ACCESSIBILITY, EXPERIMENTATION, AND THE EVALUATION OF TRANSPORTATION DEVELOPMENTS FOR DISADVANTAGED GROUPS

by

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ABSTRACT

This study examines the methods used for evaluating transportation developments, particularly those for disadvantaged groups. Two methodological questions are examined: what measures characterize the social condition to be ameliorated, and in what evaluation framework are these measures most effectively utilized?

The social condition is interpreted as a problem of accessibility. Several accessibility measures are examined, including a new measure — the mean opportunity distance of trips — which is obtained from the intervening opportunities model of spatial interaction. Three frameworks of evaluation, based respectively on predictive models, demonstration projects, and experimental designs, are reviewed. When used in a recursive process of implementation and evaluation, the experimental design framework is shown to be most effective and least used. A major strength of this framework is its explicit consideration of threats to the validity of measured changes. Threats to validity related to geographic space and designs for their control are examined in the transportation context.

Finally, the accessibility measure obtained from the intervening opportunities model is applied in the experimental design framework to an innovative, subsidiary transit service in Baltimore, Maryland. The measure is found to be suitable as an evaluation tool.

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CHAPTER I

INTRODUCTION

Transportation provides a physical link between people and distant locations of human activity. Travel over longer distances has been largely restricted in the past to coarse transportation networks, encouraging people to rely on the local community for everyday needs and on common carriers for access to centralized employment and special services. As the automobile has come to dominate personal transportation, direct links between most individuals and their surrounding environment are now virtually ubiquitous. This increased accessibility has freed individuals from reliance on local services and on services within the restricted areal extent of common carriers. Urban activities have been able to diffuse, and levels of transit ridership and service have declined.

While the automobile-owning public has benefited from — or at least coped with — these trends, a substantial minority of automobile-deficient households have literally been left behind. They are physically excluded from many activities which are assumed to be generally available to the entire population (Sagasti and Ackoff, 1971; Foley, 1975; Kemp and Cheslow, 1976). This spatially isolated population is broadly classified as the "transportation disadvantaged" (Benson and Mahoney, 1972, p. 36).

As defined by the Transportation Research Board of the National Academy of Sciences,[1] the transportation disadvantaged include the elderly, the young, the handicapped, and the poor. After discounting households with adequate private transportation available and overlaps between groups, Abt Associates (1974, p. 7) estimate the transportation disadvantaged to number over 71½ million persons (see Table 1-1). Of these, at least six million elderly and handicapped persons are estimated to have severely limited mobility resources in urban areas.[2]

Membership in the transportation disadvantaged is based on the simultaneous unavailability of private modes and inadequacy of public alternatives. Severely limited or nonexistent availability of the private automobile can be a function of age, poor health, a lack of training, or inadequate finances (Abt Associates, 1974; Institute of Public Administration, 1975a, Ch. I). Public alternatives are usually limited to fixed route, line-haul bus or rail service, or to taxicabs. These alternatives are often nonexistent (particularly in low density areas), too distant from trip ends,

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[1] From the meeting of Committee A1B10, Transportation Research Board, Washington, D.C., January 19, 1976.

[2] Totalled from Figure 4.4, U.S. Department of Transportation, Urban Transportation Advisors Council (1973, p. 11).

TABLE 1-1

ESTIMATED NUMBER OF URBAN TRANSPORTATION DISADVANTAGED PERSONS, BY TRANSPORTATION DISADVANTAGED GROUP, 1969-1970 (million)

Car Availability	ELDERLY			NON-ELDERLY			TOTAL		
	H	NH	TOTAL	H	NH	TOTAL	H	NH	TOTAL
Carless	1.86	2.79	4.65	1.52	15.31	16.83	3.38	18.10	21.48
Car Deficient	.24	.36	.60	2.90	29.25	32.15	3.14	29.61	32.75
One Old Car (not car deficient)	1.52	2.27	3.79	1.21	12.28	13.49	2.73	14.55	17.28
Total Transportation Disad.	3.62	5.42	9.04	5.63	56.84	62.47	9.25	62.26	71.51
Car Adequate	1.38	2.07	3.45	5.80	58.67	64.47	7.18	60.74	67.92
Total Population	5.00	7.49	12.49	11.43	115.51	126.94	16.43	123.00	139.43

H = Handicapped NH = Nonhandicapped

From: Abt Associates (1974, p. 7).

too difficult to use, or too expensive. The transportation disadvantaged are thus forced to rely heavily on friends and neighbors with cars, or to bear the temporal and financial costs of inadequate public modes. This reduces their level of travel and subsequent ability to acquire distant goods, services, and opportunities.

The inadequacies of public transit are not always remedied by simple increases in the quantity of vehicles and routes. Ward and Paulhus (1974) argue that expansion of the traditional service, based on relatively distinct collection, line-haul, and distribution functions,[3] is incongruous with emergent spatial patterns of people and activities. The need for innovations in the types and delivery of transportation service beyond simple additions to the existing service has been substantiated by Hedges (1974); R. Kirby et al. (1974); Perloff and Connell (1975); Ward (1975); and Heanue (1977).

In response to this need, many innovations in transportation service have been tried and evaluated.[4] According to Hilton (1974), the evaluations have been unfavorable or inconclusive in a disproportionate number of cases. While several of the attempted innovations may have in fact been inappropriate, the evaluation techniques by which they were tested could be the source of many purported

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[3] These functions are outlined by Meyer, Kain, and Wohl (1965).

[4] The Institute of Public Administration (1974) has a substantial list of services for the elderly alone.

failures. If this is true, then the development of new, effective forms of transportation service will be stifled.

Current evaluation techniques have increasingly been found inadequate by transportation policy makers and analysts (e.g., Transportation Research Board, 1975). This sentiment is emphasized in a review of transportation planning for The American Society of Planning Officials: "Planning techniques must be improved so that there is a basis for knowing whether goals are being achieved and needs met" (Engelen and Stuart, 1974, p. 6). Inadequacies with the current techniques are explored in this study, and improved methods and measures for evaluating transportation innovations are developed.

EVALUATION: FRAMEWORKS AND MEASURES

Evaluations of transportation developments are made in three contexts. First, evaluations of contemplated actions are made to rationalize the selection of an action from among the alternative proposals for change. Second, evaluations of past actions are used as learning exercises for improved future selections. Third, evaluations of ongoing actions are used as monitoring devices, which combine both learning and decisionmaking functions. In this third context:

> ".... evaluation procedures are essential to cost-effective operations, assuring that the

> transportation services are meeting designated objectives, and that unexpected events or circumstances are identified quickly so that corrective action can be taken".
>
> (Institute of Public Administration, 1975b, p. VII-1)

Whether for proposed, consummated, or ongoing actions, the ultimate goal of the evaluation process is "to provide 'proof' of [the action's] legitimacy and effectiveness in order to justify society's continued support" (Suchman, 1967, p. 2).

Most evaluators of transportation developments have a myopic concern with the reliability of measures and measurement techniques used in their "proofs". This concern is myopic because reliability is a necessary but not sufficient condition for validity. Reliable measures and measurement techniques can address unknown and sometimes nebulous phenomena in a reasonable and uniform manner; however, reliable measures and measurement techniques may misrepresent actual changes either by incorrectly labeling the actual elements of change or by being sensitive to extraneous factors. Consistent use of such measures and techniques may tend to support preconceived or false notions, subsequently leading to poor choices among innovations. Valid measures and measurement techniques, in contrast, meter the changes attributable only to the action or concept being tested, specifically addressing the "unexpected events and circumstances mentioned above. Evaluation is thus a process of measuring change and determining causes of the change.

Frameworks of Evaluation

For the purposes of discussion, there are three main evaluation processes, defined by their source of measurement and their basis of validation. These three processes are predictive models, demonstration projects, and experimental designs. Transportation planners have relied primarily on the first of these frameworks, in which service is evaluated prior to its implementation with predictive models. Predicted changes are validated by the model's theoretical foundations and its ability to predict the present with historical data. In contrast, both demonstration projects and experimental designs are used to measure changes after implementation analysis to evaluate a trial service and determine whether it should be continued. Demonstration projects — actually a primitive form of experimental design — have been used with increasing frequency and questionable success in the field of public transit. True experimental and related quasi-experimental designs have been infrequently used in the transportation context.

