport prevents the use of an opportunity (Isard, 1956). For instance, a car cannot traverse water bodies, whereas a boat can. The term 'modal barrier to access' is used in place of 'physical barrier to access' because a physical barrier is relative only to the mode of transport. Isard (1956, p. 12) notes that "...physical features, however, have crucial value as barriers only with respect to a given or assumed state of technology, and in particular of transport technology."
- d) **Social/demographic/cultural:** restrictions that are not legalized/institutionalized can prohibit the use of an opportunity (Bailey and Phillips, 1990; Joseph and Phillips, 1984; Knox, 1978). An example of these types of restrictions are that due to age, sex, cultural, and religious prejudices, some groups in society are less likely to use certain facilities.

Hagerstrand's (1970) space-time representation of human activity, summarized by Pred (1973) includes *authority constraints*. Authority constraints "...spring from the basic characteristics of 'domains'. A domain is defined as a time-space entity within which things and events are under the control of a given individual or a given group...Domains are either not accessible at all or are accessible only upon invitation or after some kind of payment, ceremony, or struggle." (Pred, 1973, p. 42) These authority constraints are similar to grouping together

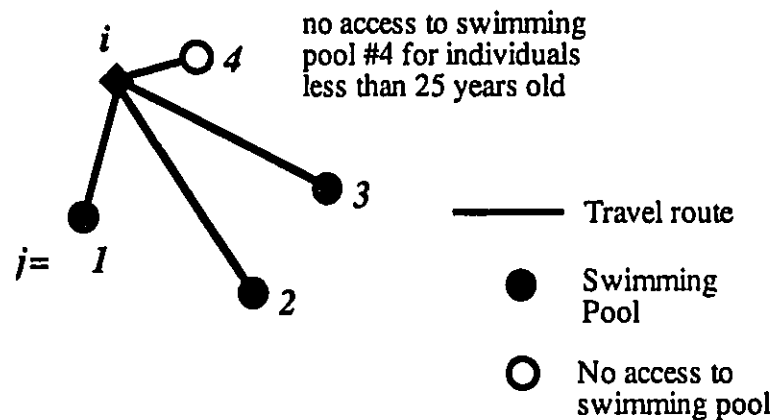
- a) economic,

- b) legal/institutional, and,
- c) social/demographic/cultural

categories of barriers to access.

An example illustrating a demographic barrier to access to an opportunity is given in Figure 13.

Figure 13: Access/Barrier to Access (Demographic Barrier to Access to an Opportunity)



3.2.7.1 Barriers to Access Versus Accessibility

Richardson and Young (1982, p. 74) use the expression *legal accessibility* to represent *legal barriers to access* described previously. "...Two sites may be spatially, modally and temporally accessible yet still be *inaccessible* because of *legal* restrictions." Hagerstrand (1974 in Moseley, 1979, p. 57) uses the term *legal/social accessibility* to describe *legal* and *social barriers to access*. "Accessibility has at least 2 sides. One is *legal/social*. Frequently an individual must fulfill certain requirements in terms of training, age, ability to pay, support from others in order to pass the *barrier* around a supply point he wants to reach." Richardson and Young (1982, p. 74), substitute the expression *modal barriers to access*, with *modal accessibility* "...Two points in space may be *accessible* by car but may not be accessible by public transport."

3.2.8 Convenience

The term and concept of *convenience* is mentioned in several literatures, which poses a problem. That is, in the planning literature, convenience is regarded as a planning principle (Chapin and Kaiser, 1979). However, what convenience means in planning practice, in operational terms, is not officially set forth in the literature encountered for this study.

Within the transportation literature, convenience has been considered by a number of researchers. Stone (1971, p. 105-106) defines *convenience* as a function of the travel path.

“Perhaps the most telling measurement of a transport system’s convenience is a hard, cold winter rain: any gaps in what should be a comprehensive service become brutally apparent...Our primary convenience requirement is to be picked up close to our departure point and dropped off close to our destination point. Second, we desire this with a minimum of inconvenience: the least possible exposure to inclement weather; the least possible discomfort and confusion caused by necessary transfers.”

In Table 6, Watson uses a ‘journey unit variable’ to indicate the convenience of travel by two different modes. The ‘journey unit variable’ represents the “amount of difficulty associated with making a given journey by each mode...A unit is assigned to each stage of the trip and the resulting total of the units represents the difficulty of making the trip.” (Watson, 1974, p. 59) Table 6 shows that the car journey is more convenient than the train journey.

Table 6: Convenience: a Journey Unit Variable

Car Journey		Train Journey	
Stage of Trip	Amount of Difficulty	Stage of Trip	Amount of Difficulty
Walk to car	1 unit	Walk to bus	1 unit
Drive	1 unit	Wait for bus	1 unit
Park	1 unit	Travel on bus	1 unit
Walk to destination	1 unit	Walk to train	1 unit
		Wait for train	1 unit
		Travel on train	1 unit
		Walk to destination	1 unit
Total	4 units	Total	7 units

Source: Adapted from Watson (1974, p. 59)

Watson notes that other features of inconvenience such as children and luggage can be built into the variable. “At present, not enough is known about the opinions of travellers on the relative effects of children, luggage, etc. on the inconvenience of a journey for such detailed adjustments to be made.” (Watson, 1974, p. 60)

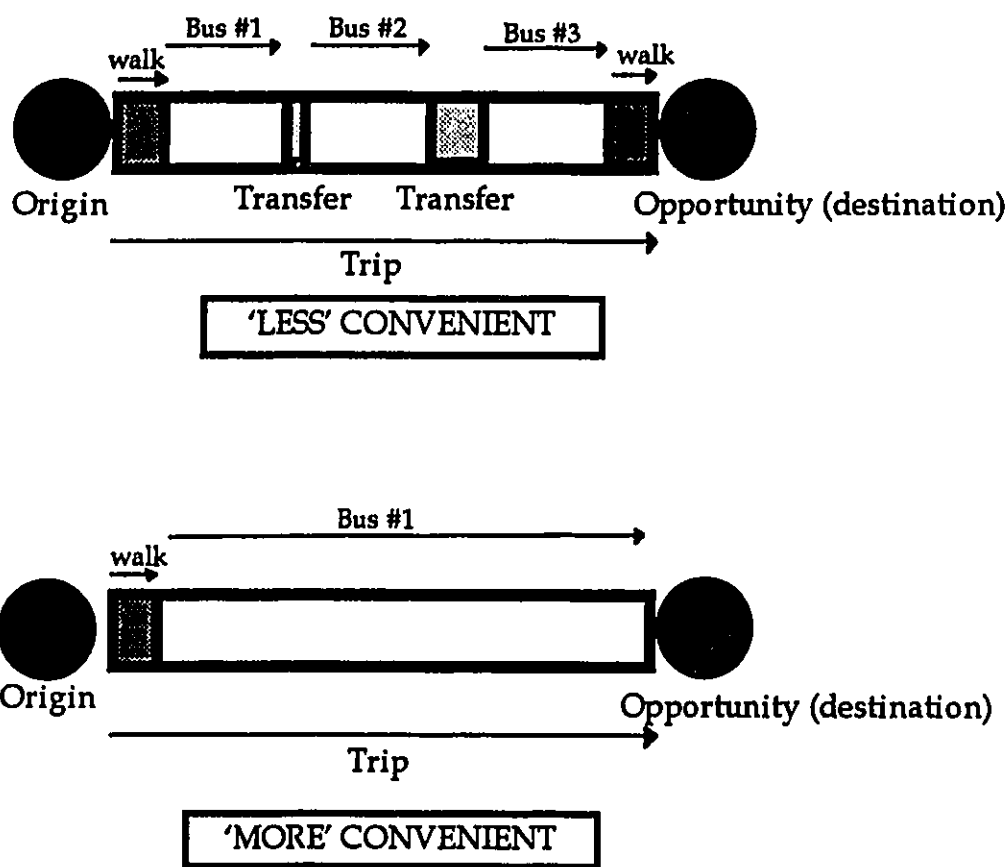
From these two definitions it is interpreted that *convenience* is a characteristic of the travel route, and encompasses:

- a) the need to change transport modes or vehicles; and,
- b) the amount of effort (distance, time or cost, etc.) involved in changing transport modes or vehicles, including walking from the origin to the

line-haul transport mode (car, bus, subway, etc.) and walking from the line-haul transport mode to the opportunity (destination).

A comparison of a 'less' convenient trip to a 'more' convenient trip is illustrated in Figure 14. Both trips include a walk to a bus at the beginning of the trip; however, the 'less' convenient scenario has two transfers mid-point in the trip, and a walk at the end of the trip.

Figure 14: Comparison of a *Less* Convenient to a *More* Convenient Trip



*Note: Shaded areas indicate inconvenience (measured in travel time)

Finally, and as might be anticipated, it may be said that *convenience* is another term which is either interchanged with *accessibility* and *accessible*, or is used to 'explain' them. Ghosh and McLafferty (1987, p. 17), in the following description, imply that the term *convenient* is synonymous with the term *accessible*.

"*Accessibility* and time taken to reach the store are two of the most important determinants of store patronage: consumers evaluate location and *convenience* in relation to their own 'time-space constraints' which define the limits (in both time and space) of daily travel. Locations such as the home and workplace serve as major

nodes around which consumer travel patterns are oriented. Stores accessible to these nodes are more *convenient* to consumers."

3.2.9 Mobility

Bannister (1983, p. 130) defines *mobility* as "...the ability of an individual to move about." Hensher provides a similar definition (1979, p. 120) "Mobility as a concept refers to the ease with which a person can move about or the amount of movement he performs. Empirical definitions of mobility invariably use the amount of travel undertaken rather than the potential for travel."

Morris, Dumble and Wigan (1979, p. 92) extend the discussion of mobility and connect it to accessibility or related concepts:

"Personal *mobility* is interpreted to mean the ability of individuals to move from place to place: this depends principally upon the availability of different modes of transportation including walking. When defined in this sense, mobility is conceptually distinct from actual travel; and the argument over *mobility* and *accessibility* as an objective in transportation planning is seen to be a futile exercise. *Mobility* and *accessibility* together influence an individual's capacity to travel in daily life."

Moseley (1979, p. 58), on the other hand, differentiates between the terms *mobility* and *accessibility* by using the opportunities aspect of accessibility to make the distinction:

"*Mobility*...depends upon such things as the person's physical attributes and disabilities, his monetary resources, the availability of mechanized means of transport and of appropriate infrastructure, but not upon the opportunities which may or may not present themselves as a result of his moving. *Accessibility* alone incorporates this latter feature. A related point is that increasing mobility alone need contribute little to a person's quality of life, since travel is rarely an end in itself. But improving accessibility to employment opportunities, to medical care...is much more closely linked to the quality of life as it is normally understood..."

As for the measurement of mobility, *trip generation rate* is the most common procedure (Popper and Hoel, 1976). The *trip generation rate* is "...the number of trips arising in unit time, usually for a specified land use." (Hobbs, 1979, p. 137) It can be estimated in three ways (Hobbs, 1979):

- 1) The most common method is by linear and multiple regression which correlates trips made and characteristics of an area (e.g. number of residents or employees, distance of zone from central area).
- 2) The second method also makes a correlation between trips and characteristics of an area. It is accomplished by first finding the trip

generation rate of a household (or car) which is assumed to be representative of a particular category (e.g. two-car family). Then, for a defined zone, the distribution of various categories (e.g. two-car family, one-car family) is multiplied by the appropriate category trip generation rate yielding a total trip generation rate for a zone.

- 3) The third method, unlike the first two, does not assume a correlation between trips made and the characteristics of an area. Instead, it determines trip generation rates for different categories of household and business (e.g. x vehicles/hour for a particular retail store).

In summary, the main difference between the concepts of *mobility* and *accessibility* is that *mobility* focusses on the availability of and access to travel routes and transport modes with little consideration of the destination of a trip. *Accessibility* as defined by Vickerman (1974, p. 676) acknowledges this destination aspect: "...location on a surface relative to suitable destinations".

3.2.10 Level of service (LOS)

Level of service (LOS) is a measure used frequently in the traffic engineering field to measure the ease of movement and is given mathematically by Polus and Kumove (1979, p. 435) as follows:

$$LOS_i = \frac{V_i}{C_i} \quad (4)$$

where:

V_i = volume or demand of traffic

C_i = capacity of transport link

i = link in system

LOS is illustrated in Figure 15 and is then discussed by referring to the literature. The Highway Capacity Manual (Highway Research Board, 1965, p. 5) defines level of service in more detail as:

"...a qualitative measure that incorporates the collective factors of speed, travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating costs provided by a highway facility under a particular volume condition."

Figure 15: Level-of-Service (LOS)

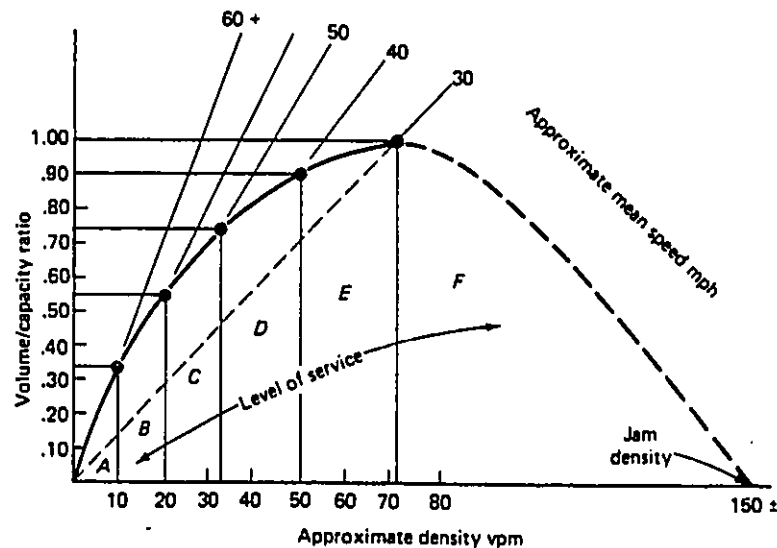


Figure 8.1. Conceptual relationship of levels of service to some measures of quality under uninterrupted flow conditions.

Source: Institute of Transportation Engineers (1982, p. 313)

The tendency of the traffic engineering field to regard level of service (LOS) in terms that focus on motorized vehicles and their operators, and exclude or ignore the values, attitudes and concerns of pedestrians and cyclists, has been sharply criticized (Wellar, 1994). A recently completed right-turn cut-off study that explored travel safety, comfort, and convenience from a pedestrian perspective includes a proposal to develop a walking security index (WSI) to counter the vehicular level of service measure (Wellar, 1995).

Moreover, and notwithstanding the popularity attached to LOS because of its (seeming) mathematical precision, the Institute of Transportation Engineers (1982, p. 472) admits that the practicalities of traffic measurement prevent making use of all the factors listed previously:

“In dealing with uninterrupted flow conditions, speed and volume have been the criteria most frequently cited because they are relatively simple to measure and understand. Density, however, is being increasingly used as a substitute for volume in certain applications because it...is the only variable other than speed over which the individual driver has functional control.”

To illustrate the sharp differences between what should be measured and what is measured for LOS, Table 7 compares the Highway Capacity Manual’s definition of level of service with the Institute of Transportation Engineers’ assessment of the factors used to calculate level of service in real-world settings.

Table 7: Defined Versus Real World Measurement of *Level of Service*

Ideal Level of Service Highway Capacity Manual (1965)	Real World Level of Service Institute of Transportation Engineers (1982)
Speed	Speed
Travel Time	Volume
Traffic Interruptions	Density
Freedom to Maneuver	
Safety	
Driving Comfort and Convenience	
Operating Cost	

As shown in Table 7, the Highway Capacity Manual's (Highway Research Board, 1965) definition of level-of-service which includes speed, travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating cost is more comprehensive than the factors (speed, volume, and density) given by the Institute of Transportation Engineers (1982). This comparison between ideal and real-world measurement of LOS suggests that the factors of travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating cost are difficult to measure operationally.

In principle, then, the Highway Capacity Manual's (Highway Research Board, 1965) definition of accessibility incorporates several factors associated with accessibility such as travel time (effort in making a trip), safety, driving comfort, and convenience. In practice, unfortunately, they do not tend to be included in the actual calculation of LOS in real world applications.

The Institute of Transportation Engineers' (1982) interpretation of accessibility on the other hand, only includes one factor—speed—which is considered by other authors as an element of accessibility. The emphasis on volume and density serves to measure the congestion on a roadway.

Several terms used to define level of service are related to terms presented earlier, however, so it is necessary to briefly refer to them for completeness.

Capacity is defined as the "...maximum number of vehicles that have a reasonable expectation of passing over a given roadway in a given time period under the prevailing roadway and traffic conditions." (Institute of Transportation Engineers, 1982, p. 471) Capacity (and volume) are usually measured in vehicle passenger units/hour.

Density, which is sometimes substituted for volume, is measured in vehicles/mile or vehicles km.

As indicated in Figure 15, LOS is categorized in levels from A to F. Level A provides the highest quality of service (operating speed is high and density is

low), and F, provides the lowest (operating speed is low and density is high, eventually reaching stoppages). (Institute of Transportation Engineers, 1982)

In the interest of completeness, it is necessary to define a (new) term that is used to define LOS.

Operating speed is "...the highest overall speed at which a driver can travel on a given roadway under favorable weather conditions and prevailing traffic conditions without at any time exceeding the safe speed as determined by the design speed." (Highway Research Board, 1965, p. 5) Operating speed is usually measured in units of kmh or mph.

Finally, and as with convenience and other terms, *level of service* is also interchanged or confused with the term *accessibility*. Bach (1981, p. 955) cautions that "the terms *accessibility* and access opportunity as well as related terms such as *level of service* demand a clear-cut definition by which each term is distinctively differentiated from the other terms. This becomes necessary because in planning theory and in planning practice these terms are often confused with each other."

3.2.11 Overview of Accessibility Terms and Concepts

An overview of accessibility terms and concepts is presented in Figure 16.

Supply facilitators and barriers refer to the physical and temporal availability/unavailability of opportunities, travel routes and/or transport modes.

Demand facilitators and barriers refer to the characteristics of individuals or groups of individuals which can be:

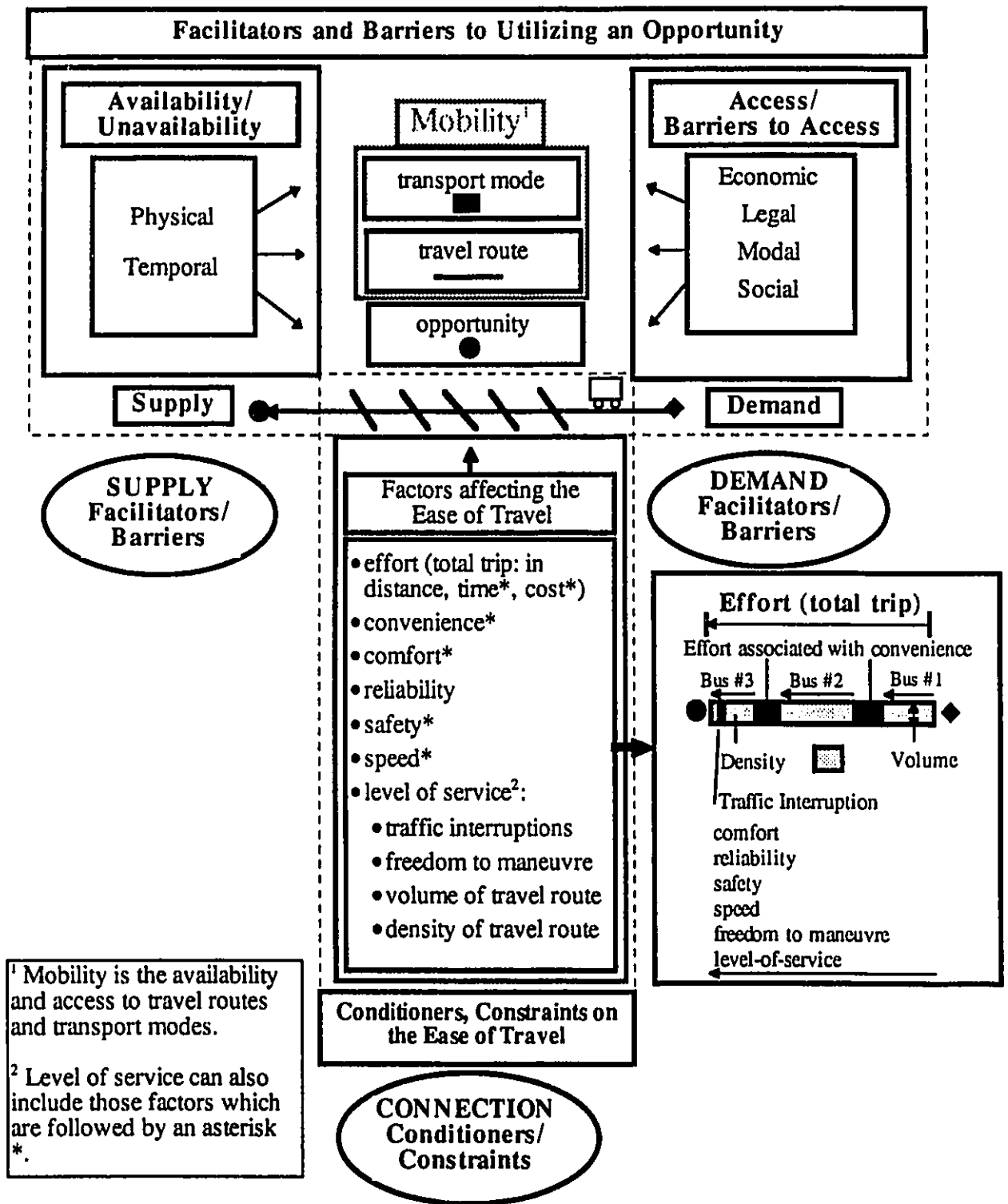
- economic,
- legal/institutional,
- modal, and/or,
- social/demographic/cultural

in nature which facilitate and/or prevent access to opportunities, travel routes and/or transport modes.

Connection conditioners and constraints increase or decrease the ease of travel or the effort in making a trip. Effort can be measured by the distance, time, and cost of a trip increase/decrease the effort, convenience, comfort, reliability, safety, speed, and level-of-service of the trip.

Mobility is interpreted in this thesis as meaning the availability and access to travel routes and transport modes.

Figure 16: Accessibility and Barriers to Accessibility



Convenience is defined as the need to and the effort associated in changing transport modes or vehicles.

Level-of-service is conceptualized as the speed, travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating cost. It is frequently operationalized as the volume of traffic divided by the capacity of a particular travel route segment.

3.3 Summary

This thesis examines the

Location: (siting of opportunities, that is, a point where there is an opportunity for spatial interaction),

Network: (location of travel routes (paths or lines between places) and the spatial characteristics of transportation networks) and,

Routing: (spatial strategy by which transport modes navigate transportation networks).

aspects of location and transportation network decisions. Thus the basic components of interest are:

- opportunities,
- travel routes, and,
- transport modes.

These components are discussed in the definitions of accessibility and related concepts. A literature search reveals a wide range in the meaning of accessibility and its associated terms:

- accessible,
- barriers (to accessibility),
- availability,
- unavailability,
- access, and
- barriers to access.

The key features of these terms in regard to the research objectives of the thesis are reviewed in depth in the following paragraphs.

Accessible

Two distinct definitions of *accessible* emerge:

- 1) *Accessible* is a binary condition. A place is either accessible or inaccessible, and the ease of travel is not a consideration.

- 2) *Accessible* is the ease of travel, where a place is considered accessible if it is easy to get to, and inaccessible if it is hard to get to.

Accessibility

The term and concept of *accessibility* has been defined in many different ways by a variety of authors. The 6 main elements of these authors' definitions are:

- 1) characteristics of the transportation network;
- 2) spatial relation or degree of connection between one location and others;
- 3) supply/availability of opportunities;
- 4) freedom of individuals to decide whether or not to participate in different activities;
- 5) attractiveness of opportunities; and,
- 6) individuals assign a utility to each of their travel alternatives, and take the choice associated with the maximum utility.

The 6 key elements of accessibility definitions can be recognized as *supply*, *demand*, or *connection* related:

- *Supply* definitions concentrate on the availability (presence) and attractiveness of opportunities.
- *Connection* definitions consider the transportation network connecting supply with demand.
- *Demand* definitions focus on the individual and the demand for travel and opportunities.

There are two aspects to the spatial dimension of the concept of accessibility that are especially pertinent:

- 1) the effect of *space/distance* on the pattern of human activity; and,
- 2) the spatial expression of accessibility shaped by *non-geographic variables*.

The definition of accessibility adopted in this thesis is given by Vickerman (1974, p. 676) who defines *accessibility* as:

"...a combination of two elements: location on a surface relative to suitable destinations, and the characteristics of transportation network or networks linking points on that surface."

This definition stresses the 'connection' aspect of accessibility. A more comprehensive definition by Stone (1973, p. 253) takes into consideration both the 'supply' and 'connection' aspects of accessibility, and is also adopted for the purposes of this inquiry.

Barriers to Accessibility

Following from the supply, demand, and connection aspects of the definition of accessibility, barriers to accessibility can be classified as either supply, demand, or connection related:

- *Supply* barriers are barriers to accessibility due to opportunities, travel routes, or transport modes which are unavailable.
- *Demand* barriers are those which occur due to a characteristic of an individual or group of individual(s).
- *Connection* barriers, unlike availability and barriers to access, do not prevent the utilization of an opportunity, but merely constrain the ease of travel. These barriers can:

increase the:

- effort (time, cost, or distance), and

decrease the:

- convenience,
- comfort,
- reliability,
- safety,
- speed, and
- level of service

of the trip/travel route.