This fact suggests a source of the current dissatisfaction with evaluation techniques. Most efforts to critique and improve existing techniques have focused on specific comparative tools, such as benefit-cost analysis, without considering the framework in which the tools are applied. Little analysis of the evaluation frameworks is reported in the transportation literature, even though unquestioned reliance on the predictive model and demonstration project frameworks may be the source of poor evaluative results.

Evaluation Measures

Another source of dissatisfaction with current evaluation techniques is the measures used. Evaluations of specialized transportation services for disadvantaged groups require measures which reflect the user's needs and desires. This perspective is quite different from that of the supplier of the service, who is generally concerned with some level of profits or with the minimization of losses. As a consequence, measures of operating costs, ridership, and revenue generation have been used almost exclusively in evaluations. The exclusive use of these measures to evaluate publicly subsidized, welfare-oriented services has been challenged by Charles River Associates (1972) and Hilton (1974), among others, as unresponsive to the user's needs. These are measures of efficiency rather than effectiveness, and are appropriate only in conjunction with and not in lieu of user-oriented indicators.

A variety of measures which reflect the user's perspective are summarized in Table 1-2. In keeping with the user's perspective,

TABLE 1-2

MEASURING THE EFFECTIVENESS OF PUBLIC TRANSPORTATION FROM THE USER'S PERSPECTIVE

Objective	Characteristic	Measure
Rapid movement	Traveltime	Interzonal traveltime Opinion survey of adequacy
Convenience and Reliability	Accessibility of Service	Population of catchment area
	Reliability	Adherence to schedule Opinion survey of perceived adherence
Safety	Accidents	Accidents per passenger mile
	Crime	Crimes per passenger mile Opinion survey of perceived accident and crime rates
Comfort and Pleasantness	Seating Availability	Number of standees
Overall citizen satisfaction/ usefulness	Usage Mode Choice	Ridership and opinion survey of usefulness

Source: Urban Institute and International City Management Association (1974, pp. 52-60) these measures emphasize the effectiveness of service rather than efficiency.

Several measures in Table 1-2 are related to the concepts of mobility and accessibility. Mobility is the ability to move in space, which reflects the physical, economic, and psychic costs of transportation borne by the traveller. For a given transportation system, groups with a greater sensitivity to these costs will have a more restricted level of mobility. Restricted mobility alone is unimportant unless there is a need or desire to transcend space. Such needs and desires can be reflected in measures of accessibility.

Accessibility can be characterized in many ways, all of which define mobility with respect to a specific set of locations. The simplest characterization reflects a binary choice: what population can and cannot reach the given locations on a given mode? The use of traveltime or distance is typical for accessibility measures in which mobility costs between the population and the given locations are summed. These summations can be "weighted" by the relative importance of each destination within the set of locations. In this most complex characterization of accessibility, the "weights" are based on observed interactions between the population and the destinations. This type of accessibility measure is derived from spatial interaction models, and is shown in Chapter

3 to characterize the actual use of available transportation to reach desirable destinations.

The preceding characteristic is central to the use of accessibility measures for evaluating transportation developments for disadvantaged groups. These groups are disadvantaged because they are spatially isolated from the goods, services, jobs, amenities, and social contacts which contribute to personal fulfillment. The mere availability of transportation to isolated people does not guarantee that their quality of life will be improved. They must actually use the service to reach the destinations where those elements which contribute to personal fulfillment are located. As a consequence, the evaluation measure must reflect attributes of the location which contribute to personal fulfillment, costs of reaching those desirable destinations, and the use of the transportation development by persons who previously could not bear those costs. Accessibility measures based on social interaction models reflect these attributes, and thus the effectiveness of a transportation development in fulfilling user needs.[5]

Contrary to this apparent relevance, accessibility measures have not been used widely in the evaluation of transportation

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[5] These measures characterize effectiveness, but not necessarily efficiency. User-oriented measures such as accessibility must be used in tandem with supplier-oriented measures to evaluate a development completely.

developments for the disadvantaged or any other group. Several reasons can be hypothesized. One reason is the preoccupation of transportation policymakers with the user's ability to board a vehicle rather than the spatial accessibility provided the user by the vehicle.[6] More importantly, evaluation from the user's perspective has not been done until recently. As illustrated by Saltzman and Solomon (1972) and Wells et al. (1972), the revenue-conscious transit industry has been preoccupied with maintaining lack-luster profits or minimizing losses. Only political pressure against publicly owned transit systems has altered the focus on efficiency to include effectiveness (Smerk, 1974). Even in long-range planning, consideration of accessibility has generally been restricted to being an input for predictive models. Accessibility is thus ignored as an evaluation measure for use in observing contemporary, social change. This restricted view is examined in Chapter 4, and the shortcomings this view causes become the basis for advocating the use of accessibility measures in an experimental design framework. For whichever reason, accessibility is not widely used to supplement other measures in the evaluation of transportation developments, even though the benefits of transportation are inseparable from the access it provides to distant

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[6] For example, see S. Brooks (1975).

opportunities which affect the user's quality of life.

THE CURRENT STUDY

It is often claimed that the development of transportation innovations is necessary to effectively serve disadvantaged groups. Innovations in service will require careful evaluation if they are to be developed fully and effectively. Three frameworks have been identified in response to this need. Within these frameworks, accessibility is a major concept of the needs of the transportation disadvantaged; however, a lack of experience with accessibility measures in an evaluative role has been indicated. Before this experience can be gained, two questions need to be considered:

(1) Given the three frameworks, which is most appropriate for the evaluation of transportation developments for disadvantaged groups?

(2) How should accessibility measures be structured and interpreted in a manner consonant with that framework?

These questions provide the foci of this study.

Before an evaluation methodology can be developed, the subject to be evaluated must itself be examined. Who are the transportation disadvantaged? What are the underlying dimensions of their mobility-related problems? These questions are examined in Chapter 2 to provide the substantive issues against which an evaluation framework and its measures can be designed.

The substantive issues are transformed into operational measures of accessibility in Chapter 3. Several candidate measures are developed and potential biases inherent to their structure are noted.

With the substantive context and its operational forms established, attention is focused in Chapter 4 on the appropriate framework in which accessibility and other measures should be applied. Each framework is considered with respect to its legal mandates, to its role in the planning process, and to documented experience in related social program evaluation. The relationship of accessibility to each framework is traced, and the framework's sensitivity to the needs for and implementation of service for the transportation disadvantaged are explored. Implications of the selected framework for the general planning process are developed at the chapter's end.

In Chapters 5 and 6, the selected framework is developed further and applied to a case study in Baltimore, Maryland. One accessibility measure is used to illustrate the control of potential threats to the validity of the measured changes.

The evaluation of transportation developments for disadvantaged groups and the use of accessibility measures are summarized in Chapter 7. Policy implications, caveats, and needed future research are outlined to conclude this study.

CHAPTER II

THE SUBSTANTIVE CONTEXT

Before a public, social action program and its evaluation methods can be developed, the conditions which necessitate public intervention should first be understood. This dictum is found throughout the evaluation literature, usually labeled as goal formation or problem definition.[1] In the present context, those conditions which necessitate public intervention are contained in Vickerman's (1974) conception of accessibility.

> "In its most abstract form, accessibility involves a combination of two elements: location on a surface relative to suitable destinations and the characteristics of the transport network or networks linking parts of that surface" (p. 676).

The transportation disadvantaged are persons who are inadequately linked to their suitable destinations. Methods for identifying and responding to inadequate linkages reveal the substantive context in which ameliorative actions are prescribed and evaluated.

Current methods for analyzing the effectiveness of transportation linkages usually focus on a region's subareas rather than its

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[1] See, in particular, Hyman and Wright (1967) and Schulberg and Baker (1968).

population subgroups (e.g. Highway Research Board [1973a]). Data are aggregated by geographic units, which often conceal the diversity and the extremes of individual conditions within the localities. These methods have been criticized by D. R. Miller (1970, Ch. 11), The Highway Research Board (1973b), Kutter (1973), K. Webb (1974), and others as insensitive to the transportation needs of specific groups and therefore inappropriate for revealing their adverse conditions.

A more promising approach to identifying the transportation disadvantaged and their needs is based on market segmentation. Market segments are population subgroups having analogous needs which are amenable to similar service characteristics. Once classified into market segments, the incidence of each category of the transportation disadvantaged can be estimated by areal unit,[2] and specific types and amounts of service can be recommended for each locale. Market segmentation has been used by Nicolaidis, Wachs, and Golob (1976) to plan transportation services for the working population, but the approach has not been applied formally to the transportation disadvantaged.

Market segmentation is used in the present chapter to identify both the limitations on accessibility of the transportation

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[2] An estimation technique is described by Falcocchio (1977).

disadvantaged and the services which have been proposed to ameliorate those limitations. This endeavor serves both to define the intended clientele and types of transportation developments for disadvantaged groups, and to summarize the numerous empirical studies of their needs. An example is drawn from Baltimore, Maryland at the conclusion of this chapter to illustrate the problems of the transportation disadvantaged and an effort to serve their needs.

THE TRANSPORTATION DISADVANTAGED: NEEDS AND SERVICES

The transportation disadvantaged are commonly identified by categories which reflect the availability of data from the decennial census rather than a formal method of market segmentation. As stated by the Transportation Research Board (1974), Blanchard (1975), and others, these categories include the elderly, the handicapped, the poor, and the young. Falcocchio and Cantilli (1974) add seven categories to this list for persons in more than one group, such as those who are both elderly and handicapped.

This informal classification has three shortcomings. First, these categories are not all-encompassing. For example, the second member of a one-car household can be very isolated by the absence of public transit. Second, many individuals who have adequate mobility resources are included in these categories. Wachs (1977) notes the example of elderly persons who are rich. Finally, each category encompasses a wide range of needs which cannot always be matched to specific, ameliorative actions.

These shortcomings could be overcome and the needs of the transportation disadvantaged more accurately identified by a formal method of market segmentation. Key to this method is the selection of appropriate variables to define market segments. Selected variables should represent the significant factors which limit accessibility of the disadvantaged to the community. The three candidate variables listed in Table 2-1 have been considered almost exclusively in the literature on the transportation disadvantaged.[3]

The first variable, employment status, is a major determinant of life styles, and thus travel behavior, of the transportation disadvantaged. A working person's time budget is largely consumed by work, the removal of which substantially alters his use of time and desired trip destinations.[4] This is particularly true for the elderly, for whom retirement means significant changes in personal needs and activities, irrespective of age.[5] For persons of working age,

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[3] This literature is comprehensively tabulated by Blanchard (1975). See also Kinley (1973).

[4] See Szalai (1972).

[5] Golant (1972, Ch. 1) emphasizes this point. See also Shanas et al. (1968), Ohio Division of Administration on Aging (1970), Markovitz (1971), U.S. Department of Transportation, Urban Transportation Advisory Council (1973), Institute of Public Administration (1975a), and Wachs and Blanchard (1975).

TABLE 2-1

MAJOR VARIABLES IN THE LITERATURE ON THE TRANSPORTATION DISADVANTAGED

1. Employment Status
    - a. Pre-employed (pre-school and school age)
    - b. Employed
    - c. Un- or underemployed (job seeking)
    - d. Beyond the labor force (not job seeking)
2. Personal Mobility Handicaps
    - a. No significant handicap effecting mobility
    - b. Mental handicap (retardation, senility)
    - c. Sensory and/or communication handicap (vision, hearing, speech)
    - d. Ambulatory handicap (semi- and nonambulatory)
    - e. Invalid
3. Mode Availability
    - a. Private vehicle available for use as driver or passenger
    - b. Primary or secondary transit within walking distance
    - d. Neither private vehicle nor primary transit available

the absence of a job is frequently symptomatic of a greater sensitivity to the financial and physical costs of transportation. Physical travel constraints can affect the employment status and subsequent income of the handicapped.[6] Whether unemployed or underemployed, the poor can be caught in a vicious circle, often unable to afford access to the jobs that will lessen the financial restraints on their travel.[7] Finally, the orientation of public transportation to serving the needs of the adult, working population often fails to serve the needs of the young.[8] In summary, employment status indicates the social condition which transportation is designed to serve, particularly as classified into the four sub-categories in Table 2-1.

As suggested by the second variable in Table 2-1, an individual's personal mobility is largely determined by his physical and mental condition. That person is handicapped, according to Section 16(d) of the Urban Mass Transportation Act of 1964 as amended,[9] when:

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[6] See Perle (1968) and Lorg (1970).

[7] This issue was a major concern of initial research on the transportation disadvantaged. See Meyer, Kain, and Wohl (1965), Cleveland Transportation Action Program (1970a), Greytak (1970), Myers (1970), California Business and Transportation Agency (1971), Chicago Mayor's Committee... (1972), Gold (1972), Gurin (1973), GrÜben (1974), Bederman and Adams (1974), and Phillips (1976).

[8] This situation is examined by Falcocchio and Cantilli (1974), Gurin (1974), and Yukubouski and Politano (1974).

[9] By Section 8 of the Urban Mass Transportation Assistance Act of 1970 (PL 91-453).

". . . by reason of illness, injury, age, congenital malfunction, or other permanent or temporary disability, [the individual] is unable without special facilities or special planning or design to utilize mass transportation facilities as effectively as persons who are not so affected." The Urban Mass Transportation Administration (UMTA) categorizes the handicapped as bed-ridden (invalids), confined to wheelchairs (nonambulatory), able to walk with the aid of devices such as canes and crutches (semi-ambulatory), and although handicapped, able to walk without serious difficulty.[10] This Federal classification reflects an increasing scale of difficulty in getting around, but ignores two, less-studied, mobility handicaps. Both mental handicaps and sensory/communication handicaps have an obvious but unspecified effect on mobility.[11] Furthermore, some people have medical problems which alter the characteristics of needed service.[12] An alternative classification of handicaps is offered in Table 2-1 to include explicitly these problems. Whichever classification is used, the magnitude of each handicap's effect on the individual's transportation needs and attitudes varies between those persons who

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[10] This last category includes persons with handicaps not related to locomotion, such as hearing impediments.

[11] A significant portion of the community can fall in these categories. For example, see Dallmeyer and Surti (1974).

[12] See Cleveland Transportation Action Program (1970b), Earickson (1970), and Nashville Metropolitan Transit Authority (1970).

have recently undergone the trauma of sudden handicap, those persons who have had their handicap for an extended time and have learned to deal with it, and those who experience handicaps which limit their mobility only for short periods.[13]

The third variable in Table 2-1 is mode availability. This variable is obviously central to the problems of the transportation disadvantaged, yet it is ignored in many studies. As emphasized by Abt Associates (1974), the availability of a private vehicle is dependent on its reliability and on the ratio of users to cars in the household. The availability of primary (line-haul) or secondary (feeder) transit is defined by frequency of service (Morlok, 1967, pp. 47-52), and by maximum walking distance to the line.[14] When neither a private vehicle nor primary/secondary transit are available, the individual must rely on walking, on the car of a neighbor, friend, or relative, or taxicabs, or on special transit services.

Studies of mode availability illustrate the limited perspective which is evidenced in much of the literature on the transportation disadvantaged. It is often implied that the provision of barrier-free transit will provide adequate accessibility for the disadvantaged.

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[13] See Abt Associates (1969; 1972), Dougherty and DeBenedictis (1975), and Knighton and Hartgen (1976) for detailed examinations of the affects of physical barriers on travel.

[14] This distance is estimated by Neilson and Fowler (1972) to be approximately 180 meters on flat ground.

This is true only if the transit system connects its patrons with their "suitable destinations", to quote the second part of Vickerman's concept of accessibility. Suitability depends on the spatial distribution of potential destinations, the transportation network, and the individual's activity space.[15] These variables are particularly important for characterizing patron response to a transportation development, and are considered explicitly in Chapter 3.

While not all-inclusive, the three variables in Table 2-1 provide a useful framework for matching the transportation disadvantaged with types of potentially beneficial service developments. These developments involve four types of intrametropolitan passenger service:

1. Primary and secondary transit — scheduled line-haul and feeder service operating over fixed routes with fixed schedules.