Availability and Unavailability

These terms deal with supply conditions, specifically as the supply (or absence) of:

- opportunities,
- travel routes, and,
- transport modes

Moreover, these terms have *temporal* and *physical* dimensions:

- The *temporal* dimension pertains to opportunities, travel routes and transport modes which are obtainable at certain times and not at others.
- The *physical* dimension deals with the supply or absence of an opportunity or transportation infrastructure.

Access and Barriers to Access

Access is the ability/inability for certain groups and individuals to gain the right to use:

- an opportunity,

- a travel route, and,
- a particular mode of transport

Access and barriers to access have:

- economic,
- legal/institutional,
- social/demographic/cultural, or
- modal

dimensions.

Additional terms: *convenience*, *mobility*, and *level of service* are frequently confused with the term *accessibility*. *Convenience* is a characteristic of a travel route as the need to change transport modes or vehicles; and, effort (distance, time, or cost, etc.) involved in changing transport modes or vehicles. *Mobility* is the ability and ease with which an individual can move about. *Level of service* is used in the traffic engineering field to measure the ease of movement. It is most commonly operationalized as the volume of traffic divided by the capacity of a transport link.

This completes the task of defining accessibility. The next step is to discuss how to measure accessibility, which is the focus of Chapter 4.

4. Accessibility Measured: Terms and Concepts

The lack of agreement as to the meaning of the term *accessibility* and its associated terms and concepts is also evident in the ambiguous use of terms, concepts, and approaches related to *measurement*. In this chapter the measurement process is considered, and various terms and concepts related to measuring accessibility are discussed.

The structure of this chapter is to first outline the conceptualization process which is the basis for the measurement process, and to then differentiate between the terms *measure*, *indicator*, *index*, *scale*, and *standard*. The need to include this step in the research design is explained by Taylor (1976, p. 121). "It is to be remembered that accessibility cannot be submitted to direct observation." That is, since accessibility cannot be directly observed, it must be measured on the basis of other directly observable phenomena. The process by which accessibility is measured begins with conceptualization.

4.1 Conceptualization

The methodological design of this research requires that the conceptualization aspect of the research be presented in some detail. The elaboration begins with a general statement from Walizer and Weiner (1978, p. 11-12)

"Conceptualization refers to the theoretical process by which we move from ideas or constructs to suggesting appropriate research operations, whereas measurement refers to the linkage process between these physical operations, on the one hand, and a mathematical language on the other. The complete process involves a triple linkage among theoretical constructs, physical measurement operations, and mathematical symbols and operations."

Thus, *conceptualization* may be defined as the "...mental process of organizing one's observations and experiences into meaningful and coherent wholes." (Walizer and Wienir, 1978, p. 28) The end product of the conceptualization process is a *concept*. A *dimension* of a concept is "...one aspect, one area, one part of the phenomena which can be discerned and potentially measured." (Walizer and Wienir, 1978, p. 33)

The next step is to define the concept as completely as possible. The defining process seeks "...to develop clearly worded conceptual definitions which carefully specify dimensions of a concept so that classification of observable and theoretically useful phenomena is possible." (Walizer and Wienir, 1978, p. 34) The product of the defining process is an *indicator*. "An *indicator* is a class, set or group of potentially observable phenomena". (Walizer and Weinir, 1978, p. 36)

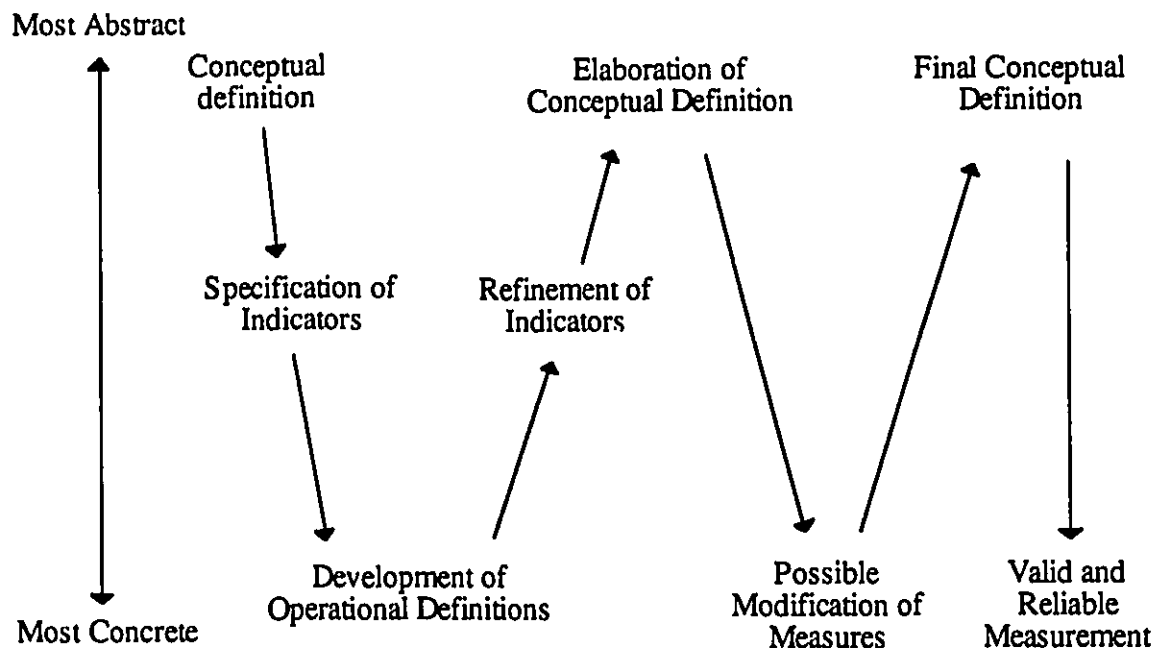
Then, an operational definition is developed. "An operational definition is a complete set of instructions for what to observe and how to measure a variable (concept)...The indicators previously selected serve as the bases for the development of operational definitions." (Walizer and Wienir, 1978, p. 36) A

variable is simply a concept which has more than "...one state, value or condition". (Walizer and Wienir, 1978, p. 34)

4.2 Measurement Process

Measurement is the implementation of the operational definition. The operational definition is "...the measurement instrument or device." (Walizer and Wienir, 1978, p. 37) Figure 17 illustrates the explication process of moving from conceptual definition to valid and reliable measurement. The feedback between the conceptual and operational levels hones the conceptual definition and improves the validity and reliability of measurement.

Figure 17: Explication Process



Source: Adapted from Walizer and Wienir (1978, p. 37)

There are four scales of measurement: nominal, ordinal, interval and ratio (Walizer and Wienir, 1978, p. 42). All four are described in Table 8. The presence of categories which are mutually exclusive and inclusive is the sole criterion for a *nominal* level variable. An *ordinal* variable must fulfill the added criterion of possessing categories that can be ordered. *Interval* level measurement requires that categories of the variable have a known distance between their scores (midpoints). Finally, a *ratio* level variable has categories with a zero point, which allows proportional statements to be made.

Table 8: Levels of Measurement According to Characteristics of Numbers Possessed by Categories of a Variable

Characteristics of numbers	Levels of Measurement			
	Nominal	Ordinal	Interval	Ratio
Mutually exclusive and inclusive	yes	yes	yes	yes
Order	no	yes	yes	yes
Known distance between intervals	no	no	yes	yes
Zero point	no	no	no	yes

Source: Adapted from Walizer and Wienir (1978, p. 42)

In the measurement of accessibility, the interval and ratio level scales are of most interest. This is because "in evaluation in urban and regional planning we normally seek to measure differences between plans; that is using an interval scale." (Whitbread, 1972, p. 99) Both the ratio and interval scales of measurement use an interval scale.

As we saw in the definition of accessibility there are two views of accessibility: one regards it as the ease of travel, whereas the other combines the possibility of use of an opportunity and the ease of travel (See Section 3.2.2.3, p. 37).

The variable in the first case, the ease of travel, is measured on a scale without a 'zero point', with respect to the total population of individuals who need/desire to use a particular opportunity. That occurs because only the difficulty of reaching the opportunity is acknowledged and no consideration is given to the possibility of reaching and using an opportunity. Ease of travel focusses solely on the travel component and measures the degree of effort (in distance, time, or cost), convenience, comfort, reliability, safety, speed, or level of service of a trip. Ease of travel, defined in such a way, represents a variable measured on a scale without a 'zero point' and therefore can be recognized as an *interval* scale variable.

The second definition, the possibility of use of an opportunity and the ease of travel is measured on a 'zero-point' scale, meaning that zero accessibility exists when it is impossible to use an opportunity. With a 'zero-point' scale, in addition to fulfilling the characteristics associated with the interval scale, this produces a *ratio*-level of measurement. Since the ratio-level of measurement has a 'zero' point, proportional statements can be made. (Walizer and Wienir, 1978)

4.3 Measurement Terms and Concepts

There are five terms and concepts that are commonly included in the measurement process: indicator, measure, index, scale, and standard. Each of these is discussed for its contribution to measuring accessibility.

4.3.1 Indicator

An *indicator*, as previously identified in the conceptualization process is "...a class, set or group of potentially observable phenomena which stands for or represents a conceptual definition." (Walizer and Wienir, 1978)

Weibull (1980) in his investigation of the theoretical basis for accessibility measurement states that the distance, gravity and cumulative opportunity accessibility measurement techniques are *indicators*. These techniques are described in the Chapter 5.

Rossi and Gilmartin (1980, p. 19) differentiate between *subjective* and *objective* indicators. "*Subjective* indicators are based on the reports persons make about their feelings, attitudes and evaluations. *Objective* indicators are based on counts of behaviours and conditions associated with given situations."

An example of a subjective indicator is a distance measurement technique which uses travel time to work obtained from estimations made by commuters in a travel survey. In contrast, an objective indicator in the above situation would be a distance measurement technique based on actual recorded travel times of commuters' journeys to work.

4.3.2 Measure

The word *measure* is not clearly defined in the literature. It is often used synonymously with the terms *indicator* and *index*.

One rare description of the distinction between indicators and measures is given by de Neufville (1975, p. 242).

"*Indicators* which are grounded in the models and concepts of users and in the best theory available about a problem tend to be more useful than operationally defined *measures*. They are better understood and accepted and fit with more analyses. Without clear underlying concepts the design of the *indicator* may be arbitrary, and is virtually impossible to determine whether it actually represents the idea it is being used for. A *measure*, however, that meshes not only with public conceptions of issues but also with economic or social theory is likely to get considerable methodological attention and improvement."

De Neufville's description suggests that indicators are conceptually defined, whereas measures are operationally defined. Here it is difficult to give an example of an accessibility *measure* since in most instances the term *measure* is used generically to mean indicators and indexes.

4.3.3 Index

"Because many variables have more than one dimension, that is, they are multidimensional, operational definitions often incorporate more than one observation (question) to categorize a variable, (and) they are often called indexes or scales." (Walizer and Wienir, 1978, p. 37)

Rossi and Gilmartin (1980, p. 175) define an index as "...a weighted combination of two or more indicators." *Scales* and *indexes* are identical, except that the construction of *indexes* is less formal than that of *scales*. There are no rules which direct the assembling of multiple indicators of a variable.

An example of an accessibility index is given in Table 9 by Johnston (1966, p. 33) for the purpose of studying bus services in rural areas. The index is obtained by summing the scores (see Total: 6 points) for the two sections: travel to work and travel to entertainment.

Table 9: Accessibility Index

Activity	Bus Service	Points
A. Travel to Work		
either	1. service arriving in town before 8am daily	2 points
or	2. service arriving in town before 9am daily	1 point
B. Travel to Entertainment		
either	1. daily bus leaving town after 9:30pm daily	2 points
or	2. a bus leaving a town after 9:30pm on less than 6 days a week	1 point
		Total: 6 points

Source: Adapted from Johnston (1966, p. 33): Only a portion of Johnston's accessibility index.

4.3.4 Scale

In comparison to the construction of an index, "the construction of scales proceeds according to a set of rules which determine how multiple indicators are developed,

tested and assembled into a composite value. This value allows a score of the variable to be assigned." (Walizer and Wienir, 1978, p. 37)

Although the term *scale* is mentioned in a general sense in the literature, in most cases there is no evidence which shows that the *scale* has been assembled according to formal rules. Therefore, an example of an accessibility scale cannot be given.

4.3.5 Standard

A *standard* is "...a reference point on a scale in comparison to which each case is scored as being above or below the threshold." (Rossi and Gilmartin, 1980, p. 179)

An example of accessibility standards used to guide location and transportation network decisions are those published by the American Public Health Association (APHA) Committee on the Hygiene of Housing in 1948. These standards specify a maximum acceptable distance to an activity such as:

- 1) nursery school: 1/4 mile maximum walking distance, one-way, (APHA, 1948, p. 44)
- 2) work: 30 minutes maximum distance or time, one-way (APHA, 1948, p. 9)

The basis for these standards is "...the avoidance of fatigue, protection from traffic and other accident hazards, and positive encouragement to use facilities." (APHA, p. 43) The standards were republished in 1960 and as noted in 1971 "...continue to be used by urban planners at the local level for evaluating existing and proposed environments and continue to play an indirect role in public investment planning for schools, parks, urban highways, and shopping centres." (Kaiser et al., 1971, p. 111-112)

A second example of an accessibility standard is Nutley's (1985, p. 38) proposal for an "...optimum standard (100% accessibility) achieved where the whole population has an adequate level of access to everyone of a set of functions defined to be socially necessary."

4.4 Overview of Accessibility Measurement Terms and Concepts

An accessibility *indicator* is a measurement tool that represents a conceptual definition of accessibility. The focus in this report is on accessibility *indicators* which represent the *spatial* dimension of the concept of accessibility and which are able to quantify the *spatial* dimension of accessibility. These indicators are described in detail in Chapter 5.

De Neufville (1975) suggests that while indicators are conceptually defined, *measures* are operationally defined. However, the term *measure*, although frequently referred to in the accessibility literature, is not clearly defined and is used synonymously with the terms 'indicator' and 'index'. For this reason, use of the term 'measure' is avoided in this report.

An *index* is a combination of two or more indicators. An examples of this measurement tool is present in the accessibility literature (See Johnston, 1966). Indexes can reflect several dimensions of a particular concept by incorporating more than one observation to categorize a variable.

Scales are similar to indexes, except that they are constructed according to formal rules. Instances in the accessibility literature where the term 'scale' is used there is no evidence that the measurement was accomplished through a scale assembled according to formal rules.

Standards are reference points on a scale which score each use as above or below a threshold. Accessibility standards have been used by organizations such as the American Public Health Association (APHA, 1948) to guide location and transportation network decisions.

The term *accessibility measure* is commonly used throughout the literature. It is difficult to ascertain whether a particular accessibility measurement is a *measure*, *indicator*, *index* or *scale* without careful examination of the particular study. Therefore, in this thesis the term *accessibility measurement technique* is used to characterize the process by which accessibility is quantified, and the term *measurement* represents the product of this process.

4.5 Summary

The terms *indicator*, *measure*, *index*, *scale*, and *standard* are used interchangeably by many authors. The lack of rigour in these terms makes it difficult to establish well-supported, clear definitions.

An accessibility *indicator* is a measurement device that represents the *conceptual* definition of accessibility, while a *measure* reflects an *operational* definition of accessibility. However, the term *measure* is used so loosely in the literature that it is not really clear what an accessibility *measure* really represents.

Indexes combine two or more indicators. *Scales* are similar to indexes in that they combine one or more indicators, but they do so according to formal rules.

An accessibility *standard* is "...a reference point on a scale in comparison to which each case is scored as being above or below the threshold." (Rossi and Gilmartin, 1980, p. 179). Accessibility standards can be used to guide location and transportation network decisions.

In this report, therefore, and as noted in Section 4.4, the term *accessibility measurement technique* is used (in place of the term *accessibility measure*) to characterize the process by which accessibility is quantified, and the term *measurement* is used to represent the product of this process.

Definition of the concept of *accessibility* and associated terms in Chapter 3, combined with an elaboration of the measurement processes by which accessibility can be quantified in this chapter, form the basis for exploring *accessibility measurement techniques* in Chapter 5.

5. Classification of Accessibility Measurement Techniques

Review of the literature identified as pertinent to this research suggests that there are three principal means of classifying accessibility measurement techniques:

- a) relative vs. integral (Ingram, 1971)
- b) process vs. outcome (Morris, Dumble and Wigan, 1979)
- c) distance vs. topological vs. gravity vs. cumulative-opportunity (Pirie, 1979)

Each of these means of classification is discussed in sequence, with emphasis on the spatial dimension of accessibility.

5.1 *Relative and Integral Accessibility*

A principal means of classifying accessibility lies in the distinction between *relative* and *integral* accessibility. *Relative accessibility* is defined by Ingram (1971) as the degree by which two places (or points) on the same surface are connected. In other words, it is the degree of difficulty or effort (measured in distance, time, or cost, etc.) that must be expended in moving between two points. As a result, the relative accessibilities of two points to each other may not be equal in degree (Ingram, 1971). This is explained in an example given by Ingram (1971) where the relative accessibilities between two points located in a network of one-way streets may not be equal to each other. This is because different routes must be taken between the two points depending on the direction of travel.

Integral accessibility, by way of comparison, is defined as the degree of interconnection, meaning the degree of difficulty or effort (measured in distance, time, cost, etc.) in moving from a given point to all other points on the same surface (within a spatial set of points $j=1....n$). The integral accessibility of the i th point is a scalar point function of the relative accessibilities at that point:

$$A_i = \sum_{j=1}^n a_{ij} \quad (5)$$

where:

A_i = *integral* accessibility at the i th point

a_{ij} = *relative* accessibility of point j at point i

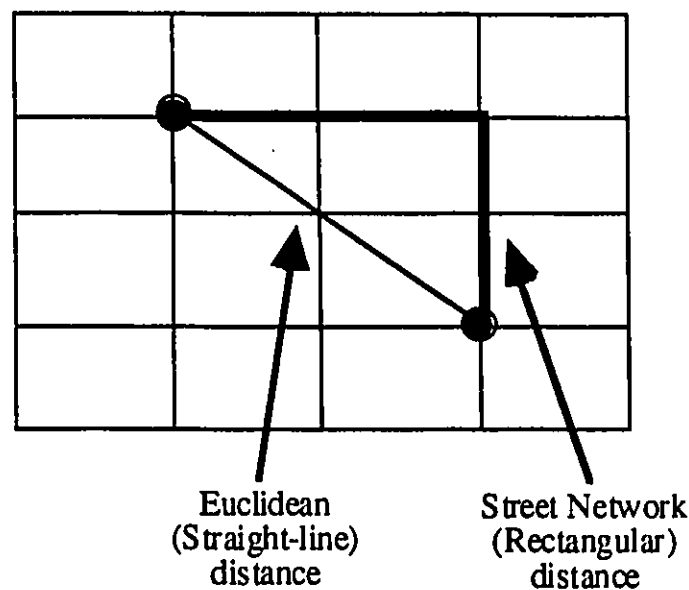
The next section examines the units used to measure the degree of difficulty or effort in moving between points.

5.1.1 Spatial Units of Separation in the Measurement of Relative and Integral Accessibility

Based upon the literature reviewed and consultations with a number of researchers and others who are familiar with the topic, it does not appear that there is an accepted 'standard' unit of accessibility.

Obviously, distance can be used to measure spatial separation. Due to grid street patterns, *street network (rectangular)* distance measures may be more appropriate than *Euclidean (straight-line)* distance measurements. (Ingram, 1971) This is because movement of people by motorized vehicle (car, bus, motorcycle etc.) takes places along roads, and not in straight lines from origin to destination 'as the crow flies'. Figure 18 illustrates the difference between a Euclidean (straight-line) and a street-network (rectangular) distance. Ingram (1971) and Oberg (1976) propose another distance unit with *barrier effects* which incorporates constraints due to physical obstacles (for instance, reduced speed on gravel roads versus paved roads).

Figure 18: *Euclidean and Street Network Distance Units of Spatial Separation*



In addition to distance units, *travel time* is often used because "a less direct and longer route may take a lesser time to navigate than a similar journey over a direct path." (Kissling, 1967, p. 143)

Further, *travel cost* is an option, either separately or as part of a *generalised cost* unit proposed by Koenig (1977) which represents the time, cost and effort in travel. An example of a generalised cost function (Hobbs, 1979, p. 136-137) is given below:

$$C_{ij} = a_{1j}t_{ij} + a_{2j}e_{ij} + d_{ij} + P_{ij} (+K) \quad (6)$$

where:

C_{ij} = generalised cost for mode m

t_{ij} = 'in-vehicle' time by mode m in minutes

e_{ij} = 'excess' travel time generated (by walking and waiting, unparking, parking, etc.) by mode m in minutes

d_{ij} = travel costs by mode m (fares, petrol, tire, etc.) by mode m

P_{ij} = terminal costs for mode m (parking, walking, tolls, garaging)

a_{1j} and a_{2j} = parameters converting time into money values, determined empirically, or assigned for a sensitivity analysis

K = constant for system in question

A *convenience* unit such as the journey unit variable (Watson, 1974), which assigns one unit to a mode or vehicle change, can also be used to measure spatial separation.

Table 10 lists the various units of spatial separation which are used in accessibility measurement. Whether the unit is an objective as opposed to a subjective measurement is held to be important. Kissling (1967, p. 143) notes that "it may be more fruitful still to measure accessibility in terms of perceived values as behaviour patterns are more likely to be stimulated by what is thought to be the situation in reality even if it is not the case." As for the operational aspect, it is a matter of record that objective or perceived measurements of spatial separation are often estimates of travel times derived from travel surveys. (Morris, Dumble and Wigan, 1979)

Bach (1981, p. 976) states that the type of unit of spatial separation must be matched with the appropriate mode for the type of facility to be located. "Street network distances in minutes of walking time or metres are most appropriate in the case of kindergartens, travel time by bicycle or by car as well as by public transit in the case of indoor swimming pools, and travel time by car or public transit in the case of general hospitals."

Bach's observation implies that as the scale increases, different modes of transport are required to traverse the distance and this influences the selection of the unit of spatial separation. "The indicator should incorporate an element of spatial separation which is responsive to changes in the performance of the transport system." (Joseph and Phillips, 1984, p. 94)

Table 10: Spatial Units of Separation

Unit	Variation	Description
Distance	Euclidean (Ingram, 1971)	Straight-line or 'Crow-fly' distance
	Street Network (Ingram, 1971)	Distance along city blocks
	Barrier Effects (Ingram, 1971; Oberg, 1976)	A distance unit supplemented for constraints due to physical obstacles (e.g. lakes)
Travel Time	Perceived (from surveys) (Morris et al., 1979)	Estimates of travel time from survey respondents
	Network estimates (Morris et al., 1979)	Shortest path algorithm
	Distance converted into time (Oberg, 1976)	Distance measurement converted into estimated travel time
Travel Cost	Generalized cost (Koenig, 1977)	Combines distance, time and cost
Convenience	Journey Unit Variable (Watson, 1974)	1 unit = a mode or vehicle change

5.2 Process and Outcome Accessibility

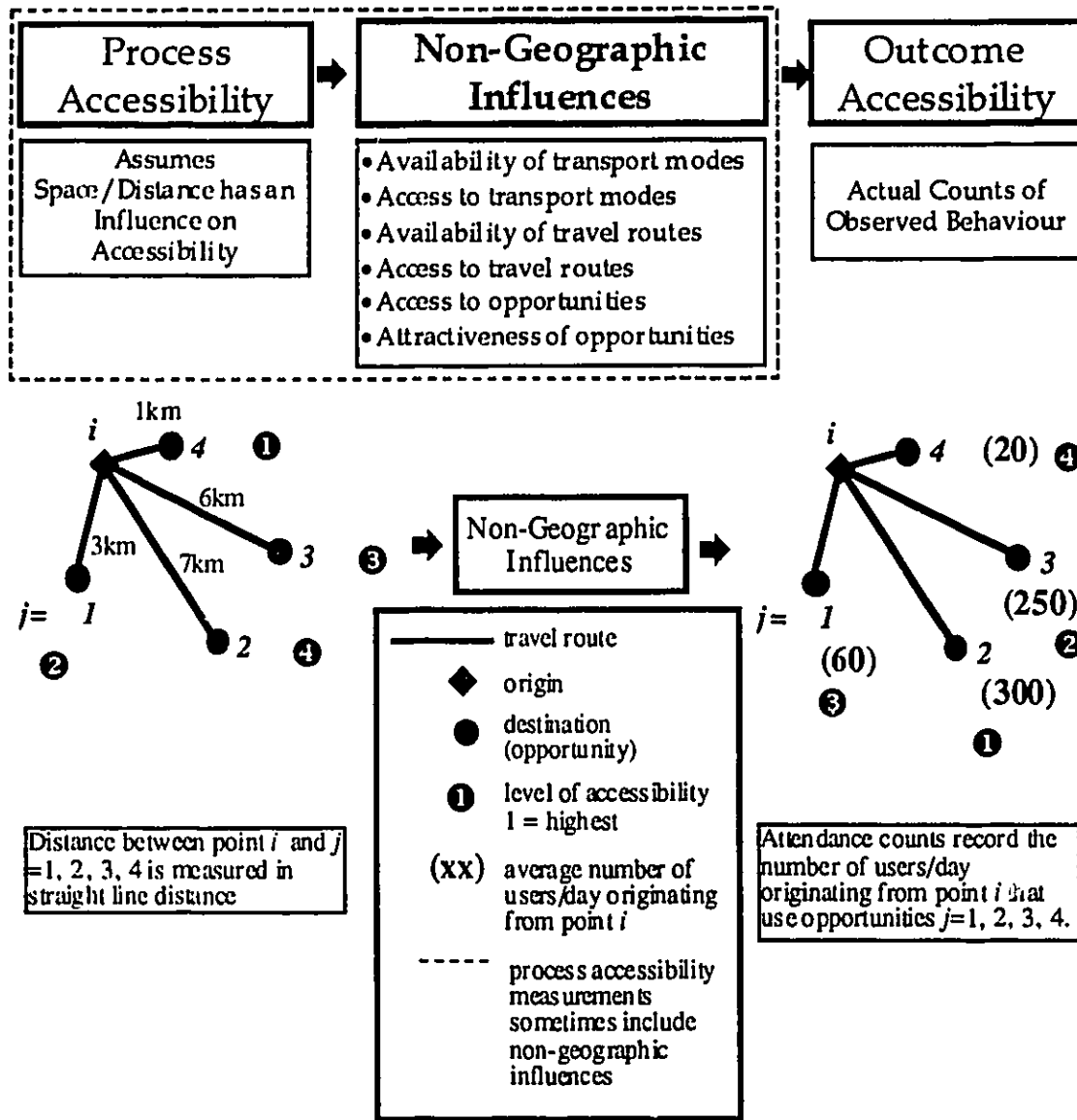
Process (or potential) measurements of accessibility investigate the potential or opportunity to travel to opportunities, by looking at the supply characteristics of the system and/or individuals (Morris, Dumble and Wigan, 1979). Examples of such measurements are those obtained from using the distance, topological, gravity or cumulative opportunity techniques. Process measurements of accessibility have a spatial component since they are based on the assumption that space/distance influences accessibility (Morris, Dumble and Wigan, 1979).