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[15] Chapin (1968) and Horton and Reynolds (1970) define activity space as the spatial pattern of activities sought by individuals or groups. This pattern is interpreted as the product of their perceived desires and spatial constraints. Activity space is synonomous with Perle's (1968) "option space" and the "life spaces" described by Falcocchio and Cantilli (1974, Ch. 6). The latter term is used in studies of activity spaces evolving through time or stages of life, as empirically summarized by Abler, Adams, and Gould (1971, pp. 174-178). Relationships between daily travel patterns and long term spatial behavior are addressed by Hurst's (1971) "movement spaces", which are summarized by Foley (1975). Andrews (1971) summarizes the activity space concept in a broad planning context.

2. Subsidiary transit[16] — supplemental service, both inter- and intra-neighborhood, utilizing mini-buses, vans, or limousines. Routes and schedules are not fixed.
3. Para-transit[17] — public use of vehicles originally designed for private use, including taxicabs, car pools, van pools, car rental fleets, and so forth.
4. Private transportation — the use of a private automobile as either driver or passenger without compensation.

Most of these services presently exist, but require expansion or modification to meet the needs of the transportation disadvantaged. Four transportation developments are usually suggested (as by Bell and Olsen [1974] and the Institute of Public Administration [1975a]):

1. Maintain or expand existing service (usually primary and secondary transit).
2. Modify the designs of existing vehicles, such as adding special driving controls in private cars, adding wheelchair lifts in buses, or lowering entry steps.
3. Directly subsidize transit users with special fares, vouchers, and so forth.[18]
4. Implement a demand-responsive service.

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[16] Proposed by Perloff and Connell (1975).

[17] Developed by R. Kirby et al. (1974).

[18] See Burkhardt (1969) and R. Kirby and Tolson (1977).

The last strategy focuses on subsidiary and para-transit, and can respond to weekly subscriptions, day-ahead reservations, or real-time telephone requests, or on a hail-a-ride basis. These transportation developments are matched with market segments of the disadvantaged in Figure 2-1.

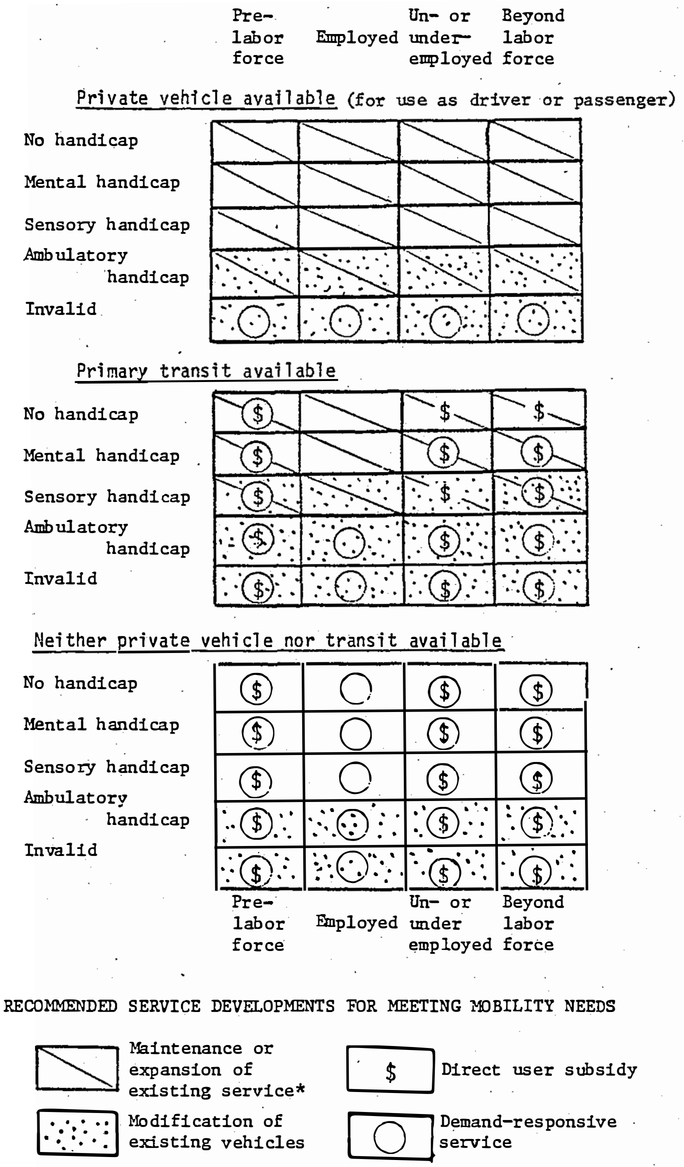
The complexity of Figure 2-1 reflects the diverse nature of the transportation disadvantaged. Their problems can be summarized as follows:

1. Persons are barred from existing transportation by readily correctable physical and financial impediments.
2. Persons are not adequately linked to their desired destinations by otherwise available transportation.
3. Persons have no transportation available.

These problems are common to both urban and rural environments.

AN EXAMPLE: NORTHEAST BALTIMORE

The problems of the transportation disadvantaged and efforts to serve their needs are now illustrated by an attempt to serve the transportation disadvantaged in Northeast Baltimore. "Northeast" is the semi-official name of several neighborhoods which comprise a six square kilometer portion of older suburbs in Baltimore City (Figure 2-2). These neighborhoods are formally united through the Northeast Community Organization (NECO), a non-profit, "umbrella" organization



* Cells for which this is the only recommendation are not necessarily part of the transportation disadvantaged.

Figure 2-1: MATCHING NEEDS OF AND SERVICES FOR TRANSPORTATION DISADVANTAGED

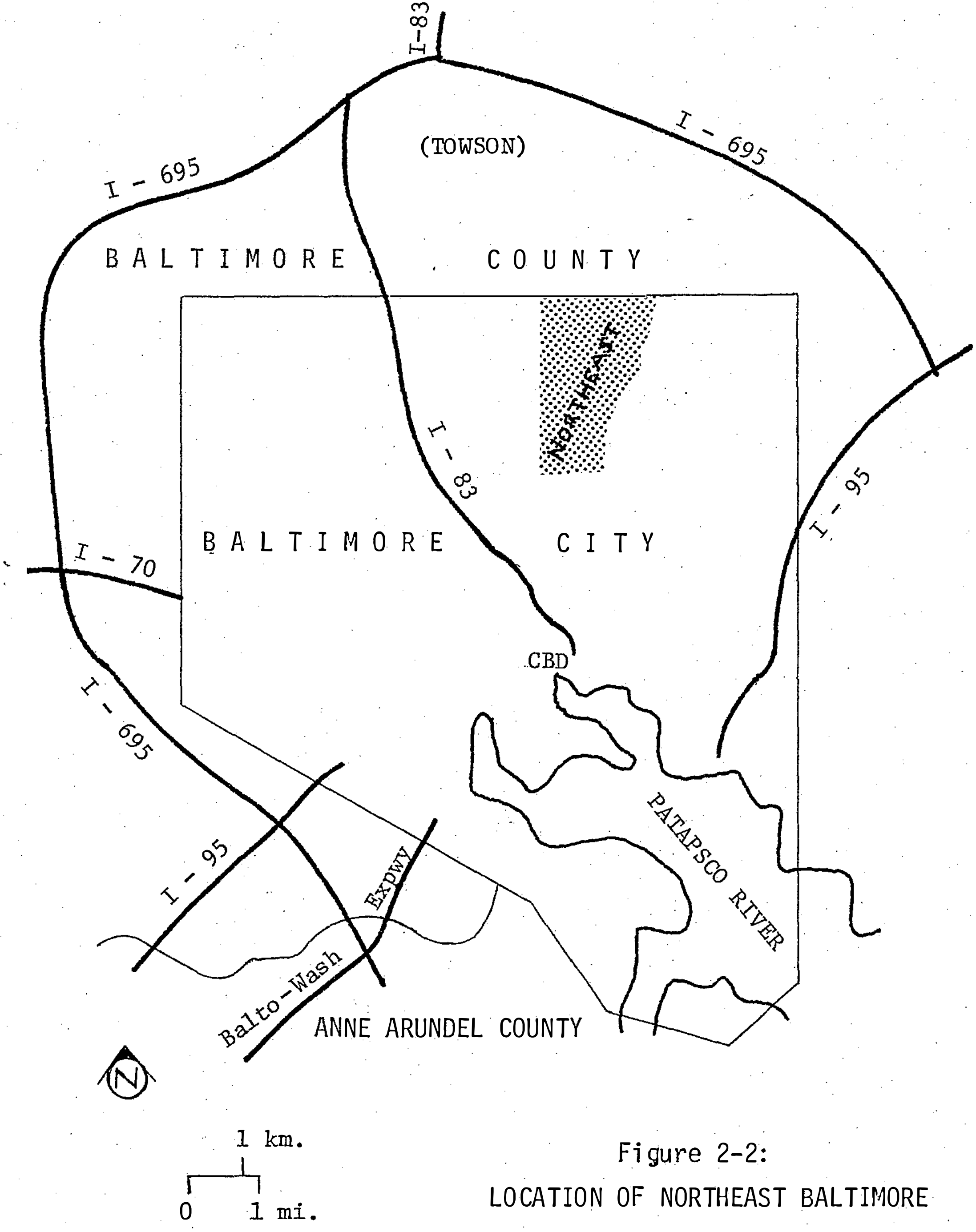


Figure 2-2:
LOCATION OF NORTHEAST BALTIMORE

which coordinates the activities of home improvement associations, local business alliances, and several other community groups.

Special transportation needs were initially brought to NECO's attention during meetings of local, elderly residents in early 1975. Concern was repeatedly expressed for personal safety and the difficulty in using regular MTA buses for local travel.[19] The NECO staff was subsequently assigned the tasks of assessing the stated needs and of planning a supplementary transportation service for the area's elderly.

The need for a supplemental service is suggested by comparing Figures 2-3 and 2-4. The former illustration shows the spatial distribution of all persons over the age of 62. This distribution, based on the 1970 census data by block, has remained relatively stable for at least a decade. Figure 2-4 indicates the areas in which elderly residents are served by the citywide MTA bus network.[20] A visual comparison indicates that a large number of residents live in areas either infrequently served or beyond easy reach of the bus network. Furthermore, the bus grid may not serve many potential east-west or diagonal trips without one or more transfers. While

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[19] City bus service is operated by the Mass Transit Administration (MTA), a statewide agency of the Maryland Department of Transportation.

[20] The area of service has recently been expanded by a new, east-west route on Cold Spring Lane, around which relatively few elderly live.