Outcome (or revealed) measurements of accessibility look at actual use of opportunities (Morris, Dumble and Wigan, 1979; Joseph and Phillips, 1984). Some examples of this type of measurement which look at observed behaviour are: total trip rates, total time spent travelling, and hospital visits. Outcome accessibility, unlike process accessibility, simply measure the actual use of opportunities and space/distance is not a built-in assumption.

Both *process* and *outcome* measurements can be considered to be relative and integral. (Morris, Dumble and Wigan, 1979) That occurs because both the *potential to travel* (process) and *actual travel* (outcome) can be measured between two points in a relative manner, or between one point and several others in an integral manner.

Figure 19 illustrates the distinction between process and outcome accessibility. *Process* measurements assume that space/distance influences accessibility, but may or may not include (illustrated by dotted line) non-geographic considerations which can also influence the final accessibility outcome. *Outcome* accessibility which looks at actual use, can be measured in counts of the number of users who use a particular opportunity.

Figure 19: Process and Outcome Accessibility



Note that in Figure 19, process measurement predicts that the opportunity $j=4$ is the most accessible to point i (closest in distance). However, non-geographic influences can influence the final outcome to make $j=2$ the most accessible, although it is the most remote opportunity from point i .

Since the focus of this thesis is on the spatial dimension of accessibility, process accessibility measurement is examined in detail. There are four main techniques used to measure process accessibility: distance, topological, gravity, and cumulative opportunity.

Next, several types of process accessibility measurement techniques are identified by Pirie (1979): distance, topological, gravity and cumulative-opportunity.

5.3 Types of Accessibility Measurement Techniques

Descriptions of the distance, topological, gravity and cumulative opportunity techniques are complemented with a discussion of the graphical and spatial components of each technique. The next section provides an introduction to these two components.

5.3.1 Introduction to the Spatial Aspects of Accessibility Measurement Techniques

5.3.1.1 Graphical Components

As noted earlier, the journal articles and theses selected by the literature search are assessed in this study from a spatial, that is, geographical perspective. As Wellar (1993, p. 8) notes:

“Geographic data or, more accurately, geographically referenced data, are observations on phenomena or features that make up our built or non-built environment. Geographic data report on where phenomena or objects of interest are located, their distributions and extent, and their adjacency, proximity or connectivity in relation to other phenomena for which a geographic location can be assigned.”

A point, line, and/or polygon synonym is used to depict the locations of real world phenomena in which an interest is held. Wellar (1993, p. 8-9) in his paper on geographic information systems explains:

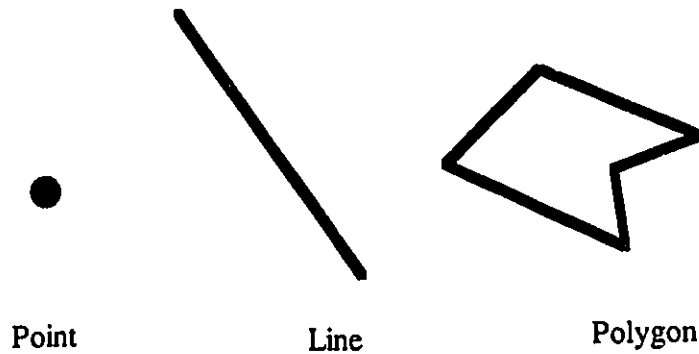
“Points equal sites in GIS. Sites can represent anything located in the real world to which x-y coordinates or a location identifier can be assigned. Or, more simply, sites are anything that can be designated by dots on maps.

Lines equal connections or links between and among points or sites in the real world in a GIS....Moreover, lines can represent the perimeters or boundaries of sites when they are treated as areas.

Polygons equal areas, zones, regions, surfaces or spaces contained within sets of observable or conceptual lines in a GIS. The polygons or areas could also include many of the points and lines already described simply by giving them the dimensions of length and width.”

Figure 20 illustrates the point, line, and polygon graphical components of accessibility.

Figure 20: Graphical Components of Accessibility



5.3.1.2 Spatial Components

The way in which these point, line and polygon graphical components are used in combination (points and lines, points and polygons, etc.) within an accessibility measurement technique constitutes the spatial component of that technique. In the following discussion the spatial components of each technique are reviewed.

5.3.2 Distance

The distance separating two points affects the degree of relative accessibility between the points. A Euclidean (straight line) distance measurement of integral accessibility is defined as the average of the relative accessibilities at that point and is given as follows:

$$A_i = \frac{1}{n} \sum_{j=1}^n d_{ij} \quad (7)$$

where:

A_i = integral accessibility at the i th point

d_{ij} = straight line distance between points i (origin) and j (destination)

n = number of destination points ($j=1$ to n)

Physical distance, travel time or cost can be used to measure separation (Pirie, 1979), and a low value of A_i (short distance, short travel time or low cost) is associated with good accessibility.

5.3.2.1 Graphical and Spatial Components

The distance measurement technique incorporates the graphical components of points (i and j) and lines (d_{ij}) shown in Equation 7. The spatial component of the distance measurement technique is this *spatial separation* (d_{ij}) measured along a line between point i (origin) and point j (destination).

5.3.3 Topological

Topological measurement of accessibility is a variation of distance measurement. Kansky (1963) devised techniques of describing networks in terms of the presence and number of links, and the direction of flow, rather than considering the distance between network vertices. The Associated Number (AN) is an example of a topological measurement technique which is the maximum distance measured in links for any one point to another point in the network. The equation is given:

$$AN_i = \max d_{ij} \quad (8)$$

where:

$\max d_{ij}$ is the maximum distance *in terms of links* from i to j

The maximum AN for any node in the network is called the diameter of the network or the total size of the network. An obvious weakness of this technique is that since it is a measure over the entire network, which uses the most remote node as a reference point, it is unable to compare accessibilities between or among points, a criticism which Vickerman (1974) has made.

Shimbel's Index (Shimbel, 1953) is another topological technique whose equation is given below.

$$Shimbel_i = \sum_{j=1}^n d_{ij} \quad (9)$$

where:

d_{ij} is the distance *in terms of links* from i to j

This is an aggregate technique to be used on a whole network. A weakness of Shimbel's Index is that it is very sensitive to network size. If Shimbel's Index is manipulated to correct for this sensitivity, the average accessibility to all points produces Equation 10. This equation enables comparisons to be made between points on different networks since it measures average rather than absolute accessibility. If d_{ij} in Equation 10 represents exact distances instead of links, then Equation 10 mirrors Equation 7 (distance accessibility measurement technique).

$$A_i = \frac{1}{n} \sum_{j=1}^n d_{ij} \quad (10)$$

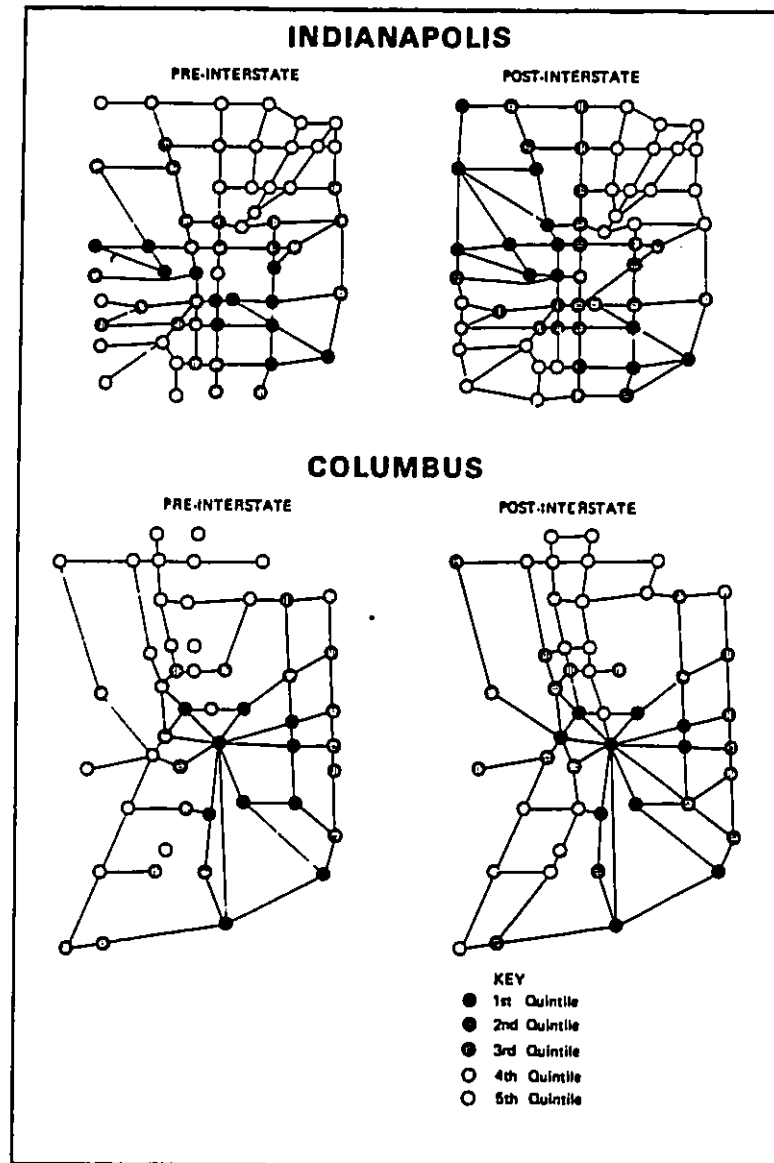
where:

d_{ij} is the distance *in terms of links* from i to j

A low value of A_i is associated with good accessibility.

Muraco (1972) illustrates accessibility patterns for Indianapolis and Columbus, USA that are derived using the Shimbel Index (Figure 21).

Figure 21: Binary Accessibility Patterns



Source: Muraco (1972, p. 392)

The ranked row sums of a Shimmel matrix are grouped into quintiles, with the first quintile having the lowest 20% (highest accessibility). In the pre-Interstate Highway period, both Indianapolis and Columbus showed accessibility patterns which declined outwards from the centre of the city. The post-Interstate pattern is not dramatically different in that relative rankings shifted only marginally, overall, for both cities, with the southeast nodes of Columbus showing a slight gain in accessibility relative to the remaining nodes for that city.

5.3.3.1 Graphical and Spatial Components

Similar to the distance technique, the topological measurement technique deals with *point* and *line* graphical components. The *spatial separation* between points is the spatial component of topological measurement.

5.3.4 Gravity

The gravity technique, originally developed by Hansen in 1959, is the most popular for accessibility measurement. An example of a gravity formulation is given by:

$$A_i = \sum_{j=1}^n d_{ij}^{-k} (S_j) \quad (11)$$

where:

A_i = integral accessibility A at i

d_{ij} = physical distance from i to j

k = distance decay parameter (constant for system in question)

d_{ij}^{-k} = reciprocal distance response function

S_j = attractiveness of opportunities in zone j

(attractor variable: this term can be added as an option to the right hand side of the equation.)

The *potential* technique is a variation of the gravity technique. Pooler (1987, p. 272) explains: "Potential is not a model of spatial interaction, but an *index or measure* of aggregate accessibility. It is related to spatial interaction in the sense that it describes the propensity for interaction on a *per capita* basis at the *destination*."

For instance Harris (1954) and Vickerman (1974) define *market potential* with retail sales (E_i) as the weighting variable:

$$M_j = \sum_{i=1}^n \frac{E_i}{c_{ij}^k} \quad (12)$$

where:

M_j = market or economic potential M at j

E_i = retail sales at i (weighting variable)

c_{ij} = measurement of impedance or transport cost between i and j

k = constant for system in question

This version has been used recently in a study by Linneker and Spence (1992) for an accessibility analysis of the impact of the M25 London Orbital Motorway on Britain.

The difference between the gravity and potential technique is related to the distinction between place and personal accessibility (outlined on page 37). The gravity technique in Equation 11 measures the attractiveness of opportunities (for example, a particular type of store) in zone j to a group of individuals in zone i . The potential technique in Equation 12, on the other hand, measures the inverse of a gravity accessibility index (Vickerman, 1974). It can be visualized as the drawing power of the store(s) in zone j from a group of individuals in zone i .

In the following sections various components of the gravity technique are discussed:

- a) attractor/weighting variables;
- b) distance decay; and,
- c) zone shape and size.

Finally, the use of gravity techniques within other models is described.

5.3.4.1 Attractor/Weighting Variables

Gravity and potential measurement techniques, unlike the distance and topological techniques can include attractor or weighting variables. A gravity technique can include attractor variables (Vickerman, 1974) such as S_j in Equation 11. Attractor variables are properties of opportunities such as: retail sales, floor area, and range of choice in a store (Vickerman, 1974); and the number of beds in a hospital. These properties can influence the desirability of travel to that opportunity. A potential technique, on the other hand, can include weighting variables (Vickerman, 1974) such as E_i in Equation 12. Weighting variables are characteristics of groups of individuals within a zone. Examples are total population or average income.

The gravity technique as a whole can be manipulated to include different variables. For example, potential spatial accessibility of public hospital services (Joseph, 1986) is formulated with S_j/C_j (an availability or per capita measure, see page 48) as the attractor variable:

$$A_i = \sum_{j=1}^n \frac{\frac{S_j}{C_j}}{d_{ij}^k} \quad (13)$$

where:

S_j = the number of beds (supply) in hospital j

C_j = catchment area population of hospital j

$$C_j = \sum_{i=1}^n \frac{P_i}{d_{ij}^k} \text{ where } P_i \text{ - pop. of census area } i]$$

d_{ij} = distance between i and j

k = constant for system in question

Population potential (Yeates, 1974) is used as a general measurement of location and accessibility (Chisholm, 1985). It is given as follows with population (P_i) as the weighting variable:

$$V_j = \sum_{i=1}^n \frac{P_i}{d_{ij}^k} \quad (14)$$

where:

V_j = population potential V at j

P_i = population at point i

d_{ij} = distance between i and j

k = constant for system in question

In the next section, two main spatial components of the gravity (and potential) techniques: distance decay and zone shape and size are discussed in detail.

5.3.4.2 Distance Decay

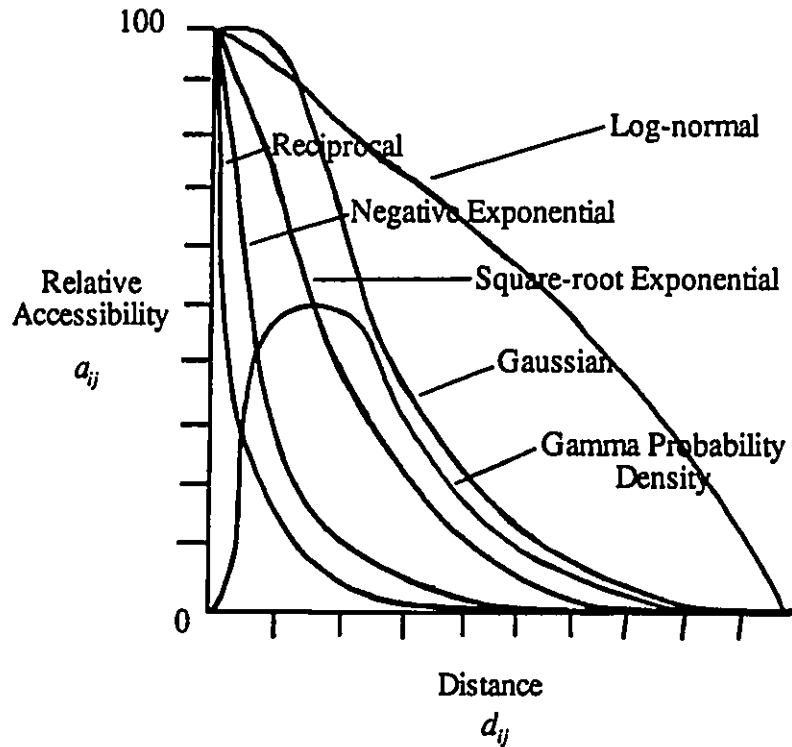
Distance-decay is defined as the decline in likelihood of traveling to a particular point with increasing distance that must be traveled to reach that point. It is operationalised within an accessibility measurement technique in the form of a distance response function (Pooler, 1987) which contains a distance decay parameter k . Distance decay effect varies depending on the phenomena being studied, and it is preferable to examine it separately for each individual study (Pirie, 1979); this is because "...the effects of distance seem to be different for different groups of people, (and) for different services". (Joseph and Phillips, 1984, p. 135). There are several distance-response functions that are pertinent to this discussion:

- a) Reciprocal (or power) (Ingram, 1971);
- b) Negative exponential (Ingram, 1971);
- c) Gaussian (Ingram, 1971);
- d) Exponential and power composite (Wilson and Kirkby, 1975; Tribus, 1969);

- e) Gamma probability density (Wellar and LaCava, 1974); and,
- f) Goux typology-based (Taylor, 1971).

The reciprocal, negative exponential, Gaussian, gamma probability density, square root exponential, and log-normal functions are illustrated in Figure 22.

Figure 22: Functions for Describing Relative Accessibility



Source: Adapted from Ingram (1971, p. 105)

The reciprocal function has the form:

$$a_{ij} = d_{ij}^{-k} \quad (15)$$

where:

a_{ij} = relative accessibility of j to i

k = constant calibrated for the network

d_{ij} = distance between zones i and j

The negative exponential function is given as follows:

$$a_{ij} = \exp(-kd_{ij}) \quad (16)$$

where:

a_{ij} = relative accessibility of j to i

k = constant calibrated for the network

d_{ij} = distance between zones i and j

Ingram (1971), has found that the reciprocal and the exponential function decay too rapidly and are unrealistic when measuring access close to the origin. He has suggested that the Gaussian curve provides a slow rate of decline close to the origin which increases with increasing distance from the origin. This function is given:

$$a_{ij} = \exp\left(-\frac{d_{ij}^2}{l}\right) \quad (17)$$

where:

a_{ij} = relative accessibility of j to i

l = constant for system in question

d_{ij} = distance between zones i and j

The study "Welfare and retail accessibility" (Hallsworth et al., 1986) uses a Gaussian function to identify the spatial distribution of those households that are disadvantaged with respect to access to food stores.

Composite functions combining an exponential and a power function are presented by Wilson and Kirkby (1975) and Tribus (1969). Wilson and Kirkby (in Pooler, 1987) use a gamma distribution:

$$a_{ij} = \exp(-k_1 d_{ij}) d_{ij}^{-k_2} \quad (18)$$

where:

a_{ij} = relative accessibility of j to i

k_1, k_2 = constants for the system in question

d_{ij} = distance between zones i and j

Tribus (1969) (in Pooler, 1987) combines the power and exponential functions in a Weibull distribution function:

$$a_{ij} = \exp(-k_1 d_{ij}) d_{ij}^{k_2} \quad (19)$$

where:

a_{ij} = relative accessibility of j to i

k_1, k_2 = constants for the system in question

d_{ij} = distance between zones i and j

Other possibilities are the gamma probability density function (Wellar and LaCava, 1974)

For $\alpha > 1, x \geq \beta$

$$a_{ij} = \frac{(d_{ij} - \beta)^{\alpha-1} e^{-(d_{ij}-\beta)/s}}{\Gamma(\alpha)s^\alpha} \quad (20)$$

where:

a_{ij} = relative accessibility of j to i

α = intensity parameter

β = location parameter

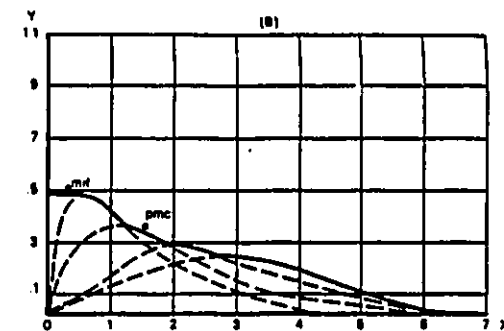
s = scale parameter

d_{ij} = distance between zones i and j

Γ = gamma probability density function

Wellar and LaCava's gamma probability density function is graphed below in Figure 23.

Figure 23: Gamma Probability Density Function



CBD

Source: Wellar and LaCava (1974, p. 59)

A magnified indicator function (MIF) can be added to the Gamma function so that the left slope of the curve doesn't decrease to zero. This aspect is useful for modelling traffic congestion and takes into account that congestion is still present in the CBD (marked as $X=0$ in Figure 23).

There are also functions based on the Goux typology of distance transformation (Taylor, 1971). Two of these functions are the square-root exponential:

$$a_{ij} = \exp(-k d_{ij}^{0.5}) \quad (21)$$

where:

a_{ij} = relative accessibility of j to i

k = constant for system in question

d_{ij} = distance between zones i and j

and the log-normal:

$$a_{ij} = \exp(-k(\log d_{ij})^2) \quad (22)$$

where:

a_{ij} = relative accessibility of j to i

k = constant for system in question

d_{ij} = distance between zones i and j

As illustrated in this discussion, the distance response function found in the gravity formulation directly incorporates the influence that space/distance has on the level of spatial interaction.

5.3.4.3 Zones

The gravity accessibility measurement technique requires that the study area be divided up into zones. "A zoning system partitions a region into units which may vary in areal extent depending on the nature of the study. For example, they may be states, counties, census tracts, or transportation study districts. The unit of collection is often the smallest unit that can be observed. From this database, the data are aggregated to the desired scale." (Wilson, 1978, p. 82) Each zone is assigned a reference point or centroid from which spatial separation to the opportunity of interest is calculated.

The gravity technique is sensitive to zone shape, size and regional configuration. In practical applications, the size of administrative areas or data collection units varies inversely with the density of the data. Where population densities are high, administrative units (states, counties, etc.) tend to be small. Dalvi and Martin (1976) investigated the effects of both aggregation level and zone configuration on accessibility for the City of London and found that both had significant effect on the value of the accessibility index.

5.3.4.4 Zone Shape

Savigear (1967) investigated the influence of the shape and size of zones on the measurement of accessibility. It was his finding that a fine mesh of spatial zones gives maximum sensitivity in a gravity-based model. This means that a fine mesh

provides a uniform coverage of the study area with each zone being equal in shape and size, and thus the mesh can register differences between areas.

Another study by Wilson (1978, p. 131 and 133) compared 25 random zoning patterns with 3 uniform zoning patterns and although Wilson was unable to establish a precise relationship he found that "zones with unusual shapes, for example, long and narrow or very large zones...distort the accessibility pattern."

5.3.4.5 Zone Size

Dalvi and Martin in their study of car-owning households in inner London, calculated accessibility of a zone as a function of travel cost to all zones in the study area. The zone size was found to have a significant effect on values of a gravity-type accessibility measurement for the City of London. "The size of this effect varies between the measures of attractiveness employed and is dependent upon the degree of fineness existing in the initial zoning system: the greater the fineness of the initial system the less pronounced would be the effect of marginal changes in the zoning configuration." (Dalvi and Martin, 1976, p. 35)

In another study, Wilson (1978, p. 138) using a random zone generating technique tests the effects of zoning systems, finding, "...at a specific scale, the model is sensitive to different aggregation systems. Therefore it is not possible to state a specific equation unless a zoning system is given."

Wilson (1978, p. 5) observes that "since the land use and traffic models are usually concerned with square mile zoning areas, accessibility models have most often been calibrated at this scale." However, he suggests that sketch planning models, which are models based on large zones (e.g. 36 square miles in area), accessibility models may achieve their greatest potential:

"The smaller the zonal unit, the more intense the local pressures upon land use in a zone. These may easily dominate the accessibility relationships in individual cases. However, at the level of sketch planning zones, local issues are no longer important since the area involved encompasses several communities per zone. The influence of accessibility on development is more likely to be a factor at this scale." (Wilson, 1978, p. 5-6)

A problem with increasing zone size is that the centroid of a smaller zone is less likely to be representative of the increased zone.

"The accessibility of a region is...equated with that of its centroid. This assumption has little impact on the accuracy of results when regions are small but, as regions increase in size it becomes progressively less reasonable to imply that the accessibility of two points at the boundary of 2 regions, and separated by only a few miles would be the same as that of their regional centroids, separated perhaps by tens of hundreds of miles." (Joseph and Phillips, 1984, p. 94-95)

Intrazonal Accessibility

As zone size increases, intrazonal accessibility values which indicate the degree of accessibility that exists within each zone, gain importance. Wilson (1978, p. 22-23) observes that "some studies have simply chosen an index of 100 for the intrazonal value which decreases as distance from the central zone increases. This theoretically implies that every point in the zone is completely accessible to every other point. For large zones or zones in non-uniform distributions this would not be true."