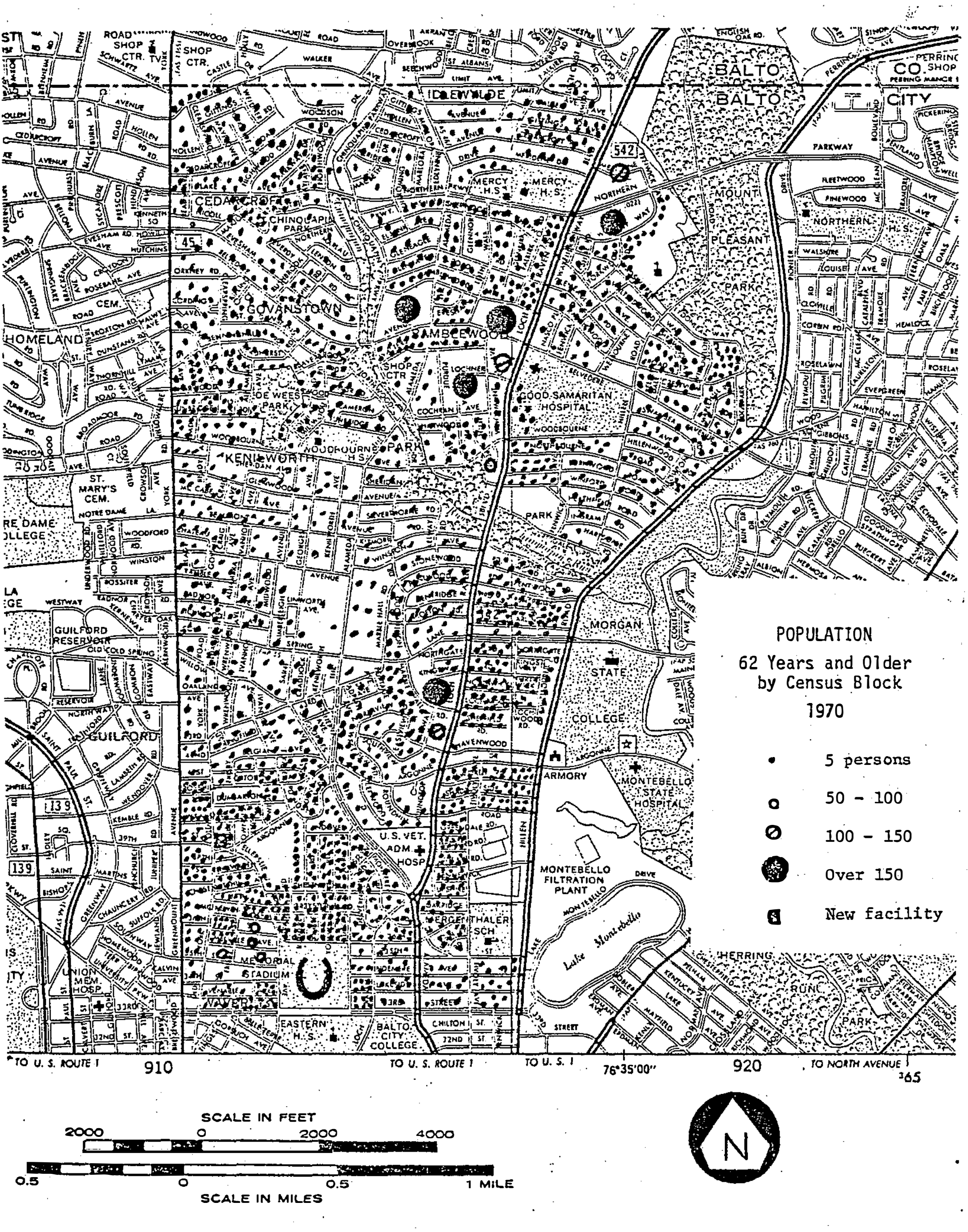

Figure 2-3: SPATIAL DISTRIBUTION OF ELDERLY PERSONS IN THE NECO AREA

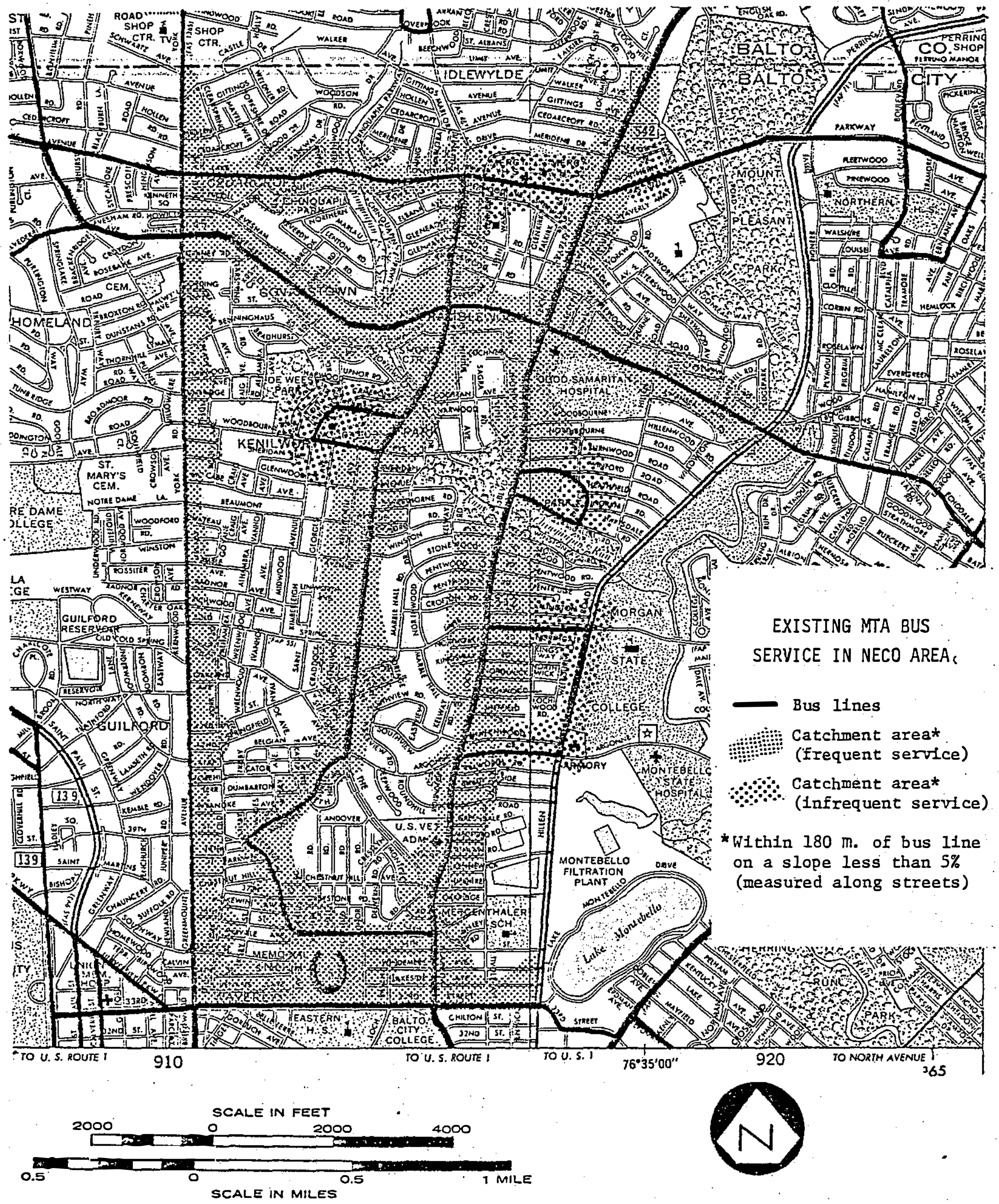

Figure 2-4: REGULAR BUS SERVICE IN THE NECO AREA

trips to downtown and more distant destinations may be served, the need for a supplemental form of transportation is apparent for intra community travel. Existing service may be efficient, but not completely effective in meeting local needs.

During the first half of 1975, the NECO staff became aware of the 16(b)(2) capital grants program funded through the Urban Mass Transportation Act as amended (PL 91-453, §8). This program provides 80 percent Federal funding for the purchase of vehicles to transport the elderly and handicapped. An application was submitted for the purchase of two vehicles through an interagency committee which administered the funds allocated to the state of Maryland.[21]

By summer's end, NECO was named as the only area-based (rather facility-based) organization to receive 16(b)(2) funding for that year. A fund-raising campaign followed in which individuals and member groups of NECO raised the $4000 needed to pay the 20 percent local share of the vehicle purchase price. After numerous delays by the purchasing agent (the MTA), the vehicles were delivered to NECO in December, 1976. The 15 months were necessary to modify each Dodge maxi-van with a raised roof, a side-mounted wheelchair lift, and a special interior arrangement for eight seats and one wheelchair position.

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[21] The committee included representatives of the Governor's Office and the state Departments of Transportation and of Mental Health and Hygiene.

After considering several options, the NECO staff and advisory personnel decided to operate the two vehicles on a door-to-door basis throughout the NECO area and immediate surroundings. Regular service was planned from 9:30 AM to 4:30 PM on weekdays.[22] A charge of 25 cents per ride was established, to be paid in advance so that only tickets and not money were to be handled by the driver. To radically simplify operations, it was decided to accept requests for service only before 2 PM of the preceding work day.

Two classes of patrons were established in recognition of the wide range of need for this service. Any resident of the NECO area who has a handicap which makes use of the regular MTA buses very difficult or impossible are considered to have the greatest need and are given scheduling priorities. Patrons assumed to have lesser needs include residents with less severe handicaps to personal mobility and all other residents over age 60. In both instances, patrons are registered and classified before or during their first request for service so that scheduling priorities can be made, the characteristics of the served clientele can be monitored, and the patron can be informed when service modifications are made.

The NECO Mini-bus Service was inaugurated on March 21, 1977. By that date, two drivers, a dispatcher, and a full-time manager had

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[22] Vehicles were also to be made available at cost to NECO member organizations during evenings and weekends.

been hired to operate the service. At the beginning of each operating day, the drivers receive their logs, which include all locations, name of clients, times, and other pertinent information for each pick-up and delivery. During the day, the dispatcher takes requests, develops the drivers' logs for the next day, and calls back patrons to confirm their reservations. The manager oversees the staff and vehicle performance, handles public relations, and assists the dispatcher as needed.

The Mass Transit Administration has since initiated a similar service through Lutheran Social Services (LSS) for the entire Baltimore area. The characteristics of their intended clientele are virtually the same as NECO's priority patrons. A system of cross referral with the LSS system is being considered, so that intra-NECO trips requested from LSS can be referred to NECO and trips beyond the NECO area requested from NECO can be referred to LSS. Joint registration of patrons to use both systems is also being discussed.

The NECO Mini-bus Service is a form of subsidiary transit not previously tried in the Baltimore region. As an innovative, flexible transportation service designed for disadvantaged members of the community, the NECO Mini-bus Service appears to be suitable testing ground for the accessibility measures and the evaluation framework developed in the following chapters.

CHAPTER III

THE MEASUREMENT OF ACCESSIBILITY

In the previous chapter, conditions which limit an individual's accessibility were reviewed, and ameliorative transportation services were outlined. A general concept of accessibility was used rather than specific measures. Accessibility measures and the descriptive models upon which they are based are now developed.

Vickerman's concept of accessibility, quoted at the beginning of Chapter 2, implies that accessibility measures should reflect user costs and the relative location of suitable destinations. User costs include the barriers and costs encountered by the user on the system. The relative location of suitable destinations has been related to the activity space of the market segment, which is defined by its constituents' range of travel and their frequency of travel over that range. These concepts are incorporated in two families of accessibility measures.

Network descriptors, the family of accessibility measures which emphasizes impediments encountered by the user, are briefly outlined in Figure 3-1. Reviewed most extensively by Kansky (1963) and Morlok (1967), these measures are drawn largely — but not exclusively — from the mathematical literature on graph theory. These