Self-potential

'Self-potential', represented as a_{ii} is sometimes used in the calculation of A_i (Integral accessibility, see Equation 11) to acknowledge the influence of point i on itself. Equation 23 is the relative accessibility form of Equation 11.

$$a_{ii} = \frac{S_i}{d_{ii}^k} \quad (23)$$

where:

a_{ii} = self potential of i

d_{ii} = physical distance from i to i

k = distance decay parameter (constant for system in question)

S_i = attractiveness of opportunities in zone i .

The role of self-potential is highly dependent on zone size, that is, the larger the zone with point i as its centroid, the more influence the zone has on itself. This problem can be counteracted by reducing the size of zone i and minimizing the potential influence of zone i on itself. However, it is not always possible to decrease the zone size so it may be necessary to calculate self-potential. The reason for this procedure is that, if it is not used, then a_{ii} equals infinity since S_i in Equation 23 is being divided by zero.

The most common way to calculate self-potential is to assume that the point i is a circle with uniform density and make d_{ii} one half the radius of point i which is meant to represent the influence of point i on itself.

$$\text{Since area} = \Pi r^2 \quad (24)$$

$$\text{Then } r = \frac{\left(\frac{\text{area}}{\Pi}\right)^{0.5}}{2} \quad (25)$$

Self-potential (Pooler, 1987, p. 270) is:

$$a_{ii} = \frac{2 S_i}{\left(\frac{\text{area}}{\Pi}\right)^{0.5}} \quad (26)$$

Another alternate solution is to use an exponential distance response function to avoid dividing by zero, although this introduces a conceptual problem resulting in

a self-potential that is equal to the total population size (or attraction variable) of the region. Or, as suggested by Goodchild (in Pooler, 1987) one could place a fine grid over the map of interest and calculate the potential at the intersections of the grid. (Pooler, 1987)

Wilson (1978, p. 10) observes that "...accessibility will vary as a consequence of redrawing the boundaries. It is therefore imperative that the boundary chosen is meaningful so that it encompasses a regional totality which functions as a whole". Masser et al. (1975) make additional recommendations for creating zoning systems:

- 1) Determine number of zones required.
- 2) Create compact zones with equal populations.
- 3) Minimize proportion of intrazonal trips.
- 4) Consider major flows between zones, minimize effects of dominant flows.
- 5) Create homogeneous zones with respect to socio-economic characteristics.

5.3.4.6 Use of the Gravity Technique Within Other Models

A gravity formulation can be used within other models to incorporate the effect of accessibility. An example of this usage can be found in Leonardi's (1981) study 'An accessibility-sensitive multiactivity spatial interaction model', which uses Hansen's (1959) formulation and Stewart's (1958) population potential measures within a spatial interaction model. Gravity formulations have also been used within four-step transportation models.

Starting in the early 1970's there was a trend towards disaggregate behavioural modelling (Ben-Akiva and Lerman, 1977; Burns and Golob, 1976; Davidson, 1977; Karlqvist, 1975; Koenig, 1974; Smith, 1980; Weibull, 1976, 1980). This modelling incorporated gravity accessibility techniques based "upon principles of *micro-economic consumer demand theory*." (Morris, Dumble and Wigan, 1979, p. 99) into the trip-generation step of the four-step transportation models (trip generation, trip distribution, modal split and assignment).

The theoretical basis of these micro-economic based gravity techniques has been the subject of several studies, and these investigations are classified into one of four approaches identified by Koenig (1977):

- 1) Common Sense (e.g. Hansen, 1959)
- 2) Axiomatic (e.g. Weibull, 1976)
- 3) Consumers Surplus (e.g. Neuberger, 1971)
- 4) Behavioural Utility (e.g. Koenig, 1977)

In general the approaches suggest that trip generation rate is likely to be influenced by accessibility. (Morris, Dumble and Wigan, 1979)

All four approaches share the following two assumptions:

- "1) people associate a cardinal utility with each of the alternatives they are facing (for example: with each available destination, travel mode, route...) and take the choice associated with the maximum utility to them as individuals; and,
- 2) as it is not possible for a planner to evaluate all factors affecting the utility associated with each alternative by a given individual, this utility can be represented as the sum of a non-random component (for the predictable factors) and a random component (for the non-predictable factors)." (Koenig, 1977, p. 148-149)

Micro-economic consumer based gravity techniques are operationalized in a *disaggregate* manner, meaning that accessibility is calculated separately for different groups as Pirie (1979, p. 302) explains:

"...sophisticated measures of accessibility can be made by computing the measure separately for different trip purposes, different travel modes and travel times, different age, sex, and occupational groups and distinct activity types at each destination. Stratification may also be complemented by including perceptual factors in the accessibility measures: for example, objective distance may be replaced by subjective distance. All of these modifications represent a transition from measures of place accessibility...to measures of person accessibility."

5.3.4.7 Graphical and Spatial Components

The gravity technique, as evident from the above discussion, includes several graphical and spatial components. *Points*, *lines*, and *polygons* are all used in the graphical representation of the gravity technique.

There are three spatial components of the gravity technique:

- 1) *spatial separation* between origin and destination (d_{ij} in Equation 11);
- 2) *distance decay parameter* (constant k in Equation 11); and,
- 3) *zone shape and size*.

5.3.5 Cumulative-Opportunity

Cumulative-opportunity measurement techniques assess the accessibility of various opportunities (destinations) according to the number which can be reached within specified travel distances, times, or costs from the point of trip origin or zone of trip generation. Isolines, which are polygons delineating points of equal travel time (isochrones), equal distance (isodistante) or equal cost, are drawn around the point of origin forming annular zones. The number of opportunities within each zone is counted. (See Figure 24 for an example of how this technique measures accessibility). If desired, the number of opportunities can be replaced by

attractiveness of opportunities. This technique does not display distance-decay effects since the accessibility to opportunities increases as travel distances increase.

Figure 24: Calculation of Cumulative-Opportunity Measurement Technique

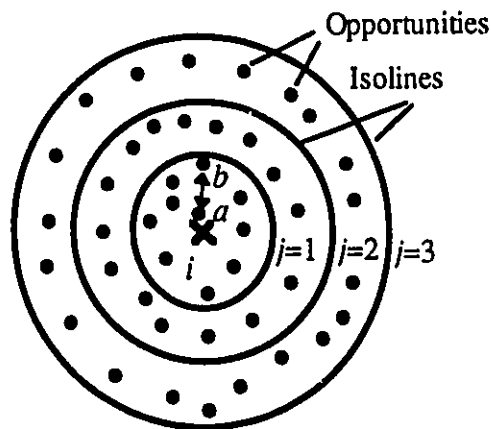
Potential Destination j	Number (N_j) of Opportunities in Destination Zone j	Units of Spatial Separation (d_{ij}) from Origin i
1	10	1
2	15	2
3	20	3

$$A_i = \sum_{j \in d_{ij}} N_j \quad (27)$$

If $d_{ij} = 1$, $A_i = 10$

If $d_{ij} = 2$, $A_i = 25$

If $d_{ij} = 3$, $A_i = 45$



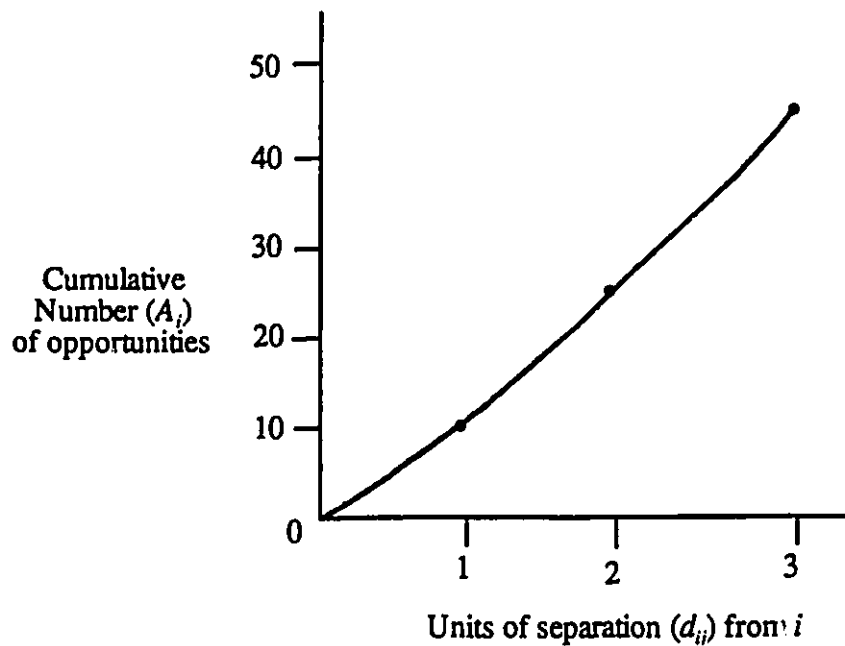
Source: Adapted from Morris et al., (1979, p. 97) and Oberg (1976, p. 31)

5.3.5.1 Accessibility Profile

An accessibility profile is a graphical representation of the cumulative opportunity measurement technique. It shows a cross-section of the distribution of opportunities from the origin to the isoline (polygon) of interest.

An example of an accessibility profile is given in Figure 25, following from the example in Figure 24 and shows that 45 opportunities are reached after 3 units of separation from the origin.

Figure 25: A Graphical Measurement Technique, the Accessibility Profile.



Source: Adapted from Morris et al., (1979, p. 97)

5.3.5.2 Graphical and Spatial Components

The graphical components of cumulative opportunity measurement techniques are *points* (point i , point j , and opportunities) in Figure 24, and *polygons* (isolines) which are zones that encompass areas deemed to be equal in distance, time, or cost from the point of origin.

The main spatial component of the cumulative accessibility measurement technique is the unit of *spatial separation* (distance, time, cost) used to define the *isolines*.

5.3.5.3 Time-Space

Time-space accessibility is a variation of cumulative opportunity accessibility. This technique cannot formally be considered a process measurement due to its reliance on outcome data as will be described. It is included in this section because of its assumption that space (and time) influences the accessibility of individuals.

True to its title, this technique incorporates time considerations. Another feature of this technique is that it makes no assumptions regarding the origin and destination of trips since it relies on disaggregate level records ('outcome' data) on the origin and destination of single trips.

Nutley (1984) uses the time-space technique for a study of rural accessibility and begins by defining a set of functions (services and facilities) which are socially

necessary for a set of villages in rural Wales, (UK). Village populations are categorized by social group (workers, housewives, elderly, and children) and are then divided into car-owners and owners. Data are collected pertaining to the frequency and timing of public transport services and to the times during which functions in the bigger towns are available. Calculations are made to find the number of people or proportion of a community who are able to reach, participate in, and then return home from one or more of these functions. Equation 28 is an example showing how the accessibility for all social groups in village i is calculated. Figure 26 illustrates a graphical result of Equation 28.

$$A_i = 100 \sum_{k=1}^S p_{ik} f_{ik} / f_N \sum_{k=1}^S p_{ik} \quad (28)$$

where in village i :

A_i = accessibility of village i for all social groups

p_k = population of social group k

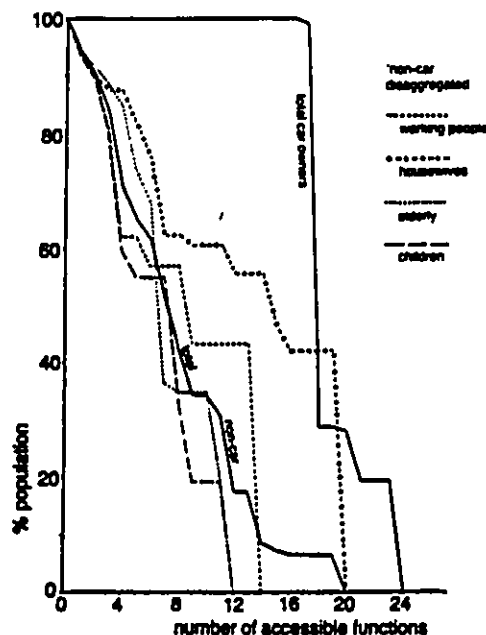
k = social group

f_k = number of functions accessible to social group k

f_N = total number of functions

S = number of social groups

Figure 26: Cumulative Accessibility Curves



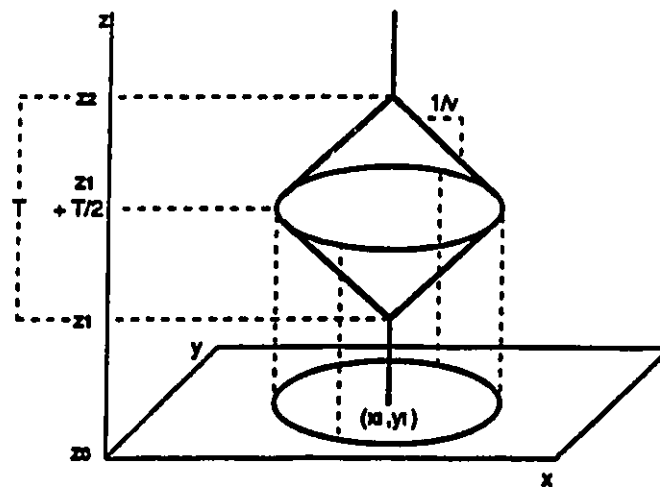
Source: Nutley (1985, p. 41) "South Radnor, Current Conditions"

In a separate study, Miller (1991, p. 287-288) uses a space-time prism to:

“...delimit what can be physically reached by an individual from specified locations during a given interval of time. The prism is determined by the location(s) at which the individual must be at the beginning and end of the interval, any time required for participation in activities during that interval and the rates at which the individual can trade time for space in movement.”

In Figure 27, the space-time prism (PPS) shows the portions of space that are possible for an individual to occupy at given times. The x and y axes represent a 2D planar space, while the z-axis represents time. The potential path area (PPA) is illustrated in the diagram as the circle in the x-y plane. It marks the spatial extent within which an individual can travel. Miller (1991) states that the PPA is of more direct concern in travel modelling, locational analysis and transportation planning, and other applications than the PPS. The 2D planar space PPA illustrated in Figure 27 is discarded for 2D discrete space version because the planar representation wastes a large amount of space as travel occurs in channels and activities occur at locations.

Figure 27: Schematic Representation of the Space-Time Prism



Source: Miller (1991, p. 290)

Miller (1991) operationalises this 2D discrete space PPA using a Geographic Information System (GIS). The data inputs to the GIS are *points* representing the origin of travel and the destinations (opportunities), and *lines* representing either straight-line or street-network distance between origin and destination.

5.3.5.4 Graphical and Spatial Components

The graphical components of the time-space measurement technique are *points* (origin and destination of travel), *lines* (distance between origin and destination), and *polygons* (2D planar space version of PPA delineates the spatial extent of travel for an individual).

There are two spatial components of this technique. The first is the *spatial separation* between origin and destination points. The second component is the spatial delineation of isolines (polygons) which represent the spatial area in which an individual is able to travel under given time constraints.

5.3.6 Strengths and Weaknesses of Accessibility Measurement Techniques

The strengths and weaknesses of the various accessibility measurement techniques are summarized in Table 11.

5.3.6.1 Distance

A strength of the distance measurement technique is that it is simple to implement (Morris, Dumble and Wigan, 1979; Pirie, 1979). However, a drawback of the distance (and topological) measurement techniques is that they ignore the 'opportunity' component of accessibility (attractiveness of opportunities), by only measuring the distance or links between points (Wilson, 1978).

5.3.6.2 Topological

The topological measurement technique is recommended on the basis that it is descriptive of network structure and can evaluate changes in network structure (Muraco, 1972). However, some criticisms of topological measurement are in the case of Associated Number, since it is a measure over the whole network, it is unable to compare accessibilities between or among points (Vickerman, 1974). Also, Shimbel's Index, another topological technique, is sensitive to network size (Vickerman, 1974).

5.3.6.3 Gravity

Unlike the distance and topological techniques, the gravity technique has the advantage of incorporating attractor variables (Oberg, 1976). However, it does have some detracting elements. There is difficulty in calculating distance decay (Pirie, 1979) (see page 86), sensitivity to zone shape and size (Dalvi and Martin, 1976) (see page 90) and difficulty in estimating and calculating self-potential (Pooler, 1987) (see page 92).

Table 11: Strengths and Weaknesses of Accessibility Measurement Techniques

Accessibility Measurement Technique	Strengths	Weaknesses
Distance	• simple to implement (Morris, Dumble and Wigan, 1979; Pirie, 1979)	• attractiveness of opportunities not included (Wilson, 1978)
Topological	• descriptive of network structure and can evaluate changes in network structure (Muraco, 1972)	• Associated Number is a measurement technique over the whole network, so it is unable to compare accessibilities between or among points (Vickerman, 1974) • Shimmel's Index is sensitive to network size (Vickerman, 1974) • attractiveness of opportunities not included (Wilson, 1978)
Gravity	• incorporates attractiveness of opportunities (Oberg, 1976)	• difficulty in calculating distance decay (Pirie, 1979) • sensitivity to zone shape and size (Dalvi and Martin, 1976) • difficulty in estimating self-potential (Pooler, 1987)

Table 11 Continued: Strengths and Weaknesses of Accessibility Measurement Techniques

Cumulative Opportunity	• weightings of relative importance of separation and number of opportunities (or attraction) are made explicit. (Morris, Dumble and Wigan, 1979) • distribution of the opportunities with increasing distance from a location may be compared against other areas. (Morris, Dumble and Wigan, 1979) • can incorporate attractiveness of opportunities	• isoline of interest may be selected arbitrarily (Pirie, 1979; Ben Akiva and Lerman, 1977) • lack of differentiation between points located within an isoline (Pirie, 1979)
Accessibility Profile	• same as for cumulative opportunity • easier for the practitioner to visualize. (Morris, Dumble and Wigan, 1979)	• same as for cumulative opportunity • no single value of accessibility (Morris, Dumble and Wigan, 1979)
Time-Space	• do not make assumption that all nodes are potential destinations and all origins are known (Pirie, 1979) • incorporates time considerations (Pirie, 1979)	• not sensitive to adaptive behaviour, that is, the fact that accessibility can be created (Pirie, 1979) • data-hungry (Pirie, 1979) • 'outcome' oriented (Pirie, 1979)

5.3.6.4 Cumulative Opportunity and Accessibility Profile

Both the cumulative opportunity technique and the accessibility profile have the advantage of first, incorporating attractiveness of opportunities. Second, these techniques make the weightings between separation and number of opportunities (or attraction) clear (Morris, Dumble, and Wigan, 1979). For example within 10km radius of a particular point 20 opportunities can be measured. Third, the distribution of opportunities with increasing distance from a location can be compared with other areas (Morris, Dumble, and Wigan, 1979). A strength particular to the accessibility profile is that its graphical form is often easier for the practitioner to visualize (Morris, Dumble and Wigan, 1979).

However, there are two weaknesses shared by the cumulative-opportunity technique and the accessibility profile. The first, described by Ben-Akiva and Lerman (1977), is that the isoline (polygon) of interest may be selected arbitrarily. In other words, there may not be a strong theoretical or a logical basis for defining an isoline. A second weakness is the lack of differentiation between opportunities which are adjacent to the origin and those just within the isoline of interest. (Pirie, 1979) For example, in Figure 24, although point *a* is closer to the origin *x* than point *b*, both points are located within the $j=1$ isoline (1 unit from the origin) and as such are considered to have the same accessibility.

5.3.6.5 Time-Space

A strength of the time-space technique is that it does not make the assumption that all nodes are potential destinations and that all origins are known (Pirie, 1979) Process measurements of accessibility, on the other hand, make both these assumptions. The destination assumption refers to the set of opportunities from which travel is assumed to take place. Drawbacks of this assumption are that this set may or may not cover all relevant destinations. Also, the opportunity set may include some destinations which are not relevant (for example, opportunities to which an individual cannot gain access to).

The assumption that all origins are known refers to the fact that origins are picked from which travel is assumed to originate. Like the destination assumption, the origin assumption also has drawbacks. The first is that in the gravity technique all travel is assumed to originate from zone centroids. Unless intrazonal accessibility is calculated, different levels of accessibility existing within individual zones are ignored (Pirie, 1979). Another drawback is that in many cases accessibility measurement techniques are operationalized with trips assumed to originate from homes (Pirie, 1979). This ignores multi-purpose, multi-linked trips (Richardson and Young, 1982) which are visits to various opportunities in a chain. In linked journeys, the origin of a trip may be an opportunity, not an individual's home. Since the time-space technique uses records on actual origins and destinations, it does not need to make these origin and destination assumptions.

A second advantage of the time-space technique is that it incorporates time considerations. However, the time-space technique does have some drawbacks.

One is that it is not sensitive to adaptive behaviour, that is, the fact that accessibility can be created (Pirie, 1979). Accessibility can be created by re-designing an individual's schedule to enable travel to and participation in needed/desired activities. This re-design might involve cancelling an activity, participating in an activity closer to home, or spending less time at each activity. However, by relying on outcome data, the time-space technique cannot readily predict ways in which accessibility can be improved in the future (Pirie, 1979).

Another weakness of the time-space technique is that it requires large amounts of data (Pirie, 1979) on the origins and destinations of single trips. Finally, the technique has been criticized on the basis that it is 'outcome'-oriented, and doesn't predict future accessibility, due to its reliance on current records (Pirie, 1979).

5.3.7 Overview of the Spatial Aspects of Accessibility Measurement Techniques

This section discusses the graphical and spatial components of various accessibility measurement techniques; the influence that scale exerts on the spatial components of the techniques; and finally, the role that scale plays in the selection of a particular measurement technique.

5.3.7.1 Graphical Components

The examination of articles and theses from a spatial perspective yielded a pattern: articles with distance and topological measurement techniques concentrate on point and line representations; those dealing with gravity measurement techniques incorporate points, lines, and polygons (zones); reports on cumulative opportunity techniques use points and polygons (zones); and, studies employing time-space measurement techniques use points, lines and polygons.

This observation is consistent with the definitions of these five types of techniques presented earlier in this chapter, and is summarized in Column 2 of Table 12 which presents the graphical components of accessibility measurement techniques.

5.3.7.2 Spatial Components

The spatial components of the distance, topological, gravity, cumulative opportunity, and time-space measurement techniques are summarized in Column 3 of Table 12. A combination of point and line graphical components allow for measurement of spatial separation along a line connecting two points (origin and destination). This spatial component of separation between origin and destination is present in the distance, topological, gravity, and time-space measurement techniques.

The graphical form of distance decay is evident in x-y plots of distance-response functions (see page 86). Distance decay is recognized as an important spatial component of the gravity measurement technique since it models the influence space/distance has on the degree of spatial interaction.

Table 12: Graphical and Spatial Components of Accessibility Measurement Techniques

Accessibility Measurement Technique	Graphical Component	Spatial Component
Distance	Point, Line	• spatial separation between origin(s) and destination(s)
Topological	Point, Line	• spatial separation between origin(s) and destination(s)
Gravity	Point, Line, Polygon	• spatial separation between origin(s) and destination(s)
		• distance decay
		• zones • shape • size
Cumulative Opportunity	Point, Polygon	• spatial delineation of isolines (polygons)
Time-Space	Point, Line*, Polygon * Miller (1991)	• spatial separation between origin(s) and destination(s)
		• spatial delineation of isolines (polygons)

A polygon graphical component allows for measurement of point phenomena within a zone or isoline (polygon). Polygon representations are part of the gravity, cumulative opportunity, and time-space techniques. The size and shape of zones in the gravity technique and the spatial delineation (extent and form) of isolines (polygons) in the cumulative opportunity and time-space technique are spatial components related to polygons.

5.3.7.3 Scale

Scale influences the spatial components of accessibility measurement techniques, specifically the spatial separation between origin and destination, distance decay, zone shape and size, and spatial delineation of isolines (polygons).

Bach (1981) notes that different units of spatial separation between origin and destination are more appropriate at particular scales (See page 77). This implies that as the scale increases, different modes of transport are required to traverse the distance between origin and destination, and that this influences the selection of the unit of spatial separation.

The distance decay constant, found in the gravity accessibility technique is also sensitive to scale. Wilson (1978) tests accessibility using a gravity measurement technique at 3 different scales (zoning system of 3 nested levels) with different random-generated zone configurations. The size of the zones is found to be crucial

in selecting the distance decay parameter in an accessibility model. As zone size increases, the distance decay parameter of an exponential impedance function declines. "The effect of zone size on the parameter values is highly sensitive for small zones." (Wilson, 1978, p. 86)

Another way in which scale influences accessibility measurement is the effect of zone size on gravity-derived accessibility values documented by Dalvi and Martin, 1976 and Wilson, 1978 and discussed on page 91. With increasing zone size, the zone centroid becomes less representative of the zone as a whole, and this introduces the need for estimating the intrazonal accessibility discussed on page 92.

Isolines (polygons) are also sensitive to scale, in that they must be set at the appropriate level to capture variations in accessibility. The isolines should be "fine enough to capture spatial structure-induced behavioural variations, yet large enough to measure significant increments in the number of opportunities." (Hanson and Schwab, 1987, p. 740)

5.3.7.4 Role of Scale in Selection of Measurement Techniques

The scale at which an accessibility study is conducted can influence the selection of the type of a particular accessibility measurement technique. Black, Kuranami and Rimmer (1982) measure accessibility at two different scales. They use a gravity-type technique for 'macroaccessibility' which measures accessibility of residents of a whole city (Sapporo, Japan) to employment. At a smaller scale, the authors use distance and cumulative opportunity techniques to measure 'mesoaccessibility'. This entails measuring accessibility to schools, shops, health services, recreation, and places of worship on a neighbourhood scale in Sapporo, Japan.

Joseph and Phillips (1984) state that in measuring accessibility for the public to general practitioners the choice of either the regional availability or the regional accessibility technique is influenced by the scale of the study. The availability approach involves a ratio of supply versus demand, as described in Chapter 3, while the accessibility approach represents a gravity measure.

"If levels of spatial aggregation are high (large zones), and even if boundaries are permeable, regional availability measures are more suitable than regional accessibility measures but, at low levels of aggregation (small zones), regional accessibility measures hold a clear advantage." (Joseph and Phillips, 1984, p. 94)

Scale influences the choice of the technique since the availability approach holds the assumption that the zone boundaries are impermeable. This means that individuals are expected to remain within the zone for general practitioner services and not to travel outside the service area for health care. If the zone is large, the permeability effect is minimal, since there is a limit to the maximum distance individuals will travel for services. However, if the zone is small,

"...and particularly in border zones, the probability that individuals might use the services...in a district other than their own increases. At

very low levels of spatial aggregation (small zones), such as the urban census tract, this permeability problem would seriously compromise the regional availability approach unless the flows in each direction across regional boundaries were always exactly counterbalancing." (Joseph and Phillips, 1984, p. 94)

These examples suggest that the distance and cumulative opportunity techniques may be particularly suited to projects at the local (neighbourhood) level. At regional scales, either the gravity technique or availability approach (which calculates the number of opportunities per capita) can be used. However, if the size of the zones into which the region has been divided are too small, an availability approach may not be appropriate. This is because there is a strong probability that individuals within these smaller zones would use opportunities outside their assigned zone.

5.4 Summary

The three principal means of classifying accessibility measurement techniques are:

- a) relative vs. integral (Ingram, 1971)
- b) process vs. outcome (Morris, Dumble and Wigan, 1979)
- c) distance vs. topological vs. gravity vs. cumulative opportunity (Pirie, 1979)

Relative accessibility is the degree to which two places (or points) on the same surface are connected. *Integral* accessibility is defined as the degree of interconnection for a given point with all other points on the same surface. (Ingram, 1971) Distance, time, cost, and convenience and variants thereof can be used to measure separation.

The second means of differentiating between accessibility measurement techniques arises from the difference between *process* and *outcome* measurement techniques. The *process* type investigates the potential or opportunity to travel to activities whereas *outcome* measurement techniques look at actual use.

Finally, accessibility measurement techniques can be classified as: distance, topological, gravity, and cumulative opportunity types.

Distance measurement techniques quantify accessibility in units of time, cost and distance based on the premise that the distance separating two points affects the degree of relative accessibility between the points.

The *topological* technique describes networks based on the presence and numbers of links, and the direction of flow, rather than considering the distance between network vertices. (Kansky, 1963)

Gravity (and potential) techniques differ from all other types in that they contain a distance decay term, which represents a decline in the likelihood of travelling to a particular point with increasing distance that must be travelled to reach that point.

Gravity formulations can incorporate a term which represents the attractiveness of opportunities. *Potential*, a variation of the gravity technique, includes a weighting variable that represents the economic importance of a zone to opportunities.

The *cumulative opportunity* measurement technique quantifies the accessibility of various opportunities (destinations) according to the number which can be reached within specified travel distances or times from the point of trip origin or zone of trip generation.

An *accessibility profile*, which plots the independent variable of units of separation against cumulative percent of opportunities is a graphical means of presenting a cumulative opportunity accessibility measurement.

Time-space accessibility delimits the spatial extent of the area that can be reached by an individual during a given interval of time.

The spatial considerations related to measuring accessibility are the:

- 1) *graphical* components of accessibility measurement techniques;
- 2) *spatial* components of accessibility measurement techniques;
- 3) influence of *scale* on the spatial components of techniques; and,
- 4) significance of *scale* in selecting and implementing accessibility measurement techniques.

The *graphical* components of accessibility measurement techniques are combinations of points, lines and polygons. Distance and topological measurement techniques concentrate on point and line representations, gravity measurement techniques incorporate points, lines and polygons; cumulative opportunity techniques use points and polygons; whereas time-space techniques employ points, lines, and polygons.

The *spatial* components of accessibility measurement techniques are spatial separation between origin and destination; distance decay; zone shape and size; and the spatial delineation of cumulative opportunity isolines (polygons). The distance, topological, and gravity, and time-space techniques contain the spatial component of separation between origin and destination. Gravity measurement also includes the spatial components of distance decay and zone shape and size. Finally, the spatial delineation of isolines (polygons) is the primary spatial element of the cumulative opportunity and time-space techniques.

Scale influences the spatial separation between origin and destination; distance decay; zone formation; and spatial delineation of isolines (polygons) in accessibility measurement techniques. *Scale* can also play a part in selecting a particular type of accessibility measurement technique.

The next chapter explores the application areas for accessibility measurement techniques, the relative use of various techniques, and the degree of use of GIS to implement the techniques.

6. Applications of Accessibility Measurement Techniques

This section investigates the accessibility literature for case or comparative study reports on:

- a) experiences with using accessibility measurement techniques in real-world situations;
- b) types of applications that use the techniques;
- c) relative use of different types of accessibility measurement techniques for various applications; and,
- d) use of Geographic Information Systems (GIS) to support the application of accessibility measurement techniques.

The basis for this examination is a group of 173 publications on the topic of accessibility consisting of journal articles, books and book chapters, departmental and research institute papers, bulletins, government, business organization and consulting company reports, and conference proceedings papers. As discussed in Chapter 2, these publications are extracted for examination by means of a keyword search for accessibility of Pirie's bibliography (Pirie, 1981); 'Geographical Abstracts Subject Index' (Geo Abstracts Ltd.) 1980-1989; 'Geobase' (Geo Abstracts Ltd.) electronic listings 1990-1994; and, cross-references from publications extracted from these three sources.

6.1 Empirical Applications Versus Techniques Focus of Accessibility Publications

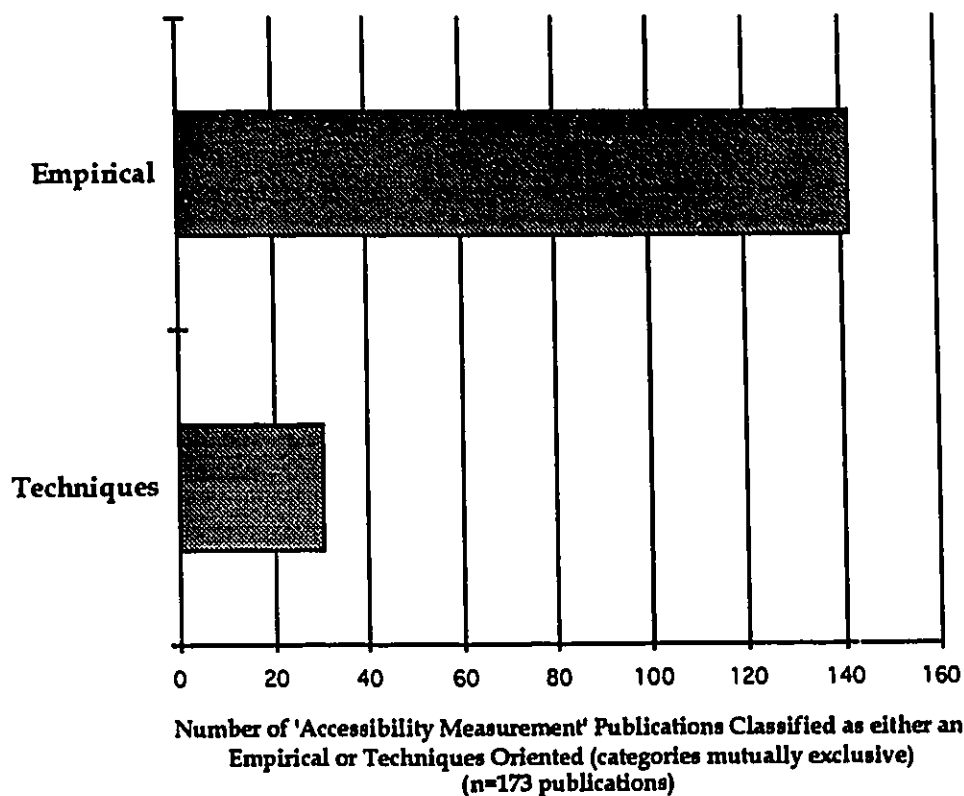
The group of 173 publications is examined for its empirical versus techniques focus and the results are presented in Figure 28.

"In science, inquiries are undertaken to:

- 1) add to knowledge of a subject matter nature; and,
- 2) to add to ways and means of continuing to add to knowledge, through new or different research methods, research techniques or research operations." (Wellar and Harris, 1992, p. 91)

As can be seen in Figure 28, there is a strong focus on the former type of inquiry, that is the empirical applications of accessibility measurement techniques. However, there is less focus on the latter type of inquiry, the development and improvement of techniques of measuring accessibility.

Figure 28: Empirical Versus Techniques Orientation of Accessibility Measurement Literature



Publications are classified as 'techniques driven' if they explore the mathematical form and underlying assumptions of accessibility measurement techniques. As such, the use and substitution of different attractiveness variables is not considered to be a 'techniques' contribution. Techniques-oriented publications add to the "ways and means of continuing to add to knowledge" (Wellar and Harris, 1992, p. 91). On the other hand, publications which use existing measurement techniques to investigate phenomena such as rural transport and employment opportunities are simply adding to the knowledge of subject matter.

In the next section, the 142 applications-oriented publications are explored in more detail.

6.2 Applications of Accessibility Measurement Techniques

The heavy emphasis in the literature on the applications of accessibility measurement techniques poses the question: for what purposes have the techniques been used? The results of the classification of 142 application-oriented publications are presented in Table 13. The publications are categorized (in a mutually exclusive manner) according to their main application area of focus:

transportation planning/modelling, urban/regional structure, health care, economy, service/facility location, rural studies, employment, shopping, housing, social indicators, population growth, recreation, and crime.

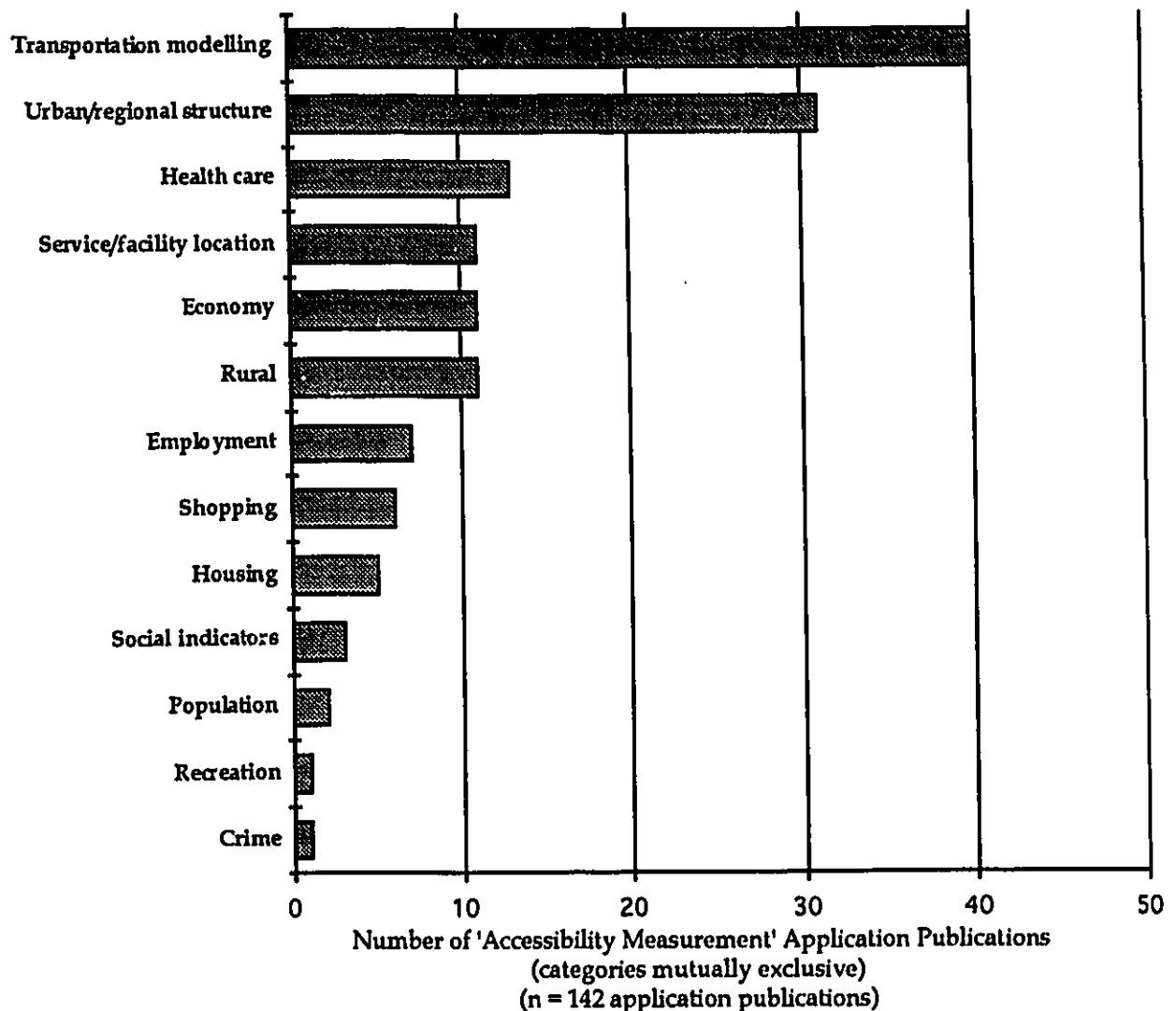
Table 13: Type of Accessibility Measurement Technique by Application

Application	Total Articles	Accessibility Measurement Techniques						Use of GIS
		Distance	Topological	Gravity	Micro-economic consumer behaviour	Cumulative Opportunity	Time-space	
Transportation Planning/Modelling	40	12	10	14	4	15	1	0
Urban/Regional Structure	31	10	4	25	0	6	1	0
Health Care	13	4	0	7	1	2	0	0
Economy	11	2	3	6	0	0	0	0
Service/facility location	11	5	0	5	1	2	1	1
Rural Studies	11	4	0	1	0	5	5	0
Employment	7	1	0	4	0	2	0	0
Shopping	6	3	0	3	0	2	0	0
Housing	5	3	0	0	0	2	0	0
Social Indicators	3	0	0	1	0	3	0	0
Population Growth	2	2	0	0	0	0	0	0
Recreation	1	1	0	0	0	0	0	0
Crime	1	0	1	0	0	0	0	0
Total	142	47	18	66	6	38	8	1

*Columns are not mutually exclusive, Rows (Applications) are mutually exclusive

Figure 29, derived from Table 13, shows that transportation modelling/planning/network studies and urban/regional structure/planning are the most common application areas, followed by health care, service/facility location, economy, rural studies, employment, shopping, housing, social indicators, population growth, recreation and crime studies.

Figure 29: Areas of Application for Accessibility Measurement Techniques

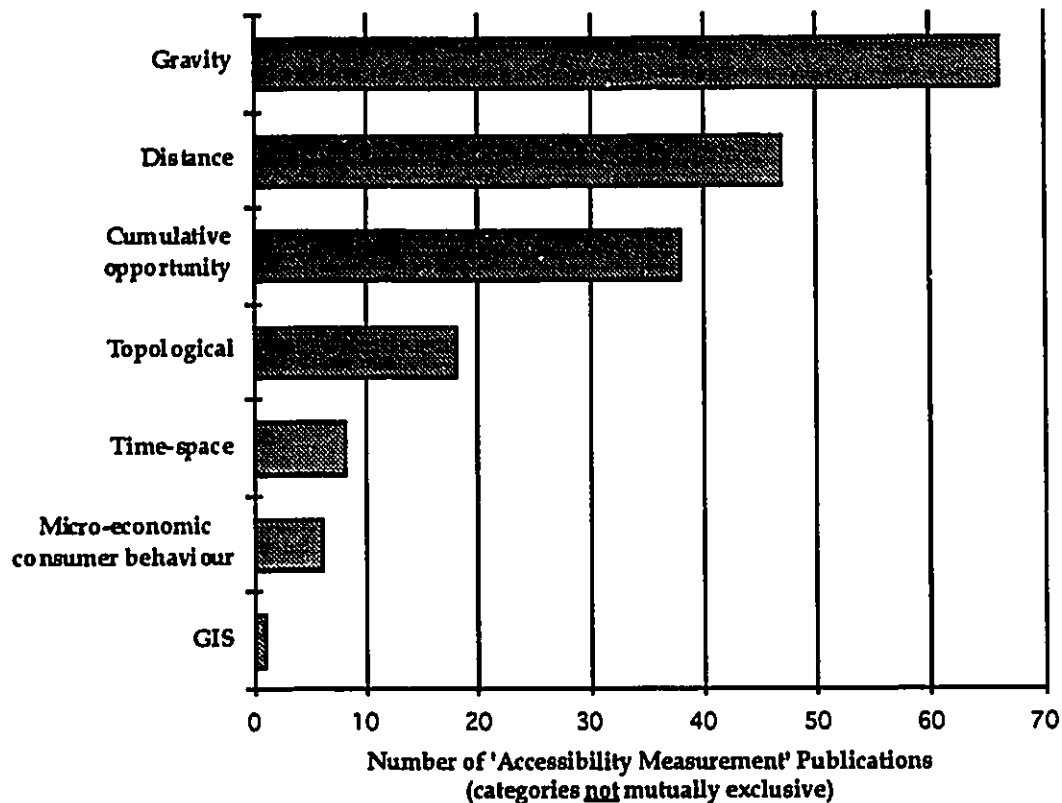


6.3 Relative Use of Various Accessibility Measurement Techniques

The empirical publications are examined for the relative use of accessibility measurement techniques and the results are presented graphically in Figure 30. As illustrated in Figure 30, gravity-based measurement techniques are by far the most

commonly used. However, distance and cumulative opportunity are also popular. Topological (network-focussed) measurement techniques are more common than time-space techniques. Micro-economic behaviour-based measurement techniques are less popular. Some of the papers review several techniques and therefore the categories in Figure 30 are not mutually exclusive.

Figure 30: Relative Use of Various Types of Accessibility Measurement Techniques



6.4 Use of Geographic Information Systems to Implement Accessibility Measurement Techniques

The use of Geographic Information Systems (GIS) to implement accessibility measurement techniques is lacking in the searched journal literature (up until 1994); only three articles (Algeo, 1993; Miller, 1991; Okafo, 1990) discussed how a GIS could be used to implement an accessibility measurement technique. Two of these articles (Miller, 1991; Okafo, 1990) do not appear in Table 13 since they are classified as 'techniques' driven (see page 108) and focus on improving the techniques of accessibility measurement.

Algeo (1993) uses a GIS to implement a gravity measurement of accessibility to daycare facilities. Miller (1991) and Okafo (1990) both investigate the way in which a GIS can be used to operationalise a time-space measurement technique.

Although accessibility measurement techniques can deal with discrete graphical elements (points, lines, and polygons), the use of GIS to implement the techniques is very infrequent. This is surprising, given that GIS has superior abilities in the ability to “calculate the distance of a straight or curved path between points (or areas)” (Wellar, 1993, p. 12), and which could aid in the implementation of distance, topological and gravity techniques. GIS is also proficient in “count(ing) the number of points (sites) within an area (zone)” (Wellar, 1993, p. 11), which is a necessary operation in the gravity and cumulative opportunity techniques.

6.5 Summary

The accessibility literature search yielding 173 publications is examined on the basis of four ‘filters’ or criteria:

- a) reports on experiences with using accessibility measurement techniques in real-world situations;
- b) types of applications that use the techniques;
- c) relative use of different types of accessibility measurement techniques for various applications; and,
- d) use of Geographic Information Systems (GIS) to support the application of accessibility measurement techniques.

Transportation modelling/planning/network studies and urban/regional structure/planning are the most common application areas of accessibility measurement techniques followed by health care, service/facility location, economy, rural studies, employment, shopping, housing, social indicators, population growth, recreation and crime studies.

Although the accessibility measurement techniques can be represented by discrete graphical elements, the use of GIS to implement the techniques is very infrequent.

In the next chapter, the relationship between accessibility and location and transportation network decisions is explored in preparation for the real-world survey of organizations. That phase of the inquiry surveys public and private organizations for the role accessibility plays in *real-world* location and transportation network decisions.

7. The Relationship between Accessibility, Location, and Transportation Network Decisions

The purpose of this chapter is to examine in general terms the underlying goals and jurisdiction of public and private organizations over location and network decisions, and the role accessibility plays in these decisions.

Before location and transportation network decisions are discussed separately, it must be emphasized that location and transportation system decisions influence each other. McCarthy (1984, p. 76) explains that the

“implementation of policies which affect a transport system’s characteristics will also have repercussions upon the location of residences, firms, commercial activities, and so forth. This will feed back upon the transport system and, to a greater or less degree, change its characteristics. Thus, accessibility covers both transport and land use in an area, and recognizes that they are highly interdependent.”

The location and transportation network decisions which are the focus of this thesis, and previously outlined in Chapter 3, are of the following types:

- 1) **Location:** the siting of *opportunities*, that is, the point or place where there is an opportunity for spatial interaction;
- 2) **Network:** the location of *travel routes*, and the spatial characteristics of transportation networks (which are composed of travel routes); and,
- 3) **Routing:** the spatial strategy, plan, logic, algorithm, or other kind of reasoning by which *transport modes* (e.g. road vehicles) navigate transportation networks (e.g. a regional road system).

In regard to how location, network and routing factors affect decision-making in relative terms, Nutley notes that Decision Types 1 and 2 involving new infrastructure cannot be changed as quickly as Decision Type 3 dealing with routing or transport mode strategy. “In the longer term, general accessibility could be improved by normal land-use planning, involving changes in settlement pattern, availability of functions, and road building. In the shorter term...planning is dominated (although not exclusively) by transport.” (Nutley, 1984, p. 359)

The next several pages discuss the three types of decision in order to lay a foundation for the empirical research that follows.

7.1 Location Decisions

Location decisions relate to the siting of opportunities, that is, the point or place where there is an opportunity for spatial interaction. Both public and private organizations need to locate opportunities (Landis, 1993; Bach, 1980) In the context

of location decisions, these opportunities refer to facilities which distribute services. In Canada, the public sector has some control over the location of private sector facilities through zoning laws. (Commission on Planning and Development Reform in Ontario, 1993; Transport 2021, 1993b)

Public sector services are "programs and services provided or subsidized by a government or other public body." (Commission on Planning and Development Reform in Ontario, 1993, p. 144) Public sector facilities are "buildings and structures for the provision of public services." (Commission on Planning and Development Reform in Ontario, 1993, p. 144) On the other hand, the private sector is the "part of a national economy which is not subject to direct government ownership and control." (Goodall, 1987, p. 377) "The most distinguishing factor between business (private sector) and public sector is - business sells products and services for profit; government provides services to guarantee or enhance the health, safety and well-being of the governed." (Parr, 1992, p. 249)

Differences exist in the underlying goals of public and private sectors. Price and Blair (1989, p. 221) elaborate on these differences. "Different location principles may apply to suppliers of private and public sector activities, with the former having commercial aims and the latter perhaps being influenced by equity considerations."

"Private sector services exist to meet an actual or perceived potential demand and they locate where they can best serve their market." (Price and Blair, 1989, p. 221), whereas, "public service facilities are usually planned in a longer term context than is usual in retailing and are less subject to commercial constraints." (Price and Blair, 1989, p. 77)

Price and Blair (1989, p. 80) state that the public and private sectors make different location decisions based on differing goals of equity and profit. "Studies of public service provision in which equity considerations are prominent differ from studies of other forms of service provision in their emphasis rather than their method, but there are significant differences in the location patterns that result when equity instead of profit is the guiding principle in decision-making."

The private sector focus on profit, and the resulting locational patterns have been criticized. "(Retailers) are also keenly aware of the advantages accruing from decentralisation to suburban or out-of-town centres, but they have attracted criticism as a result for not embracing the needs of the poor, old, and immobile in their perception of the market." (Price and Blair, 1989, p. 222)

What role does accessibility play in public and private location decisions? Accessibility measurement techniques are used to evaluate the location of both public and private sector facilities (Landis, 1993; Bach, 1980), thereby evaluating the equity and/or profit-making ability of a particular location.

Location decisions can involve a single facility; a system of facilities; or the optimization and timing of plans for a system of facilities. These decisions are listed below:

- 1) single central facility;

- 2) system of central facilities; (Bach, 1980, p. 303)
- 3) for an existing system of central facilities, "new facilities have to be added owing to a spatial and/or qualitative shift of demand for infrastructural services"; (Bach, 1980, p. 303)
- 4) "a combination of central locations selected out of a multitude of potential locations"; (Bach, 1980, p. 303)
- 5) "a system of central facilities must be timed in accordance with the projected shift of demand and/or the midrange capital budget system". (Bach, 1980, p. 303)

Decisions on the location of a single central facility can be made on the basis of 9 alternative definitions for central locations relating supply to demand points (Bach, 1980, p. 303):

- "Model 1: Central point: the point minimizing the sum of distances.
- Model 2: Median point: the point minimizing the sum of rectilinear distances.
- Model 3: Arithmetic mean point: the point minimizing the sum of squared distances.
- Model 4: Center point: the point minimizing the maximal distance.
- Model 5: Facility-oriented point of potential: the point maximizing facility usage.
- Model 6: User-oriented point of potential: the point maximizing access opportunity for the sum of locations of users.
- Model 7: User-oriented point of equalized potential: the point equalizing access opportunity for the individual location of users with regard to all other locations of users.
- Model 8: Radial point: the point from which all users can be reached within a maximum allowable distance.
- Model 9: Constrained radial point: the point from which the maximum number of users can be reached within a maximum allowable distance."