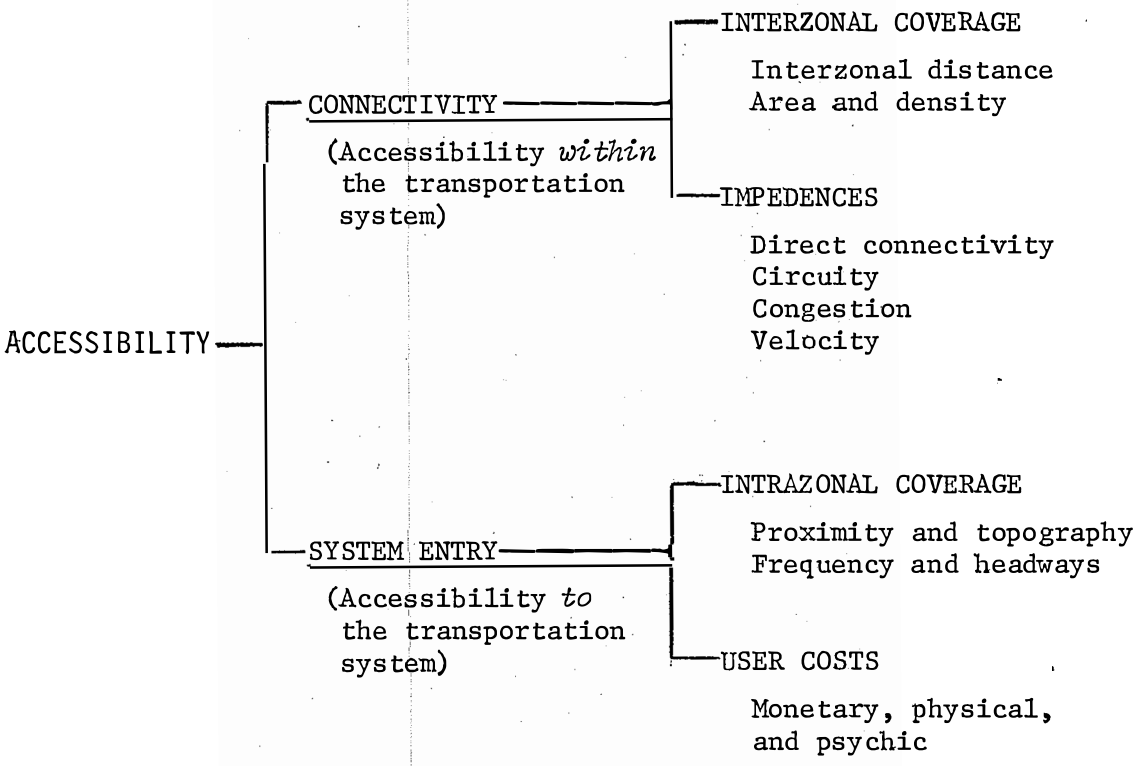


Figure 3-1: THE FAMILY OF NETWORK DESCRIPTORS

measures characterize the transportation system, but not the destinations served by the system or the extent to which the system is used.

In contrast to network descriptors, the family of accessibility measures based on spatial interaction models emphasizes the frequencies and spatial distribution of travel by users of the transportation system. These spatial interaction models characterize the relative locations of suitable destinations with travel patterns, and user costs are represented by the proxy measure of distance. This family of accessibility measures is outlined in Figure 3-2.

As shown in Figure 3-2, spatial interaction indices of accessibility can be based on either physical space or opportunity space. Physical space between locations is measured as Euclidian or rectilinear distance or as traveltime. In opportunity space, physical distance is used only to rank locations with respect to each other by proximity. Opportunity space between locations is then measured as the accumulated size or number of destinations in equal or closer proximity. Examples of physical space and opportunity space are illustrated in Figure 3-3.

Several accessibility measures are now considered for evaluating transportation innovations. Measures proposed in the current literature are reviewed and their inherent problems examined. An alternative measure based on the intervening opportunities model of

- ACCESSIBILITY
  - MEASURES BASED ON PHYSICAL SPACE
    - DISTANCE-INTERACTION MEASURES

      $A = f(T_{ij}) = g(c_{ij})$
    - DISTANCE-ATTRACTION MEASURES

      $A = f(T_{ij}) = g(O_i, D_j, c_{ij})$
  - MEASURES BASED ON OPPORTUNITY SPACE
    - AGGREGATE-OPPORTUNITY MEASURES

      $A = f(D_j, c_{ij})$
    - INTERVENING OPPORTUNITY MEASURE

      $A = f(T_{ij}) = g(\Sigma D_k, D_j)$

A = Accessibility

T_{ij} = Trips from zone i to zone j

c_{ij} = Cost, distance, or traveltime between i and j

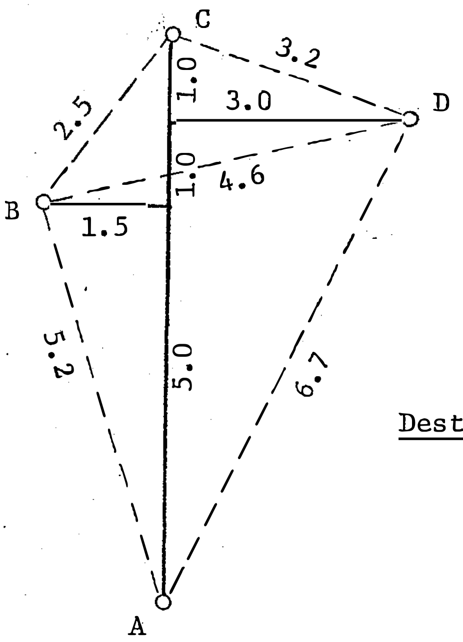
O_i = Number of origins in zone i

D_j = Number of destinations in zone j

ΣD_k = Number of destinations closer to the origin than j

Figure 3-2: THE FAMILY OF SPATIAL INTERACTION INDICES

PHYSICAL SPACE



Rectilinear distances follow solid lines.

Euclidean distances follow dashed lines.

Destination	Size
A	6
B	4
C	10
D	2

OPPORTUNITY SPACE*

Measured in Euclidean Distance

		TO			
		A	B	C	D
FROM	A	3	8	17	11
	B	19	2	9	15
	C	19	12	5	15
	D	19	14	7	1

Measured in Rectilinear Distance

		TO			
		A	B	C	D
FROM	A	3	8	15	21
	B	19	2	9	15
	C	19	12	5	15
	D	19	14	7	1

* Based on one-half the size of the trip's destination plus the sum of all closer destinations (including the origin).

Figure 3-3: EXAMPLES OF PHYSICAL SPACE AND OPPORTUNITY SPACE spatial interaction is then developed, and its theoretical properties relevant to evaluation are considered to conclude this chapter.

ACCESSIBILITY MEASURES IN THE LITERATURE

Distance between locations along a transportation network is the simplest measure of accessibility proposed in the current literature. As developed by Shimbel (1953), this measure is the sum of all interzonal distances to a given locale or zone of origin.[1] Shimbel has also noted that the sum of these measures over all zones of origin is a measure of the network's dispersion. Because these measures are affected by the number of locales or zones as well as the network's configuration, Vickerman (1974) has suggested that both measures be averaged over the number of zones considered.[2] In any case, interzonal distance can be defined as planimetric distance, traveltime, number of communication links, or other metrics relevant to the particular substantive context.[3]

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[1] The term "interzonal" is used because locations are usually aggregated by areal units which are called traffic zones or transportation zones.

[2] For similar reasons, Pardee et al. (1969, p. 112) define accessibility as mean dispersion and its standard deviation.

[3] These distances are measured between zone centroids, which can be interpreted as the point of that zone's "expected location" if potential origins and destinations are distributed uniformly within its boundaries.

Interzonal network descriptors are generally inappropriate as evaluation measures in the present, user-oriented context. The relationship of the network to its intended clientele is frequently addressed by aggregating potential origins and destinations into zones, and measuring network characteristics between zone centroids. Distortions can be caused by zonal geometry, as illustrated in Figure 3-4. More importantly, these measures neither weight locations by their relative attractiveness nor reflect patron response to spatial impedances which can vary over distance.[4]

To counter the latter drawbacks, Vickerman (1974) has suggested an accessibility measure which is based on the simplest spatial interaction model. As derived by Cesario (1976), the probability P_{ij} that a trip which originates in zone i will end in zone j is defined as:

$$P_{ij} = \frac{f(c_{ij})}{\sum_{j} f(c_{ij})} \tag{3.1}$$

where $f(c_{ij})$ is the generalized cost of travel between zones i and j. Usually this function takes one of three forms:

$$f(c_{ij}) = d_{ij}^{-\beta} \tag{3.2}$$

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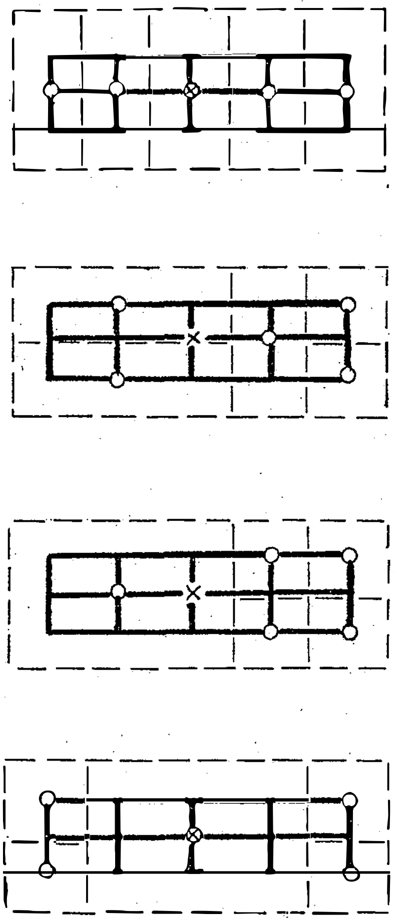
[4] Stutz (1973) and Tinkler (1974) suggest the use of arbitrary weights to reflect the decreasing marginal effect on travel of increasing distance.