Bach (1980) states that models 1-5, 8 and 9 contain a concept of *accessibility* and models 6 and 7, one of *access opportunity* (See Chapter 3, page 37).

Location decisions involving a system of facilities (p. 130 - Decisions 2, 3, 4 and 5) can be solved by a location-allocation model which is a technique that can simultaneously determine:

- "1) the best locations for new...(facilities) based on stated corporate objectives; and,
- 2) the allocation of consumers to those (facilities) based on the expected pattern of consumer travel." (Ghosh and McLafferty; 1987, p. 127)

Consumers can be allocated to facilities in four alternative ways according to Bach (1980, p. 304):

“Model A: District boundaries formed by points of equal distances between neighbouring central facilities.

Model B: District boundaries formed by points of equal potential between neighbouring facilities.

Model C: Districts as attraction-dependent and distance-dependent spheres of influence of central facilities.

Model D: District boundaries formed by points of a maximum allowable distance from a central facility”.

Accessibility measurements can be incorporated into location-allocation models and are then maximized or weighted (Ghosh and McLafferty, 1987) depending on the goal for the location of the central facility as demonstrated by Bach (1980). Location-allocation modelling isn't examined in detail in this thesis since it constitutes a separate topic on its own. The point of interest to make, however, is that accessibility measurements within these models incorporate:

- a) the effect of distance/space on the location of facilities; and,
- b) the extent of each facility's service area.

7.2 *Transportation Network Decisions*

Transportation network decisions relate to the:

- 1) **Network:** the location of *travel routes*, and the spatial characteristics of transportation networks (which are composed of travel routes); and,
- 2) **Routing:** the spatial strategy, plan, logic, algorithm, or other kind of reasoning by which *transport modes* (e.g. road vehicles) navigate transportation networks (e.g. a regional road system).

The location of travel routes refers to the linear location of new roads, highways, railway lines, and initiation of new airline and shipping routes. The spatial characteristics of transportation networks describes the interconnection between travel routes (connections, intersections and number of these links) between travel routes. Accessibility measurement techniques have been used in transportation planning to examine opportunities created by new roads (Jones, 1982); to look at regional economic development effects of new roads (Dodgson; 1974; Botham, 1980; Linneker and Spence, 1992); and, to evaluate the spatial structure of transportation systems (Taylor, 1976; Muraco, 1972).

For the most part in Canada, decisions on the location of travel routes and the spatial characteristics of transportation networks are controlled by the public sector (Transport 2021, 1993b; Canada Mortgage and Housing, 1993), although private sector consulting and construction firms may be involved in designing and building the travel routes (See, for example, Eedy, 1982; O'Connell, 1982).

The strategy by which some transport modes navigate the transportation network is called *routing*. *Routing* means "legal travel from one point to another along a designated transportation network. Used in this context, legal means making only allowable turns or transfers." (Landis, 1993, p. 33) The goals of vehicle routing and scheduling "are minimizing the number of routes created and minimizing the total dead head time." (Bodin et al., 1993, p. 284)

Routing, or the strategy by which transport modes navigate transportation networks, is implemented by both the public and private sectors. The public sector regulates safety concerns such as the inspection of commercial vehicles, load restrictions, speed limits and other regulations (Canada Mortgage and Housing Corporation, 1993). Both public and private sectors work within these regulations to move goods and people. The public sector's main role with respect to the transport mode strategy is moving people by providing and subsidizing public transportation (Canada Mortgage and Housing Corporation, 1993).

Street routing can be classified in two ways. One class is called *point-to-point routing*. A second class is called *neighborhood routing*.

Point to point (or node) routing is found in the following activities:

- "1) routing a fleet of vehicles delivering goods to a specified set of locations;
- 2) courier delivery services; and,
- 3) scheduling of field services personnel." (Bodin et al., 1993, p. 283)

In *neighborhood routing*, most streets in an area require service, and occur in such applications as:

- "1) household refuse collection;
- 2) scheduling of meter readers;
- 3) door-to-door delivery of telephone books; and,
- 4) third class mail alternatives." (Bodin et al., 1993, p. 283)

Key features of point-to-point and neighborhood routing over street networks are the following:

- "1) customers are geocoded (or assigned) to the street segment rather than the nearest intersection;
- 2) travel times between customers or the customers and the depot are computed as shortest paths over the street network rather than being computed as a function of the 'crows-fly' or Euclidean distances between these points; and,
- 3) travel paths between customers are found over the street network." (Bodin et al., 1993, p. 283)

The incorporation of key feature 2, travel times as shortest paths over the street network, demonstrates that accessibility is an essential consideration in street routing strategy.

7.3 Summary

The location and transportation network decisions which are the focus of this thesis are of the following types:

- 1) **Location:** the siting of *opportunities*, that is, the point or place where there is an opportunity for spatial interaction;
- 2) **Network:** the location of *travel routes*, and the spatial characteristics of transportation networks (which are composed of travel routes); and,
- 3) **Routing:** the spatial strategy, plan, logic, algorithm, or other kind of reasoning by which *transport modes* (e.g. road vehicles) navigate transportation networks (e.g. a regional road system).

Decisions on the location of opportunities (Decision Type 1) can incorporate different accessibility considerations, depending on the goals which relate supply to demand points. Location decisions involving a system of opportunities can be solved by a location-allocation model which simultaneously determines the location of new opportunities and the service area of each opportunity. Accessibility measurements within these models incorporate the effect of distance/space on the location of opportunities and the extent of each opportunity's service area.

Accessibility measurement techniques have been used for transportation network decisions (Decision Type 2) to examine opportunities created by new roads, to look at regional economic development effects of new roads, and to evaluate the spatial structure of transportation network decisions.

Routing decisions (Decision Type 3) can incorporate accessibility techniques by way of a shortest path algorithm which solves for an optimal route over the street network.

Through examination of the accessibility *literature*, this chapter has explored the role that accessibility plays in location and transportation network decisions of public and private organizations. The next chapter outlines the procedure for the *real-world* inquiry into the role accessibility plays in *real-world* location and transportation network decisions of public and private organizations.

8. Procedure for Surveying the Real-World Usage of Accessibility Measures

The second phase of the thesis is a survey of the conceptual and operational use of accessibility measures in the *real world* by public and private sector organizations. An *interview* approach is selected in order to allow exploration of responses, and also to explain and confirm concepts using graphical aids. The interview has three main objectives:

- 1) to ascertain how accessibility is *defined* in conceptual and operational terms;
- 2) to determine how accessibility is *measured* and *implemented* in operational terms; and
- 3) to obtain recommendations on the most substantive, relevant literature on the topic of accessibility as seen by practitioners with day-to-day responsibilities for transportation, planning and operations.

Again, emphasis is placed on the spatial dimension of accessibility.

An additional purpose of the survey is to establish if, and how, practitioners model and graphically represent their findings. Of particular interest is the nature, degree and extent to which geographic information systems (GIS) are employed as research-action tools in association with accessibility plans and decisions (Landis, 1993; Wellar, 1993; Wellar and Harris, 1992).

8.1 Scope

Interviews are limited to practitioners with responsibility for accessibility as it relates to walking, cycling, subway transit, auto, truck and bus traffic. For reasons of resource constraints (time and money) the study does not include airplane, boat or train mode of transport. Further, interviews are limited to practitioners who operate at the urban and regional scale, most notably the Regional Municipality of Ottawa-Carleton (RMOC), and transit authorities.

8.2 Definition of the Research Population

Public and private facilities and routes are planned and decided upon by both public and private organizations. Within public sector organizations accessibility is a concern of transportation planners, traffic engineers, comprehensive planners, and environmental planners (Polus and Kumove, 1979). Such employees are retained by municipal, regional and city governments, and provincial transportation ministries.

Within the private sector, organizations offering comprehensive planning, environmental planning, transportation design and engineering services (Polus and Kumove, 1979) and firms with a specialized focus (e.g. library or recreational

planning) plan locations of facilities and routes. These organizations also assist public sector organizations in their location decisions. Finance and insurance, health care, real estate, retail, wholesale, service, distribution (courier and trucking), utility, and communication firms are also concerned with accessibility and independently employ individuals who make location decisions (Castle, 1993).

The research population for this study therefore consists of public and private sector entities that are responsible for, or are affected by the accessibility features and outputs of transportation systems, and of urban and regional land use planning and development processes. It is acknowledged that 'ordinary citizens' have clear and direct interest in the topic of accessibility (Wellar, 1994). However, that is a major area of study in its own right, and is considered to be beyond the purview of the proposed inquiry. As a result, 'ordinary citizens' are not included in the research population, and the focus is limited to the enterprise aspect of accessibility.

8.2.1 Segments/Organizations Studied

The market segments and organizations which have a concern for accessibility and thus are eligible for study are noted in Table 14.

Table 14: Market Segments and Organizations Studied

Public Sector:
• Federal Government Departments/Agencies • Provincial Ministries of Transport • Regional Authorities • Cities & Municipalities • Transit Authorities • Emergency Services - Ambulance, Fire & Police
Private Sector:
• Engineering, Planning, and Land-Use/Transportation Consultants • Trucking (line-haul) and Courier Companies

Due to the length of this list, and limited time and resources not all organizations and market segments are included in the interviews. Instead, constraints require that the initial public interviews be limited to practitioners in federal government departments, provincial ministries of transport, regional authorities, cities & municipalities, transit authorities and emergency services (ambulance, fire and police). Similarly, private sector interviews are limited to engineering, planning and land-use/transportation consultants; and, trucking, delivery, and courier companies.

8.3 Research Sample

8.3.1 Procedure for Selection and Screening of Participants

The study procedure involves an initial contact by telephone with each organization. Potential participants from these individual companies and organizations are screened by the question, "Do you advise/plan/decide upon the location of facilities or routes?" If the answer is affirmative, then an attempt is made to schedule an interview with this individual or combination of individuals. And, if the response is in the negative, then the company or organization is discarded.

Due to the difficulty in obtaining interviews with some of the organizations and individuals, and especially those concerned about disclosing 'trade or corporate secrets', this sample represents a non-probability sample. Specifically, it is an availability sample, as discussed in Chapter 2 (page 22).

8.3.2 Public Sector

Within the public realm, the (British Columbia) B.C. Ministry of Transportation (and Highways) is selected as an example of a Provincial Ministry of Transport. The Regional Authorities profiled are Greater Vancouver Regional District (GVRD), Regional Municipality of Ottawa-Carleton (RMOC), and the Municipality of Metropolitan Toronto (Metro Toronto). Representing the Cities and Municipalities category are The Municipality of Burnaby (an inner suburb) and the Municipality of Delta (a largely rural municipality) selected from the 15 municipalities under GVRD's jurisdiction. The City of Ottawa (city core) is selected from 9 municipalities under RMOC's jurisdiction. BC Transit and OC Transpo are profiled as Transit Authorities. Finally, emergency services are represented by the Ottawa-Carleton Regional Ambulance Centre, the Ottawa Fire Department, and Ottawa Police.

It is emphasized that the sample of public sector agencies is not intended for statistically inferential purposes. Rather, the sample is intended to serve the immediate, explorative interests of this research, and to provide a basis for subsequent inquiries of a formal, comparative nature.

8.3.3 Private Sector

The selection of the Vancouver Engineering, Planning and Land-Use/Transportation Consultants (Urban Systems, Terry Partridge & Associates) is based on examining the 'Urban and Regional Planners' section of the Vancouver BC-Tel yellow pages (BC-Tel, 1994). Both firms fulfill the selection and screening criteria; however only a short *telephone* interview was conducted, because of scheduling problems. Due to the difficulty in obtaining full interview responses, these two firms are not directly included in the findings.

The initial source for candidates in Ottawa-Carleton is the 'Engineers' and 'Consulting Engineers' section of Tele-Direct's Ottawa-Hull yellow pages (Tele-Direct, 1994). As a filter, the firm must list the word 'planners' in its ad, since the 'Engineers' and 'Consulting Engineers' section is made up of many firms which have a focus on construction or maintenance services, and not on the planning element. Out of the total of twelve firms which satisfy this criterion, four companies which pass the selection and screening and agreed to an interview are: UMA Engineering; J.P. Braaksma & Associates; Delcan Corporation; and the Toronto-based IBI Group.

Canadian Freightways in Vancouver has been selected as an example of a trucking firm, and Fedex is an example of a courier company. Both these firms fulfill the selection and screening criteria and are available for interview.

The sample is biased towards the public sector in terms of numerical representation, since a higher proportion of public sector organizations are interviewed. The public sector portion of the sample is representative of the public sector, since it covers a wide range of public sector segments. However, the private sector portion is more limited and covers only 2 market segments.

Organizations, departments and individuals dealing with transportation network decision-making, as opposed to location decision-making, are over-represented in the sample. Interviews with four of the five public sector market segments are conducted with individuals who deal with the transportation network side of accessibility (Provincial Ministries of Transport, Regional Authorities, Cities and Municipalities, Transit Authorities, and Emergency Services).

The private sector interviews also concentrate on the transportation network side of accessibility. The private market segment of trucking, delivery, and courier companies deals exclusively with transportation network decisions. However, the second private market segment, the engineering, planning and land use transportation consultants consider both facility location and transportation network decisions.

8.4 Pre-Test

An initial set of four interviews (two public, two private) is used to pre-test the survey instrument. The protocol was modified to the form presented below, but care was taken to ensure that interviews could be incorporated into the final set of interview findings. It is appropriate to note and thank the following participants for their assistance in the pre-testing and re-formulating the instrument used for interviews:

- a) Ms. Maria Salay, British Columbia Ministry of Transportation;
- b) Mr. Gary Vlieg and Mr. Joe Stott, Greater Vancouver Regional District;
- c) Mr. Terry Partridge, Terry Partridge and Associates (not included in findings); and,
- d) Mr. Gary Ronahan, Canadian Freightways.

8.4.1 Interview Procedure

The procedure calls for interviews conducted at the interviewee's site, and the intention is that between 40 minutes to an hour should be sufficient. A semi-structured interview approach is taken, in which the protocol is followed as closely as possible, but with some flexibility. The questions comprising the interview protocol are as follows:

1. How do you define accessibility?
2. What is meant by good accessibility/bad accessibility?
3. Is distance a criterion? What is near and what is far? What is the unit of separation?
4. What barriers exist to limit access?
5. What are the criteria and relative importance of factors in selecting a new location for a facility or route?
6. If an accessibility measure is used, how is it classified:
 - relative or integral?
 - process or outcome?
 - type - distance, topological, gravity or cumulative opportunity?
 - other?
8. Do you use a GIS system? Are results presented graphically?
9. What are the pertinent journal articles, research reports or other references that you use or have used in your work?
10. Can you recommend any other individuals/organizations to interview?

For completeness it is necessary to explain why an open-ended procedure is used. An open-ended set of questions is deemed appropriate at this exploratory stage, and follows the approach developed by Wellar (1994) in his similar study for the Canadian Trucking Association. In Wellar's study the pre-testers suggested that the open-ended approach could and likely would yield responses for the research, but would also provide guidance and ideas for a follow-on directed survey. In particular, the open-ended approach not only yielded responses to questions but also yielded follow-on questions for the next research round.

A pre-test of the questionnaire involving both public and private sector organizations indicates that an open-ended questionnaire is appropriate for three reasons:

- 1) The open-ended approach does not require knowing the specifics of pertinent questions or how to phrase them.

- 2) Due to legislative/institutional/organizational differences, a closed format questionnaire is simply inapplicable.
- 3) The questions are used as a protocol, not as a mailed questionnaire. As such the series of open-ended questions form the basis of a dialogue with the respondents, and do not represent the entirety of the discussions that took place.

8.5 Summary

An interview approach is used to survey the conceptual and operational use of accessibility measures in the real world by public and private sector organizations. Four objectives of the interviews are to find:

- 1) how accessibility is defined in conceptual and operational terms;
- 2) how accessibility is measured and implemented in operational terms;
- 3) recommendations on the most substantive and relevant literature on the topic of accessibility; and,
- 4) if and how practitioners model and graphically represent their findings and if geographic information systems are used.

The interviews are limited to urban and regional scale accessibility as it relates to the walk, cycle, subway transit, auto, truck and bus modes of transport. The research population for this study consists of public and private sector entities that are responsible for, or are affected by the accessibility features and outputs of transportation system and land use planning and development processes.

The market segments and organizations which are studied in this thesis come from both the public and private sectors. The public sector organizations are: federal government departments and agencies; provincial ministries of transport; regional authorities; cities and municipalities; transit authorities; and emergency services.

The two private sector segments interviewed are engineering, planning and land-use/transportation consultants; and trucking, delivery, and courier companies.

The sample taken is an availability sample in that participants representing a market segment or type of organization must pass a screening and selection test and must be available for interview.

For reasons associated with willingness to participate in the study, the sample is biased towards the public sector as opposed to the private sector. Further, the sample of survey respondents contains more segments/organizations/individuals responsible for the transportation network aspect, as opposed to the location of opportunities aspect, of accessibility.

9. Defining and Measuring Accessibility in the Real World

The findings of the personal interviews with public and private organizations focus on:

- 1) their definition of accessibility;
- 2) whether accessibility is measured;
- 3) how accessibility is measured:
 - a) relative or integral
 - b) process or outcome
 - c) type of measurement technique
 - distance
 - topological
 - gravity
 - cumulative opportunity
- 4) organizations' definition of 'near', and units used to measure spatial separation (time, cost and/or distance);
- 5) barriers to accessibility;
- 6) criteria and relative importance of factors in selecting a new location for a facility or route; and,
- 7) the use of GIS to implement accessibility measurement techniques.

9.1 Definition of Accessibility

The key elements of definitions of accessibility given by the private and public sector organizations are presented in Table 15, using the same classification scheme outlined in Chapter 3. Some organizations' definitions contain more than one key element, so the categories are not mutually exclusive. The elements of definitions emphasized by the organizations are arranged according to their supply, demand, and connection emphasis.

Table 15: Key Elements in Public and Private Organizations' Definitions for Accessibility

Organizations n=19*	SUPPLY		CONNECTION								DEMAND	
	Availability	Attractiveness	Characteristics of the Network								Freedom	Utility
			Effort	Convenience	Comfort	Reliability	Safety	Speed	Level of service	Spatial		
Public												
Federal Department of Finance	✓	✓	✓									
B.C. Ministry of Transportation								✓	✓			
RMOC			✓						✓			
GVRD			✓	✓								
Metro Toronto			✓	✓								
City of Ottawa										✓		
Municipality of Burnaby	✓											
Municipality of Delta	✓											
OC Transpo			✓	✓								
BC Transit			✓	✓								
Ottawa-Carleton Regional Ambulance			✓	✓								
Ottawa Fire Department			✓	✓								

Table 15 Continued: Key Elements in Public and Private Organizations' Definitions for Accessibility

Table 15 Continued: Key Elements in Public and Private Organizations' Demands for Performance															
Organizations n=19*	SUPPLY		CONNECTION										DEMAND		
	Availability	Attractiveness	Characteristics of the Network							Spatial	Freedom	Utility			
			Effort	Convenience	Comfort	Reliability	Safety	Speed	Level of service						
			✓												
Ottawa Police															
Private															
UMA												✓			
Engineering															
J.P. Braaksma & Associates			✓									✓			
Delcan			✓												
IBI Group			✓												
Canadian Freightways			✓	✓											
Fedex			✓	✓											
Total # of Mentions	3	1	14	8	0	0	0	1	5		1	0	0	0	
Total Supply, Connection and Demand Aspects	4				28								1		

* A total number of 19 organizations participated in survey

A supply-oriented definition (discussed on page 37) focusses on either or both the:

- 1) availability of opportunities; and,
- 2) attractiveness of opportunities.

Emphasis on the supply side of accessibility is evident in the definitions used by the Federal Department of Finance, and the Municipalities of Burnaby and Delta. For the Federal Department of Finance, the availability of needed services within an isolated northern community and the attractiveness of services (order or level of services) is important in determining eligibility for Northern tax credits. If needed services are not available to residents in a community, then a trip must be made to neighbouring centre possessing such services (Wellar, 1989). The interviews with the Municipalities of Burnaby and Delta addressed the supply of educational and recreational facilities within their jurisdictions.

A *demand*-related definition (discussed on page 37) has two sub-types:

- 1) Freedom of individuals to decide whether or not to participate in different activities. (Freedom)
- 2) Individuals assign a utility to each of their travel alternatives and take the choice associated with the maximum utility. (Utility)

A demand definition is not encountered in the interviews undertaken and the agency reports reviewed. This may be explained by the fact that this interpretation of accessibility focusses on the individual and in this study organizations, are surveyed, not individuals.

The *connection* definition (introduced on page 37) emphasizes:

- 1) Characteristics of the transportation network:
 - effort (distance, time, cost, etc.) required to traverse a travel route
 - convenience
 - comfort
 - reliability
 - safety
 - speed
 - level of service
- 2) Spatial relation or degree of connection between one location and others. (Spatial)

The connection definition is more common among the sampled organizations than either the supply or demand type. The first sub-type of the connection definition, the *characteristics of the transportation network*, is the most often cited with 28 mentions. The second type of connection, the *spatial relation or degree of connection between one location and others*, is only cited once.

Within characteristics of the transportation network, and as illustrated in Table 15, the *effort* required to traverse a travel path is most frequently used to define accessibility. It received 14 mentions from the 19 organizations in the sample.

Convenience is considered to be a component of accessibility by the GVRD, Metro Toronto, OC Transpo, BC Transit, Ottawa-Carleton Regional Ambulance, Ottawa Fire Department, Canadian Freightways and Fedex. For example, OC Transpo (Colin Leech, in conversation), defines accessibility via bus transit as the minimization of waiting time, waiting time between transfers, walking time between home and the bus stop and walking time between the final bus stop and the opportunity.

Level-of-service is a key element in the definition of accessibility for BC Ministry of Transportation, RMOC, UMA Engineering, J.P. Braaksma and Associates, and Delcan. In this study, *comfort*, *reliability*, and *safety* have not been recorded as elements in the definition of accessibility.

The second sub-type, *the spatial relation or degree of connection between one location and others*, is cited by one organization, the City of Ottawa. Chris Lyon, of the City of Ottawa (in conversation), defines accessibility as the ability of individuals to reach a particular land use via any type of mode of transport.

There does not appear to be a distinction in kind or degree between the private and public sectors' definitions of accessibility. The distribution of survey responses between supply, demand, and connection definitions mirrors that of the literature search. That is, the most common way by which accessibility is defined is by the characteristics of the transportation network or connection type definition, while the supply and demand type definitions are used infrequently.

The results of dividing the previous table, Table 15, into decision type are presented in Table 16. Decision type refers to the kind of decision (location, network or routing decision) that the interview respondent is familiar with/responsible for within the organization.

Examination of Table 16 suggests that except for location decisions which stress the supply dimension of accessibility, all other combinations of location, network, and/or routing decisions have a heavy emphasis on the connection aspect of accessibility relative to the supply and demand aspects.

Table 16: Matrix Comparing Decision Type (Location, Network, Routing) with Emphasis (Supply, Demand, Connection) in the Organizations' Definitions of Accessibility

Decision Type	Emphasis in Organizations' Definition of Accessibility (n=19)*1, 2		
	Supply	Connection	Demand
Location	3	1	0
Network	0	6	0
Routing	0	4	0
Location, network	0	3	0
Location, routing	0	1	0
Network, routing	0	0	0
Location, network, routing	0	2	0
Total	3	17	0

*Note: ¹ Vertical Columns: Not mutually exclusive, Horizontal Rows: mutually exclusive

² The number of organizations participating in this part of the study = 19

9.2 Is Accessibility Measured?

Table 17 shows that just over half (11 out of 19) of the organizations surveyed use an accessibility measurement technique. Three organizations, one public-Ottawa Police, and two private-Canadian Freightways and Fedex, are not willing to confirm or reveal the use of an accessibility measurement technique. This suggests that accessibility may be an important part of their institutional/corporate strategy. A comparison of the public and private sectors does not display any marked difference in the relative use of accessibility measurement techniques.

Table 17: Relative Use of Accessibility Measurement Techniques in the Real World

Organizations (n=19)	Measurement Technique	None	Unconfirmed
Public			
Federal Department of Finance	✓		
B.C. Ministry of Transportation	✓		
RMOC	✓		
GVRD	✓		
Metro Toronto	✓		
City of Ottawa		✓	
Municipality of Burnaby		✓	
Municipality of Delta		✓	
OC Transpo	✓		
BC Transit	✓		
Ottawa-Carleton Regional Ambulance		✓	
Ottawa Fire Department	✓		
Ottawa Police			✓
Private			
UMA Engineering	✓		
J.P. Braaksma & Associates	✓		
Delcan	✓		
IBI Group		✓	
Canadian Freightways			✓
Fedex			✓

9.3 How is Accessibility Measured?

All the organizations which do use an accessibility measurement technique are classified in Table 18 according to whether they are:

- a) relative or integral;
- b) process or outcome; and,
- c) distance, topological, gravity, or cumulative opportunity.

Table 18: Classification of Public and Private Organizations' Accessibility Measurement Techniques

Organizations	Relative OR Integral		Process OR Outcome		Type of Measure			
	Relative	Integral	Process	Outcome	Distance	Topological	Gravity	Cumulative Opportunity
Public								
Federal Department of Finance	✓		✓		✓			
B.C. Ministry of Transportation		✓	✓	✓			✓	
RMOC		✓	✓	✓			✓	
GVRD		✓	✓	NR			✓	
Metro Toronto		✓	✓	✓			✓	
OC Transpo	✓		New*	Existing*	✓			
BC Transit	✓		New*	Existing*	✓			
Ottawa Fire Department	✓		✓	✓	✓			
Private								
UMA Engineering		✓	varies				✓	
J.P. Braaksma & Associates		✓	varies				✓	
Delcan		✓	varies				✓	

New* = new bus routes, Existing* = existing bus route

9.3.1 Relative and Integral Accessibility

Relative accessibility is less common than *integral* accessibility.

Those organizations who measure accessibility in an integral manner, make use of a gravity model, which is in turn part of the trip distribution module of a four-step transportation model. This trip distribution module “seeks to establish the links between urban zones in respect of trip destinations”. (Goodall, 1987, p. 483)

The gravity model seeks to identify and quantify the destinations of trips originating from defined zones. Thus, integral accessibility measurement as implemented by the survey respondents is a modelling tool for travel behaviour.

On the other hand, those organizations using relative accessibility techniques, are making location decisions such as where to put a bus stop (OC Transpo, BC Transit), where to put a fire station (Ottawa Fire Department) and which locations should receive the Northern and Isolated Community tax benefit (Federal Department of Finance). All these organizations state that particular types of facilities/services should be within a given distance from the customers/community.

Thus the greater use of integral measurement techniques may be due to the sample being biased towards these organizations making transportation network decisions as opposed to location decisions. On the other hand, it may indicate that the use of accessibility measurement techniques is more common for the purpose of modelling travel behaviour than for making location decisions.

9.3.2 Process and Outcome Accessibility

Process measurements of accessibility investigate the potential or opportunity to travel to activities. Process measurements are those obtained from using an accessibility measurement technique, such as distance measurement techniques used by the Federal Department of Finance, OC Transpo, BC Transit, and the Ottawa Fire Department. The B.C. Ministry of Transportation, RMOC, GVRD, Metro Toronto, UMA Engineering, J.P. Braaksma and Associates, and Delcan Corporation use a gravity measurement technique.

Outcome measurements of accessibility look at actual use. Some examples of outcome measurements are traffic volume surveys conducted by the B.C. Ministry of Transportation, Regional Municipality of Ottawa Carleton, Greater Vancouver Regional District, and Metro Toronto. OC Transpo and BC Transit record the number of transit passenger trips, while the Ottawa Fire Department monitor the total time spent travelling to fire emergencies.

Most of the public organizations use process and outcome measurements. The B.C. Ministry of Transportation, RMOC, and Metro Toronto conduct traffic studies to determine traffic volumes. In addition to measuring outcome accessibility, all three of these organizations use a gravity measurement technique which produces a process measurement of accessibility.

OC Transpo and BC Transit use a simple distance measurement technique which sites bus transit routes 400m/450m from residences. (OC Transpo, 1985; BC Transit, 1991) This represents a process measurement. For existing bus routes, outcome measurements in the form of ridership levels are used to modify the routes by changing the routing, frequency of service, and/or operating hours, or by discontinuing services (BC Transit, 1991).

The private organizations (consulting companies) interviewed in this study suggest that the process/outcome nature of accessibility measurement varies according to the study. In some consulting studies traffic counts are used to measure accessibility in an outcome manner (UMA Engineering, Delcan). In other instances a gravity technique is used within a four-step transportation model which produces a process measurement.

9.3.3 Types of Accessibility Measurement Techniques

Compared to the distance, topological, and cumulative opportunity measurement techniques, the *gravity* type is the most common. In all instances in this study, the gravity measurement technique resides within the trip-distribution module of a four-step transportation model. The four steps are:

- 1) trip generation (number of trips);
- 2) origin-destination matrix;
- 3) modal split (auto and transit); and,
- 4) trip distribution.

However, whether the use of a gravity technique within such a model can be considered an active implementation of accessibility measurement is debatable, since the gravity formulation is embedded within a step of the modelling software. It is beyond the scope of this study to address that issue.

Distance is the second most common type of measurement technique. As outlined on page 134, in the discussion of relative accessibility, the distance measurement technique is used by organizations such as the Federal Department of Finance, OC Transpo, BC Transit, and Ottawa Fire Department to aid in location decisions. On the other hand, topological and cumulative opportunity measurement techniques are not encountered in this study.

These real-world results mirror the findings of the literature search in that the gravity and distance measurement techniques are the most widely used for accessibility measurement.

9.4 Definition of 'Near' and Units of Spatial Separation

9.4.1 Definition of 'Near'

Table 19 examines public and private organizations with respect to their scale of responsibility/interest, and their definition of optimal accessibility (or 'near'). Specific accessibility targets published by some of the organizations are listed in *italics*.

The *scale of responsibility* of an organization, established in the personal interviews, can be: inter-regional (meaning between regions or metropolitan areas); regional; local; and/or site.

Comparing the scale of responsibility with the scale of optimal accessibility for the organizations suggests that the two are related. For instance, the Federal Department of Finance Task Force on Northern and Isolated Areas (Wellar, 1989) and the B.C. Ministry of Transportation which operate at the inter-regional scale, define 'near' as up to a distance of 120km and travel time of an hour by car/bus, respectively, whereas Ottawa Police and the Ottawa Fire Department which operate at a local and site level perceive that 5 minutes and 2-3 minutes as 'near'. The consulting companies of UMA Engineering and Delcan which are engaged in studies varying from site to regional scale find that the definition of 'near' varies with the type of study.

The *mode of transport* also appears to influence an organization's definition of optimal accessibility. For instance, the GVRD and BC Transit (Transport 2021, 1993b; BC Transit, 1991), cite an accessibility target for distance to a rapid transit line as (1km/900m from residences) compared to a shorter target distance to a bus route (400m/450m from residences). A second example of the influence of mode of transport is that J.P. Braaksma and Associates consider 20-30 minutes by any transport mode whether it be bus, car, cycle or walk to be 'near'.

A different definition of 'near' is given by the Ottawa-Carleton Regional Ambulance Centre. An ambulance unit that is on the road or 'mobile' is considered more near to an emergency than a unit on stand-by, *ceteris paribus*, because it takes an average of 3 minutes to 'go mobile'.

Table 19: Definition of *Near* and Units of Spatial Separation

Organizations	Scale	Definition of 'Near'	Spatial Unit of Separation		
			Distance	Time	Cost
Public					
Federal Department of Finance	Inter-regional	<120km distance to community offering higher level services	✓		
B.C. Ministry of Transportation	Inter-regional	45 mins-1hour Vancouver OR 20 mins Victoria commute	✓	✓	
RMOC	Regional	NR	✓	✓	
GVRD	Regional	90% of population within 400m of bus route (by 2006)¹ 30% of population within 1km of rapid transit line (by 2021)¹¹	✓	✓	
Metro Toronto	Regional	<2km away from transit 95% of all places of residence and employment within Metro Toronto within 15 mins of public transit in peak hours and within 30 mins during remainder of 24 hr day based on walk and wait time (by 2011)²	✓	✓	
OC Transpo	Regional, local, site	400m walk to transit 95% of the region's population within 400m of a transit route³	Location, Routing ✓	Routing ✓	
BC Transit	Regional, local, site	1/4 mile/450 m bus 900m rapid transit 450m from residences to bus stops⁴ 900m from residences to rapid transit⁴	Location, Routing ✓	Routing ✓	
Ottawa-Carleton Regional Ambulance	Regional, local, site	ambulance is 'mobile' (on the road)		✓	
City of Ottawa	Local, site	ability to get to a particular land use using any preferred mode	✓		
Municipality of Burnaby	Local, site	NR	NR	NR	NR
Municipality of Delta	Local, site	NR	NR	NR	NR

Table 19 Continued: Definition of *Near* and Units of Spatial Separation

Organizations	Scale	Definition of 'Near'	Spatial Unit of Separation		
			Distance	Time	Cost
Ottawa Police	Local, site	2-3 mins		✓	
Private					
Canadian Freightways	Inter-regional	NR	✓		
UMA Engineering	Regional, local, site	varies	✓	✓	
J.P. Braaksma & Associates	Regional, local, site	20-30 mins any mode or 5 mins walk-transit		✓	
Delcan	Regional, local, site	varies	varies		
IBI Group	Regional, local, site	1/4 mile, 5 mins walk	NR	NR	NR
Fedex	Regional, local, site	Nepean, Ottawa	✓	✓	

NR = No Response, *Italics* = signify that the organization has published an accessibility target.

¹ Transport 2021 (1993b, p. 54)

² Municipality of Metropolitan Toronto (1992, p. 82)

³ OC Transpo (1985, p. 16)

⁴ BC Transit (1991, p. 9)

⁵ Cresap (1991, Vol. II, p. 1)

9.4.2 Units of Spatial Separation

Distance and *time* are both common units of spatial separation, whereas *cost* is not encountered at all in this survey. In many cases, a combination of distance and time is used. For instance, Canadian Freightways and Fedex aim to minimize distance travelled to reduce costs and to minimize travel time to ensure that deliveries are made on time (Gary Ronahan, Mike Pescod, in conversation).

In the case of transit authorities (OC Transpo and BC Transit), distance is used to site the location of bus stops and bus routes whereas distance and time is used for bus routing and scheduling (OC Transpo, 1985; BC Transit, 1991).

9.5 Barriers to Accessibility

Barriers to accessibility as defined in Chapter 3 can be of 3 types:

- 1) **barriers to access:** social/demographic/cultural, legal/institutional, economic, modal;

- 2) **unavailability:** temporal, physical; and,
- 3) **constraints on the ease of travel.**

9.5.1 Barriers to Access

A *barrier to access* is a filter or criterion which prevents certain groups and individuals from using an opportunity, travel route, or transport mode. Barriers to access can be:

- 1) economic;
- 2) legal/institutional;
- 3) social/demographic/cultural; and/or,
- 4) modal.

Only legal/institutional and modal barriers to access are encountered in this study and specific examples are listed in Table 20.

Table 20: Barriers to Access

Legal/Institutional	Modal	
	Built	Natural
1-way streets ¹	road configuration ⁵	topography ^{2, 9, 10, 11}
land-use zoning restrictions ²	road width ^{5,6}	environmentally-sensitive areas ^{2, 10}
regional licensing for freight carriers ³	road closure ^{7,11}	water-bodies ^{1,2, 6, 11}
integration (fare-sharing arrangements) between transit providers ⁴	right-of-ways ⁸	E-W sunrise/sunset light patterns (poor driving visibility) ¹
	railroads ^{8,9}	inclement weather ¹¹
	bridges ^{8,9}	
	major transportation corridors ^{8,9}	
	golf-courses ¹	
	parks ¹	

¹Fedex, ²GVRD, ³Canadian Freightways, ⁴Metro Toronto, ⁵OC Transpo, ⁶BC Transit, ⁷City of Ottawa, ⁸J.P. Braaksma and Associates, ⁹Ottawa Fire Department, ¹⁰Delcan, ¹¹Federal Department of Finance

Legal/institutional barriers are restrictions which are legalized, or occur due to jurisdictional or corporate arrangements. Examples of such barriers are *one-way streets* which are an impediment to couriers (Fedex), and *land-use zoning restrictions* which preclude the development of certain facilities in certain locations (Greater Vancouver Regional District). *Regional licensing* for freight carriers can prevent a

trucking company from servicing particular areas (Canadian Freightways). *Lack of a fare-sharing agreement or integration* between transit providers in a metropolitan area can mean that certain public transportation trips are not possible (Metro Toronto).

Modal barriers to access can be *built* (constructed by humans) or *natural*. Built barriers to access such as *road configuration* may pose problems for transit (OC Transpo). For example, the concentric cul-de-sac may make transit use difficult if not impossible if the turning radius is too small for a bus. (Ministry of Transportation and Ministry of Municipal Affairs, Ontario, 1992) Roads must also be wide enough to accommodate buses (OC Transpo, 1985). *Right-of-ways, railroads, bridges* and *major transportation corridors* can be advantageous to particular modes of transport, but disadvantageous to others (J.P. Braaksma and Associates, Ottawa Fire Department). *Golf courses* and *parks* can be barriers to cycle, car and truck modes (Fedex), but can be advantageous to pedestrians.

Natural barriers such as *topography* (GVRD, Ottawa Fire Department, Delcan, Federal Department of Finance) and *water bodies* (Fedex, GVRD, BC Transit, Federal Department of Finance) are shared by many organizations and modes. Barriers that are less commonly shared are *environmentally sensitive areas* (GVRD, Delcan) which preclude the development of certain facilities and transportation network infrastructure, and *inclement weather* (Federal Department of Finance). *East-west sunrise and sunset light patterns* are a natural barrier to clear driving visibility for Fedex.

As indicated above, however, and this warrants emphasizing in the face of competing needs and capabilities involving urban and regional movement, a **barrier to one organization may be an advantage to another organization**. For instance, while a *major highway* may improve accessibility for cars, trucks, ambulances and motorbikes, it may be a (built, modal) barrier to access to traffic involving pedestrians, large fire trucks and cyclists.

9.5.2 Unavailability

Unavailability refers to the absence of an opportunity, travel route, or transport mode. Unavailability can be categorized as *physical* and/or *temporal* (Chapter 3). Table 21 lists examples of physical and temporal unavailability mentioned by survey respondents. Unavailability, similar to barriers to access, affects different organizations in different ways.

Physical unavailability is exemplified in the *lack of sidewalks, parking* and *public transportation* which can prevent trips. In the case of *lack of essential services* in northern, isolated communities, results in lengthy trips to larger, neighbouring communities, or can result in the denial of needed services. (Wellar, 1989)

Temporal availability refers to an opportunity, travel route or transport mode which is only available at discrete times and/or for a limited length of time. For example, public transportation schedules may only allow access to certain places at limited times per day. For BC Transit (1991) this is experienced in *limited bus frequency* or *limited hours of operation* "...as passenger demand changes by day of the

week, the span of operation is generally less on Saturdays than (on) weekdays while (on) Sunday and holidays (it) is less than (on) Saturdays." (BC Transit, 1991, p. 10) For northern, isolated communities the *frequency* (daily, weekly, or monthly) of *visiting and delivery services* can vary. (Wellar, 1989)

Table 21: Unavailability

Physical	Temporal
lack of sidewalks ^{1,6}	limited bus frequency ⁴
lack of parking ²	limited hours of bus operation ⁴
lack of public transportation ^{3,4}	frequency of visiting/delivery services to an isolated community ⁵
lack of essential services within a community ⁵	

¹City of Ottawa, ²J.P. Braaksma and Associates, ³Delcan, ⁴BC Transit, ⁵Federal Department of Finance, ⁶OC Transpo

9.5.3 Constraints on the Ease of Travel

Constraints on the ease of travel, in comparison, are factors which make a trip more difficult and increase the effort, inconvenience, etc., but do not prevent it. Constraints on the ease of travel (listed in Table 22) vary between organizations.

Congestion is a constraint on the ease of travel shared by many organizations, whereas other constraints (listed in Table 22) are specific to only a few organizations. For example, the *number and location of access points to a major transportation corridor* is an issue for only the RMOC and B.C. Ministry of Transportation. In planning regional and provincial roads these two organizations find that an increase in the number of access points to highways tends to slow down traffic. Also, the location of access points near population centres attracts commercial activity around the access point and can result in high traffic volumes and congestion. *Concentric road patterns* slow down transit travel. *Construction or reconstruction* activities such as paving or utility line work are a concern for emergency services such as the Ottawa-Carleton Regional Ambulance Centre and Ottawa Fire Department. *Weather* poses a problem as driving is more difficult for residents of remote areas (Federal Department of Finance), plus for emergency services such as the Ottawa-Carleton Regional Ambulance Centre it contributes to more emergencies. *Signal lights* can also slow down travel for ambulances. The *lack of central mail-rooms* means Fedex must wait for a signee to come to the reception. For Canadian Freightways, a line haul carrier, an increased *number of transfer points* can result in lost time and increase the risk of damage to goods as they are transferred.

Table 22: Constraints on the Ease of Travel

congestion ^{1, 2, 3, 4, 5, 6, 7, 8, 9}
and location of access points to a major transport corridor ^{1, 9}
concentric road patterns ^{7, 10, 11}
construction ^{4, 12}
weather ^{4, 13, 14}
signal lights ⁴
lack of central point in large office buildings for goods delivery ⁶
increased number of transfer points in goods delivery ¹³

¹RMOC, ²UMA Engineering, ³J.P. Braaksma and Associates, ⁴Ottawa-Carleton Regional Ambulance, ⁵Ottawa Police, ⁶Fedex, ⁷BC Transit, ⁸GVRD, ⁹B.C. Ministry of Transportation, ¹⁰OC Transpo, ¹¹City of Ottawa, ¹²Ottawa Fire Department, ¹³Canadian Freightways, ¹⁴Federal Department of Finance

The barriers to accessibility cited by public and private organizations are presented in Table 23. Of the three types of barriers to accessibility, *constraints on the ease of travel* are the most frequently cited, followed by *barriers to access* and then *unavailability*. Within barriers to access, the modal type is the most common, evenly distributed between built and natural sub-types. Social and economic barriers to access are not documented. Finally, there doesn't appear to be any difference between public and private sector barriers to access in this study.

Table 23: Barriers to Accessibility

Organizations n=19	Barriers to Access					Unavailability		Constraints
Public	Social	Economic	Legal	Modal		Temporal	Physical	
				built	natural			
Federal Department of Finance					✓	✓	✓	
B.C. Ministry of Transportation								✓
RMOC								✓
GVRD			✓		✓			✓
Metro Toronto			✓					
City of Ottawa				✓			✓	✓
Municipality of Burnaby				NR				
Municipality of Delta				NR				
OC Transpo				✓				✓
BC Transit				✓	✓	✓	✓	✓
Ottawa-Carleton Regional Ambulance								✓
Ottawa Fire Department				✓	✓			✓
Ottawa Police								✓
Private								
UMA Engineering								✓
J.P. Braaksma & Associates				✓	✓		✓	✓
Delcan				✓	✓		✓	
IBI Group				NR				
Canadian Freightways			✓					✓
Fedex			✓	✓	✓			✓
Total # mentions	0	0	4	7	7	2	5	13

9.6 Factors in Selecting a New Location for a Facility or Route

Factors in deciding on a new location for a facility or route vary greatly between organizations as indicated in Table 24. The next several pages present the key findings from interviews with officials and reviews of materials on the organizations' real-world interest in accessibility matters.

Table 24: Factors in Deciding on a New Location for a Facility or Route

Organizations	Decision type	Specific Decision	Factor #1	Factor #2	Factor #3	Factor #4
Public						
Federal Department of Finance	location		Population	Presence of an all-weather road	Distance	
B.C. Ministry of Transportation	network		Time	Volume	Environment	Cost
RMOC	network		Volume	Time	Environment	Cost
GVRD (varies according to mode)	network		Transportation Performance, Time	Cost	Social equity	Environment
Metro Toronto	network		Transportation performance	Urban structure	Social equity	
City of Ottawa	network		Interconnectivity	Land use	Reduce autos	
Municipality of Burnaby	location		Land availability	Ratio (per-capita) measure		
Municipality of Delta	location		Political will	Cost	Land availability	
OC Transpo	location network routing	<u>Transit:</u> Growth: Old:	Road hierarchy demand	Layout of collectors		
		<u>Bus-stops</u>	Proximity to intersections	Proximity to opportunities (parks, churches)		

Table 24 Continued: Factors in Deciding on a New Location for a Facility or Route

Organizations	Decision type	Specific Decision	Factor #1	Factor #2	Factor #3	Factor #4
BC Transit	location network routing	<u>Transit:</u> Growth: Old:	Density	Characteristics of street system	Location of origins w.r.t destinations	
Ottawa-Carleton Regional Ambulance	routing		Demand Severity of emergency	Bed Availability	Time	
Ottawa Fire Department	location routing	Station:	Time	Not near barriers	Near access pts to major route	No station overlap
Ottawa Police	routing	Travel path:	Road hierarchy			
Private			Time			
UMA Engineering (varies according to type of facility)	location network	Fast food, mini mall, gas bar: Recreation: Library, hospital:	Volume of drive-by traffic Proximity to regional road Proximity to regional road	Visibility Visibility	Proximity to agglomeration	

Table 24 Continued: Factors in Deciding on a New Location for a Facility or Route

Organizations	Decision type	Specific Decision	Factor #1	Factor #2	Factor #3	Factor #4
J.P. Braaksma & Associates (varies according to type of facility, route)	location network	Provincial highway: Regional road: Location of facility:	Time Capacity, Level of service Land availability	Land availability Time Subjective	Cost Cost	Environment
Delcan (varies according to type of facility)	location network	Shopping centre: University: Winter getaway: Restaurant: Fast food, mini-mall, gas bar:	Parking availability High transit use Inaccessible location Demographic/ethnic profile Convenience		Ease of entering and exiting site	
IBI Group	location network		Demand	Cost	Travel orientation	Social, political, economic, environment
Canadian Freightways	routing		Time	Volume	Distance	Number of Transfer Points
Fedex	routing		Demand	Time	Distance	Loop Pattern

9.6.1.1 Federal Department of Finance

In determining whether residents in isolated and remote communities are eligible for northern tax credits the Department of Finance (Wellar, 1989) defines a community's accessibility to needed services according to the following criteria:

- a) size of community (population);
- b) presence of an all-weather road; and,
- c) distance to neighbouring larger communities.

The size of community is important since "smaller northern and/or isolated centres tend to offer relatively fewer services, and less competition for services than their counterparts in more densely developed areas. This occurs because there is little or no drive-through or hinterland demand for either higher-order or competing services...conversely, however, larger northern and/or isolated centres tend to offer relatively more services than their southern or ecumene counterparts, in part because they assume a higher-order importance." (Wellar, 1989, p. 6)

The second criterion, the presence of an all-weather road, is considered since the "tax eligibility may be warranted on the grounds of isolation if the area is not served by an all-weather road." (Wellar, 1989, p. 29)

The third criterion, the distance to neighbouring larger communities, takes into account the "psychological, social, economic and physical health aspects of being off the beaten path or being isolated in physical terms." (Wellar, 1989, p. 20)

9.6.1.2 British Columbia Ministry of Transportation

The British Columbia Ministry of Transportation's main criteria for the planning of transportation network infrastructure are travel time, and volume or demand of traffic. Avoiding environmentally sensitive areas and the infrastructure costs are of secondary concern.

9.6.1.3 Regional Authorities

The regional authorities' (RMOC, Metro Toronto, and GVRD) responses show similarities. RMOC approaches transportation planning from a network perspective, whereby the volume or capacity of the network is modified by the addition or upgrading of new routes, followed by consideration of the average travel time over the network. Environmental sensitivity, land cost and availability are also criteria for network decisions.

The GVRD considers transportation performance to be the primary criterion.

"The primary economic goal of the transport system is to move people and goods effectively, efficiently, safely, and reliably...at an affordable cost. In addition, the region's citizens expect their transport system to meet social and environmental goals, such as:

- to provide transportation equitably to a diverse population;
- to help reduce its negative impacts on the region's livability.”
(Transport 2021, 1993a, p. i)

Metro Toronto decides on the location of transportation network infrastructure by assessing the:

- transportation performance;
- urban structure; and,
- social equity

produced by the proposed changes (Metropolitan Toronto Planning Department, 1993).

9.6.1.4 City of Ottawa and Municipalities of Burnaby and Delta

The City of Ottawa bases transportation network decisions on the inter-connectivity of the transportation network, type of land-use which must be served, and with an aim to reduce auto use. The Municipalities of Burnaby and Delta use land availability, political will, a prescribed ratio of facilities to residents, and cost to guide their facility decisions.

9.6.1.5 Ottawa Fire Department

The Ottawa Fire Department's stations are located centrally in fire zones such that most of the zone can be reached in 5 minutes from the station (Cresap, 1991). The station must not be located near barriers such as major highways because of their limited access points and risk of congestion. Fire stations are best located near access points to major routes such as regional roads but, again, not highways. The last criterion for the location of fire stations is that the station service areas should not overlap in order to give maximum efficiency.

For fire emergencies, paths to the fire scene are based on direct routes from the nearest station. The strategy of individual fire trucks is to take main routes (roads or quasi-roads such as the Transitway (which is dedicated to buses), but not freeways) to get as close as possible to the fire, before committing to local roads. Route runs are frequently practiced by officers at the station through a blackboard exercise to improve the firefighters' mental maps, in which officers draw streets from memory showing how to 'best' get to the site.

9.6.1.6 Ottawa-Carleton Regional Ambulance

For the Ottawa-Carleton Regional Ambulance, a similar series of considerations are involved. The type of emergency is the first factor because a major trauma must be routed to particular hospitals, thereby affecting the destination. Bed availability which determines how much space is available at each hospital also influences the destination. Finally, travel time is very important in selecting a

particular route. The exact route taken depends on the area knowledge of individual drivers.

9.6.1.7 Ottawa Police

Officers are responsible for making their own route decisions within their assigned car zones. They frequently test how quickly they can move between two points within their zones.

9.6.1.8 OC Transpo and BC Transit

For transit authorities, the criteria for selecting a location for a route are different for growth areas as opposed to currently-served areas.

In growth areas, bus routes are designed on a community-by-community basis. For OC Transpo, the hierarchy and layout of roads —arterial (regional), collector, and local roads— is taken into consideration. For BC Transit, the density of development, the characteristics of the street system (i.e. a grid), and the destinations to which the residents are expected to travel to are all taken into account in transit planning. OC Transpo states that new bus routes are judged on their *efficiency* (how well they are laid out in terms of 'covering' the served area), and *effectiveness* (are they in the right place in terms of pick-ups and drop-offs).

For currently served areas, passenger counts are used to alter and improve existing bus routes by re-structuring stopping locations and routing, or by discontinuing service. (BC Transit, 1991)

9.6.1.9 Engineering, Planning and Land-Use/Transportation Consultants

For UMA Engineering, J.P. Braaksma and Associates, and Delcan the criteria for selecting a new location for a facility/route varies with the client that they are serving, and the type of decision (location or network) which is being made (Table 24). Criteria for the location of facilities includes the volume of drive-by traffic, visibility, proximity to agglomerations and regional roads, parking availability, degree of transit use, inaccessibility, demographic and ethnic profile, convenience, and the ease of ingress and egress from the site. (Table 24)

Criteria employed by consultants for the placement of routes include capacity or demand, level of service, time, cost, travel orientation, land availability and a host of social, economic, energy, political and environmental criteria. The priorities vary with the type of road, that is, provincial, regional (arterial), collector, and local roads.

9.6.1.10 Canadian Freightways

Canadian Freightways, a trucking company, has the following criteria for selecting a location for a *line-haul route*: time, volume, distance, number of transfer points plus possession of a license for operating in particular areas, safety, and type of load.

Travel time is important in order to fulfill customer deadlines. The *volume* of the freight moved also plays a part in determining the route. For instance, in 1993 Canadian Freightways made a major routing decision change for that reason. Instead of routing City Z's freight from the origin (City A) through City B, it now goes through City C, even though it is faster to go through City B. This change was made because City C's terminal has a greater volume of freight, and full loads can be taken from the origin (City A) to City C. *Travel distance* is another a determinant in route selection, and is minimized in order to reduce operating costs.

The number of *transfer points* is very important since every time a transfer is made, time is lost and there is a risk of damage to the goods.

Government *licensing* regulates the number of carriers within geographic zones and can prevent a company from servicing certain regions.

Due to high insurance liability, *safety* is critical. Highways such as the Coquahalla (through the Rockies) are avoided at certain times due to unpredictable weather conditions. Safety also affects travel time. Drivers often maintain below posted limits to minimize the risk of accidents.

Finally, the *type of load* also influences routing decisions, since dangerous goods such as radioactive material cannot be shipped by rail or in association with consumable goods.

9.6.1.11 Fedex

Fedex's central dispatch allocates drivers to general areas, based on postal codes. Management allows individual drivers to decide on their own routes to complete their average 35 stop-counts per day, within a general loop pattern. Fedex routes are determined primarily by demand (where customers are located), and secondarily by the minimization of travel time and distance.

9.6.2 Overview of Real-World Criteria for Location and Route Decisions

There does not appear to be a discernible difference in the criteria used by the public and private sector organizations in Table 24. This lack of distinction is underlined in the case of transportation/land-use planning consultants who work for both public and private sector clients. They suggest that the criteria depend on the type of decision (location or network) and the type of facility or network feature (road type), and less on whether the organization is public or private.

One pattern that does emerge is that time is the most critical factor for those organizations making routing decisions (Ottawa-Carleton Regional Ambulance Centre, Ottawa Fire Department, Ottawa Police, Fedex, Canadian Freightways). All these organizations perform point-to-point routing and list time as an important criterion in deciding on a new route.

An investigation of equity versus profit-making goals of public and private sectors has not been addressed directly in this study. However, only 2 (out of 13) public sector organizations --Metro Toronto and GVRD-- mentioned the term 'equity'.

Criteria for making location and transportation network decisions, such as time, distance, characteristics of the street system, interconnection, and proximity cited by organizations in the survey have been shown to define accessibility in the literature search (Table 5, page 38). This suggests that accessibility is indeed a significant factor in location and transportation network decisions.

9.7 Geographic Information Systems

None of the organizations contacted use a geographic information system in conjunction with an accessibility measurement technique. If the organization possesses a geographic information system it is mainly for inventory purposes, that is, for cataloguing the placement or location of sewers, houses etc. Dispatchers for emergency services refer to large wall maps, and do not make use of digital maps.

9.8 Summary

Personal interviews with public and private organizations examine the definition of accessibility; use of accessibility measurement techniques; classification of the techniques used; organizations' definition of 'near' and units used to measure spatial separation; barriers to accessibility; criteria and relative importance of factors in selecting a new location for a facility or route; and, finally the use of GIS to implement accessibility measurement techniques.

This chapter contains key empirical findings on the real-world application of accessibility measurement techniques. As a result, a brief comment is presented to overview the findings for each interview topic.

9.8.1.1 Definition of Accessibility

Definitions for accessibility given by the public and private sector organizations are classified according to their *supply*, *demand*, or *connection* emphasis.

A *supply* definition is only cited by three organizations in this survey, and a *demand* definition of accessibility is not encountered at all.

A *connection* definition which emphasizes the characteristics of the transportation network is the most frequent interpretation of accessibility. The first sub-type of the connection definition, the characteristics of the transportation network comprised of effort, convenience, and level of service, is the most prevalent. The second sub-type, the 'spatial relation/interconnection between one location and others' is only cited once.

9.8.1.2 Relative Use of Accessibility Measurement Techniques

Just over half of the organizations surveyed use an accessibility measurement technique. Three organizations, one public and two private, are not willing to confirm or reveal use of a technique. This suggests that accessibility may be an important part of their institutional/corporate strategy. A comparison of the public and private sectors does not display any marked difference in the relative use of accessibility measurement techniques.

9.8.1.3 Classification of Accessibility Measurement Techniques

Relative accessibility is less common than *integral* accessibility. Both *process* and *outcome* measurements are used by most of the public organizations which measure accessibility. The private organizations' use of process and outcome techniques varies according to the type of study. *Gravity*, followed by *distance* measurement is the most common way of measuring accessibility. On the other hand, *topological* and *cumulative opportunity* measurement techniques are not encountered at all.

9.8.1.4 Organizations' Definition of 'Near' and Units used to Measure Spatial Separation

Preliminary results suggest that the scale of the definition of 'near' varies with an organization's scale (sphere) of responsibility and the mode of travel used. *Distance* and *time* are both common units of spatial separation, whereas cost is not documented.

9.8.1.5 Barriers to Accessibility

Barriers to access can be *economic*, *legal/institutional*, *social/demographic/cultural*, and *modal*. Only legal/institutional and modal barriers to access are encountered in this study. Economic and social/demographic/cultural barriers are not documented.

The *modal* variety are the most common barriers to access and are evenly distributed between *built* and *natural* sub-types. It is recalled that a barrier to one organization may be an advantage to another organization.

Unavailability refers to the absence of an opportunity, travel routes or transport mode. Unavailability can be categorized as *physical* and *temporal*, and both types are recorded in the real-world survey. Like barriers to access, unavailability affects different organizations in different ways.

Constraints on the ease of travel are factors which make a trip more difficult and increase the effort, inconvenience, but do not prevent it. Constraints on the ease of travel vary between organizations. *Congestion* is a constraint shared by many organizations. Of the three types of barriers to accessibility, constraints on the ease of travel are the most frequently cited, followed by barriers to access and then unavailability. A comparison of barriers to access to the public and private sectors doesn't reveal any marked differences.

9.8.1.6 Factors in Selecting a New Location for a Facility or Route

Factors in deciding on a new location for a facility/route vary greatly between organizations, and there does not appear to be a marked difference in the criteria used by the public and private sector organizations. *Time*, however, does appear to be a critical factor for those organizations making routing decisions.

Criteria for making location and transportation network decisions, such as time, distance, characteristics of the street system, interconnection, and proximity cited by organizations in the survey have been shown to define accessibility in the literature search (Table 5, page 38). This suggests that accessibility is indeed a significant factor in location and transportation network decisions.

9.8.1.7 Geographic Information Systems

None of the organizations use a Geographic Information System in conjunction with an accessibility measurement technique.

10. Summary and Conclusions

At present, accessibility is a significant factor in location and transportation network decisions. Concern about and interest in accessibility can be related to more recent events such as: changing demographics (an aging population), and the implications for location and transportation decisions (Marsland, 1991; Transport 2000, 1991; Transportation Association of Canada, 1993); serious fiscal/financial constraints on government's ability to expand transportation networks (Hoel, 1990; Regional Municipality of Ottawa-Carleton, 1993; Transport 2021, 1993a,b; Button and Rietveld, 1993); and, increased emphasis on cost-cutting by business and the use of 'just-in-time' and other measures to minimize transshipment, warehousing, and storage costs (Delaney, 1991; Arbeit, 1993; Wellar, 1993; Oliver, 1994; Gleckman, et al., 1994).

Interest in accessibility is also evidenced in recent reports from the Transportation Association of Canada (1993); Canada Mortgage and Housing (1993); Ministry of Municipal Affairs, Ontario (1994); Ministry of Transportation and Ministry of Municipal Affairs (1992); and Regional Municipality of Ottawa-Carleton (1993).

A preliminary search of the learned literature yielded a number of studies of accessibility measurement techniques (Dalvi and Martin, 1976; Davidson, 1977; Morris et al., 1979; Nutley, 1984; Pacione, 1989; Pirie, 1979; Vickerman, 1974; and White, 1979). Yet only one study conducted a number of years ago (Polus and Kumove, 1979) surveys the usage, definition and form of accessibility measurement techniques in the real world by practitioners. One goal of this inquiry, therefore, is to address the imbalance in the literature by exploring the real-world usage of accessibility techniques.

The research hypothesis used to organize the study is that public and private sector organizations use similar accessibility measurement techniques. This follows from the broadly-held view that public and private organizations make similar location and transportation network decisions. (Parr, 1992; Wellar, 1993; Landis, 1993; Arbeit, 1993; Dangermond, 1993) Specifically, these location and transportation network decisions are:

- a) **location:** the siting of *opportunities*, that is, the point or place where there is an opportunity for spatial interaction;
- b) **network:** the location of *travel routes*, and the spatial characteristics of transportation networks (which are composed of travel routes); and,
- c) **routing:** the spatial strategy, plan, logic, algorithm, or other kind of reasoning by which *transport modes* (e.g. road vehicles) navigate transportation networks (e.g. a regional road system).

This thesis combines a literature search with a real world survey to explore the definition and measurement of accessibility. The literature search consists of a purposive sample of journal articles, books, bulletins, departmental and research

institute reports, conference proceedings papers, government, business organizations and consulting company reports, and theses (Figure 3 and Figure 4).

In the real-world survey, personal interviews are conducted with 19 public and private organizations which comprise an availability sample (Appendix A, Table 14). A total of thirteen (13) organizations are drawn from the following areas of the public sector: federal government departments/agencies; provincial ministries of transport; regional authorities, cities and municipalities; transit authorities; and emergency services (ambulance, fire, and police).

Six (6) firms are selected from the private sector segments of: engineering, planning, and land-use/transportation consultants. And, firms are also chosen from the line-haul trucking and courier delivery industries.

The literature search and survey explore and relate the following topics:

- 1) definition of accessibility;
- 2) relative use of accessibility measurement techniques;
- 3) classification of accessibility measurement techniques;
- 4) spatial units of separation and the measurement of spatial separation;
- 5) barriers to accessibility;
- 6) criteria and relative importance of factors in selecting a new location for a facility or route; and,
- 7) use of GIS to implement accessibility measurement techniques.

10.1.1.1 Definition of Accessibility

Definitions of accessibility in the learned literature and in the survey interviews are categorized according to their *supply*, *demand*, and/or *connection* emphasis (Table 5, page 38; Table 15, page 127). *Supply* definitions concentrate on the presence and attractiveness of opportunities, while *demand* definitions interpret accessibility from the perspective of the individual. *Connection* definitions, on the other hand, emphasize the transportation network connecting supply to demand.

The distribution of survey responses between the supply, demand and connection aspects of accessibility mirrors that of the literature search (Table 5, page 38; Table 15, page 127). The most popular or common way that accessibility is defined in both the literature search and real-world survey is by the *characteristics of the transportation network* or the *spatial relation/degree of connection between one location and others* (Table 5, page 38; Table 15, page 127). Conversely, much less support exists for the supply and demand definitions. In fact, the demand definition, though encountered in the literature search, is not mentioned at all by any participants in the real-world survey (Table 5, page 38; Table 15, page 127).

The first sub-type of the connection definition, the characteristics of the transportation network, is most often cited in the personal interviews. The second

sub-type, the spatial relation or degree of connection between one location and others, is only cited once (Table 15, page 127).

In both the literature and real-world surveys, the most widely recognized sub-element of characteristics of the transportation network is the *effort* required to traverse a travel route (Table 5, page 38; Table 15, page 127).

Other performance characteristics such as *convenience, comfort, reliability, safety, speed, and level of service* of the transportation network are considered by some authors to be a component of accessibility. In the real world survey, *convenience* and *level of service* are frequently and explicitly associated with accessibility; other characteristics such as *comfort, reliability, and safety* tend not to be explicitly documented (Table 5, page 38; Table 15, page 127), although they may be an inherent part of other characteristics or criteria (Wellar, 1989).

The *spatial* dimension of the concept of accessibility has two aspects:

- 1) the effect of space/distance on the pattern of human activity; and,
- 2) the spatial expression of accessibility shaped by non-geographic variables. (Khan, 1992)

The first aspect of the spatial dimension of accessibility, the effect of space/distance, is represented by the connection definition of accessibility, in particular by the element of *effort* (time, cost, distance, etc.) required to traverse a travel path.

The second aspect, the spatial expression of accessibility shaped by non-geographic variables, can be influenced by the:

- 1) *characteristics of individuals who constitute the demand for opportunities, travel routes and transport modes* (reflects the demand-type definition of accessibility); and,
- 2) *presence and characteristics of opportunities, travel routes and transport modes* (represents the supply-type definition of accessibility).

10.1.1.2 Relative Use of Accessibility Measurement Techniques

There is an abundance of literature on the topic of accessibility measurement (Figure 4, page 29). A total of 173 publications which contain an accessibility measurement technique are examined, of which 142 focus on the empirical applications of accessibility measurement techniques, and 31 of the selected publications emphasize the development and improvement of techniques of measuring accessibility (Figure 28, page 109).

Within the empirically oriented publications the most common application areas are transportation modelling/planning/network studies, and urban/regional structure/planning, followed by health care, service/facility location, economy, rural studies, employment, shopping, housing, social indicators, population growth, recreation, and crime studies (Figure 29, page 111).

In the real-world survey, just over half of the organizations interviewed use an accessibility measurement technique (Table 17, page 132). Three organizations—one public and two private are not willing to confirm or reveal use of a technique (Table 17, page 132). This refusal may indicate that accessibility is an important part of their institutional/corporate strategy. A comparison of the public and private sectors does not reveal any differences in the degree of use of any type of accessibility measurement technique.

10.1.1.3 Classification of Accessibility Measurement Techniques

Integral accessibility which is the degree of interconnection for a given point with all other points on the same surface (Table 17, page 132), is more commonly used by the organizations interviewed than relative accessibility or the degree to which two points on the same surface are connected.

Process measurements of accessibility are those obtained through the use of an accessibility measurement technique, whereas outcome measurements look at observed behaviour. Of the organizations which use accessibility measurement techniques, most of the public organizations collect both process and outcome measurements, whereas the private organizations indicate that the process/outcome nature of their measurements varies with the client and study (Table 18, page 133).

Gravity and distance techniques are the most common techniques of measuring accessibility in both the literature search and real-world survey (Figure 30, page 112; Table 18, page 133). However, cumulative opportunity measurement techniques are well represented in the literature search are not encountered in the survey. Topological and time-space measurement, though not as popular as the other types in the literature search are also not encountered in the real world interviews.

Comparing the public and private sectors on the basis of the types of accessibility measurement techniques used does not reveal a pattern. This suggests that the public/private nature of an organization may not influence the type of accessibility measurement technique.

10.1.1.4 Spatial Units of Separation and the Influence of Scale upon the Measurement of Spatial Separation

Spatial Units of Separation

Distance and time are both common units of spatial separation in the literature search and survey (Table 10, page 78), whereas cost, though documented in the literature search is not encountered at all in the survey. In many instances, a combination of distance and time is used (Table 18, page 133).

Measurement of Spatial Separation

From the literature search it appears that the *spatial separation between origin and destination* directly incorporates the effect of space/distance into the distance, topological and gravity accessibility measurement techniques. Bach (1981) suggests that the measurement of spatial separation between origin and destination can be influenced by:

- a) scale, and
- b) mode of transport.

Bach notes that as scale increases, different modes of transport are required to traverse the spatial separation between origin and destination and this can influence the selection of the unit of spatial separation (distance, time, and/or cost).

Findings consistent with those opinions and expectations are obtained from the real-world interviews in relation to the organizations' definition of 'near' or 'optimal spatial separation between an origin and destination'. Preliminary results suggest that the scale of responsibility of an organization (inter-regional, regional, local, and/or site) varies with the organization's definition of 'near' (or optimal accessibility). For instance, an organization working at an inter-regional scale may perceive 'near' as over 100 km (by motorized mode) (Wellar, 1989), whereas an organization operating at a smaller local scale may view 'near' as 3-5 minutes (by walk mode) (BC Transit, 1991).

The 'optimal spatial separation between an origin and destination' also appears to be influenced by the mode of transport. For instance, the GVRD and BC Transit (Transit 2021, 1993b; BC Transit, 1991) cite an accessibility target for distance to a rapid transit line (1km/900m from residences) compared to a shorter distance to a bus route (400-450m from residences).

10.1.1.5 Barriers to Accessibility

Barriers to accessibility, as evidenced in both the literature search and survey (Figure 10, page 47; Table 23, page 143) can be recognized as 3 types:

- 1) barriers to access;
- 2) unavailability; and,
- 3) constraints on the ease of travel.

Barriers to access refer to a 'filter or criterion which prevents certain groups and individuals from using an opportunity, travel route, or transport mode'. Barriers to access can be:

- 1) economic (Joseph and Phillips, 1984; Bailey and Phillips, 1990);
- 2) legal/institutional (Hagerstrand, 1974);
- 3) social/demographic/cultural (Bailey and Phillips, 1990; Joseph and Phillips, 1984; and Knox, 1978); and/or

4) modal (Isard, 1956).

In response to survey questions, many organizations cite *legal/institutional* and *modal* barriers to access, whereas *economic* and *social/demographic/cultural* are not documented (Table 20, page 139). And as discussed in Chapter 3, it is emphasized that a barrier to access for one organization may be an advantage or 'open door' to another organization.

Unavailability refers to the absence of an opportunity, travel route, or transport mode. Unavailability can be classified as:

- 1) physical (Joseph and Phillips, 1984), and/or
- 2) temporal (Burns, 1979).

Instances of both *physical* and *temporal* unavailability are documented in the real-world survey (Table 21, page 141).

Constraints on the ease of travel are factors which make a trip more difficult and increase the *effort*, or *decrease convenience, comfort, safety, reliability, speed* and *level-of-service*, but do not prevent a trip. Constraints on the ease of travel vary between organizations (Table 22, page 142). *Congestion* is a constraint shared by many organizations, whereas other constraints are specific to only a few organizations (Table 22, page 142).

A comparison of the public and private sector barriers does not reveal any differences in the frequency of reporting of the three types of barriers to accessibility (Table 23, page 143). For both the public and private sectors, constraints on the ease of travel are the most frequently cited, followed by barriers to access and then unavailability (Table 23, page 143).

10.1.1.6 *Criteria and relative importance of factors in selecting a new location for a facility or route*

Factors in deciding on a new location for a facility, route, and/or strategy for navigation the transportation network vary greatly between organizations (Table 24, page 144). However, the findings from the interviews of members of the availability sample do not appear to establish a difference in the criteria used by the public and private sector organizations. Time, however, does appear to be a critical factor for those organizations (Ottawa-Carleton Regional Ambulance, Ottawa Fire Department, Ottawa Police, Fedex, and Canadian Freightways) making routing decisions.

Criteria for making location and transportation network decisions, such as time, distance, characteristics of the street system, interconnection, and proximity cited by organizations in the survey have been shown to define accessibility in the literature search (Table 5, page 38). This suggests that accessibility is indeed a significant factor in location and transportation network decisions.

10.1.1.7 Geographic Information Systems

Examination of the accessibility measurement literature suggests that the measure type (distance, topological, gravity, and cumulative opportunity) employed is related to the graphical elements (point, line and/or polygon) comprising the inquiry (Table 12, page 104). For instance, distance and topological techniques deal with point and line representations, gravity techniques use points, lines and polygons, cumulative opportunity measurement techniques combine point and polygon elements, and time-space techniques employ point, line, and polygon elements.

Despite the fact that the strength and widespread appeal of Geographic Information Systems (GIS) is their capacity to manipulate point, line and polygon representations (Wellar, 1993), there is little use of GIS to implement accessibility measurement techniques in either the literature search or real-world survey. Only 3 articles in the literature search (up until 1994) (Algeo, 1993; Miller, 1991; Okafo, 1990) discuss how a GIS can be used to implement an accessibility measurement technique.

In the real world survey, none of the organizations contacted use GIS in conjunction with an accessibility measurement technique. If the organization possesses a GIS, it is used mainly for inventory purposes, that is, for cataloguing the placement or location of sewers, houses etc.

10.1.1.8 Discussion of Results and Further Research

The results of the real-world survey suggest that there is little difference between the public and private sectors in terms of their:

- definitions of accessibility;
- degree of use of accessibility measurement techniques;
- usage of specific types of accessibility measurement techniques; and,
- criteria used to make location, transportation network and/or routing decisions.

Since this report represents an exploratory study, further research is required to confirm these findings. Such confirmatory studies could again, similar to this study, sample a population comprised of public and private organizations who make location, transportation network, and routing decisions.

However, a few changes might be made. In further studies, the population should not be restricted to Canadian organizations and firms. Surveys in other countries would enable a comparison of the results to see to what extent the results of this study were influenced by the institutional, economic, political, geographic and/or climatic environment in Canada.

Also, the private sector sample could be expanded to include the retail sector, which has been identified as an application area, but was not included in this

survey. As well, the public sector sample could incorporate organizations who make decisions on the location of health care and educational facilities.

Further studies might also include individuals and citizens in the research population, which would allow accessibility to be explored from the perspective of the individual (demand-side) and the demand for travel and opportunities.

Use of a random sampling procedure, in place of an availability sample, would enable the hypothesis (that public and private sector organizations use similar accessibility measurement techniques) to be tested statistically.

However, due to the fact that accessibility may be an integral part of an organization's strategy, whether it be a public organization with security concerns (e.g. police) or a private organization with competitive pressures (e.g. retail store), a random sampling procedure may not be feasible. This is because not all organizations may be willing to be interviewed, and even if an organization agrees to an interview, the respondent may not be willing to answer all survey questions (see Table 17, page 132 for examples of unconfirmed responses) Thus, an availability sample as was obtained in this study may be the only practical way in which to sample the population.

Further research focussing on the spatial aspects contributing to differences in the way accessibility is defined, measured, and incorporated into location, transportation network, and routing decisions is recommended. Specifically, these spatial aspects are the:

- a) location, transportation network, and/or routing orientation of the decision;
- b) graphical representation (by points, lines, and/or polygons) of the decision; and,
- c) scale (local, city, regional, national, or international) of the decision.

10.1.1.9 Concluding Remarks

More than five decades ago, Stewart (1942, p. 70) commented on the value of measuring accessibility,

“The introduction of some measure of influence at a distance, whether the potential or another is a necessity in many social, economic and political problems. Indeed the failure of policy makers in public affairs to recognize the raw physical factors of number and distance has been a most unfortunate contributing factor to the tragedy of the times.”

Still, “...inconvenient locations and poor transport connections involve expenditure of time and money, and cause frustration.” (Black, Kuranami and Rimmer, 1982, p. 1374).

The present research demonstrates that much progress has been made in developing and using ‘some measure of influence at distance’, referred to herein as

accessibility measurement referred to by Stewart over 50 years ago. And, it further demonstrates that many important research and real-world situations require and warrant continued examination and application.

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Appendices

Appendix A: Organizations and Individuals Interviewed

Ottawa

Federal Department of Finance: Dr. Barry Wellar

Regional Municipality of Ottawa-Carleton (RMOC), Transportation Dept.: Mr. Phillips

City of Ottawa, Transportation Dept.: Mr. Chris Lyon

OC Transpo: Mr. Joel Kaufman, Mr. Colin Leech (telephone interview)

UMA Engineering: Mr. John Port

J.P. Braaksma & Associates: Dr. John Braaksma

Delcan Corporation: Mr. Ron Jack

Ottawa-Carleton Regional Ambulance Centre, Ministry of Health: Mr. Doug Armstrong (telephone interview - not full script), Mr. Denis Rondeau

Ottawa Fire Department, Communications Dept.: Mr. John Wilkie

Ottawa Police: Staff Sergeant Frank Bowes

Fedex: Mr. Michael P. Pescod

Transport 2000: Mr. Darrell Richards

Vancouver

British Columbia (B.C.) Ministry of Transportation and Highways: Ms. Maria Salay (Vancouver), Mr. Henry Lew (Victoria) (telephone interview)

Greater Vancouver Regional District (GVRD): Mr. Joe Stott, Mr. Gary Vlieg

The Corporation of the District of Burnaby (Municipality of Burnaby), Planning Department: Mr. Lou Pelletier, Ms. Peggy Lyon

The Corporation of Delta (Municipality of Delta), Planning Department: Mr. Jim LeMaistre

BC Transit: Mr. Terry Narum, Mr. Jim Prokop

Canadian Freightways: Mr. Gary Ronahan

Urban Systems: Mr. Ed Hall (telephone interview - not full script)

Terry Partridge and Associates: Mr. Terry Partridge (telephone interview - not full script)

Toronto

Municipality of Metropolitan Toronto, Planning Department: Mr. Rob Pringle, Mr. Dipak Dhrona

IBI Group: Mr. Neil Irwin (telephone interview - not full script), Mr. Bruce Mori