	Accessibility of the network	Accessibility of location "x"
(a)	$\bar{A} = 4.0$ $\bar{A}(.5) = 2.4$	$\bar{A}_x = 3.0$ $\bar{A}(.5)_x = 2.0$
(b)	$\bar{A} = 5.0$ $\bar{A}(.5) = 3.0$	$\bar{A}_x = 3.6$ $\bar{A}(.5)_x = 2.5$
(c)	$\bar{A} = 3.8$ $\bar{A}(.5) = 2.2$	$\bar{A}_x = 3.6$ $\bar{A}(.5)_x = 2.5$
(d)	$\bar{A} = 6.2$ $\bar{A}(.5) = 3.8$	$\bar{A}_x = 5.0$ $\bar{A}(.5)_x = 5.0$

Circles are zone centroids, which are defined by the dashes.

$\bar{A}$ = Mean interzonal accessibility

A(.5) = Average median interzonal accessibility (average distance to the nearest 50% of centroids to the origin)

Figure 3-4: DISTORTIONS IN AVERAGE DISTANCE MEASURES CAUSED BY ZONE CONFIGURATIONS

$$f(c_{ij}) = \exp(-\beta d_{ij}) \qquad (3.3)$$

$$f(c_{ij}) = \exp(-\beta_1 d_{ij}^{-\beta_2}) \qquad (3.4)$$

where:

d_{ij} = intercentroidal distance between zones i and j.[5]

β = an empirically determined parameter.[6]

Vickerman (1974), who inventoried this list, suggests that the selection of a cost function should be based on a "best fit" criteria between modeled interaction levels and actual origin-destination data. Wilson (1967) agrees, hypothesizing that the different forms reflect different perceptions of travel costs. Once the cost function is selected and calibrated to observed interactions between zones,[7] P_{ij} can be interpreted as the ease of a zone's access to another zone given the origin's accessibility to all destinations. The resulting distance-interaction measure of accessibility, $A(d)_i$, is:

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[5] Cost can be defined as physical distance, traveltime, monetary cost, or a combination of the foregoing.

[6] Early studies set $\beta = 2$ in Equation 3.2 to follow strictly the Newtonian analogy. See Carrothers (1956).

[7] See Wilson et al. (1969), Batty and Mackie (1972), Cesario (1973; 1975a; 1975b), H. Kirby (1974), and Batty (1976).

$$A(d)_i = \sum_j f(c_{ij}) \qquad (3.5)$$

Equation 3.5 is summed over i to produce a regionwide index A(d). In both $A(d)_i$ and A(d), the effect of distance on accessibility decreases with increasing distance.[8] Rather than an arbitrary weighting, this distance-decay accessibility index is based on observed behavior.

The distance-decay accessibility index $A(d)_i$ bridges the gap between network descriptors and spatial interaction indices with conflicting consequences. On one hand, $A(d)_i$ is an improvement over interzonal distance measures in that the deterrence of perceived travel costs is explicitly incorporated in a manner which reflects observed travel behavior. However, destination attractiveness[9] is not explicitly modeled, although it affects observed interactions and thus the calibrated value of β. The resulting potential for biases seriously undermines the foregoing improvement and severely limits the usefulness of $A(d)_i$ as an accessibility measure.

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[8] The often cited rationale is the greater deterrence of an additional mile to a potential trip of ten miles compared to that of one mile at the end of a 100 mile trip.

[9] Destination attractiveness is the desirability of reaching that site if spatial impedences are not considered. In operational terms, destination attractiveness is usually defined by actual trip ends at that site or by some measure of mass such as area, number of facilities, or amount or retail expenditures. For example, see Lakshmanan and Hansen (1965).

By explicitly including the attractiveness of destinations, distance-attraction measures of accessibility are more comprehensive than the preceding forms. These measures are based on the balancing factors in the family of spatial interaction models presented by Wilson (1970, Ch. 2; 1971; 1974, Ch. 6; 1975).

Two measures are based on singly-constrained models. $A(a)_i$ is the accessibility of people in zone i to their region, and takes the form:

$$A(a)_i = \sum_j M_j f(c_{ij}) \tag{3.6}$$

where M_j is a measure of "mass" which indicates the zone's attractiveness. By including only origins of members of a specific market segment, this measure is the accessibility to the region of that market segment in the given location. A regionwide index A(a) is simply $A(a)_i$ summed over all zones i , and measures the accessibility of the entire market segment to all attractive destinations. A similar measure defines the accessibility of destination facilities in zone j to its clientele:

$$A(b)_j = \sum_i M_i f(c_{ij}) \tag{3.7}$$

where M_i is the "mass" or population of zone i. $A(b)_j$ can be interpreted as the accessibility of the region's population to a particular destination or facility of interest, which is demonstrated by the known number of trips which terminate in the zone.

The most complex accessibility measures based on physical distance are defined by balancing factors in doubly-constrained spatial interaction models. In these models, the number of trips originating in each zone (O_i) and destined for each zone (D_j) are given. The accessibility of a population in zone i to destinations in the region is a function of spatial impedences, demonstrated attractiveness of the destinations, and competition exerted by other potential users of these destinations. This complex measure of the population's accessibility, labeled $A(ab)_i$, takes the form:

$$A(ab)_i = \sum_j b_j D_j f(c_{ij}) \qquad (3.8)$$

where b_j, representing competition, is the inverse of $A(ba)_j$ in Equation 3.9. The accessibility of facilities in j is a function of spatial impedences, the number of potential users by zone of origin, and competition of other destinations for those potential users. Labeled $A(ba)_j$, this complex measure of the facilities' accessibility takes the form:

$$A(ba)_j = \sum_i a_i O_i f(c_{ij}) \qquad (3.9)$$

where the competition factor, a_i, is the inverse of $A(ab)_i$. In Equation 3.8 and 3.9, the juxtaposition of a and b indicates that the index is based on the first balancing factor which is in part dependent on the second. Regionwide values of A(ab) and A(ba) are obtained by additional summation over i and j respectively.

Given the inclusion of spatial impedences and destination attractiveness in all distance-attraction models, their definition as operational variables raises three questions in the literature (particularly by Isard [1960, Ch. 11], Taaffe and Gauthier [1973, pp. 97-98], and Lowe and Moryadas [1975, Ch. 9]):

(1) Which locations are relevant for inclusion in the model?

(2) How is site attractiveness or "mass" of the locations measured?

(3) How is the impedence of space measured?

Since people's travel behavior varies substantially for work, retail, and other types of trips, these questions are posited for a given trip purpose. The singular number is emphasized since multi-purpose trips have yet to be addressed adequately in spatial interaction models.

The question of locational relevance has been raised specifically by Wilbanks (1970) and Daccarett (1975), who argue that all possible destinations are not considered in the individual's travel decisions and therefore should not be included in the summation. These problems occur with network descriptors, and are countered only by arbitrary or hidden weights. In contrast, distance-attraction measures explicitly weight a location's relevance by the population's observed reactions to its site attractiveness (mass) or to its geographical situation (spatial impedences and competition). Relevance is adequately represented by destination attractiveness and spatial impedences, particularly if the distance-attraction models are applied to a relatively homogeneous population, such as market segments of the transportation disadvantaged, whose responses to distance and site attributes have a relatively small variance.

If relevance is characterized in part by site attractiveness, then how is this concept measured? A measure of facility "mass", such as floor space, may be appropriate if it is closely correlated to observed trip attractions. Such is usually the case with ubiquitous facilities where functional and qualitative differentiation is closely related to store size, although socio-economic and/or racial differentiation can affect the measure's validity. Similar logic can be applied to the trip generating characteristics of an area, which is usually tied to population size, density, and income. Wilson (1971, p. 13) prefers the use of actual trips generated (O_i) or attracted (D_j) rather than mass (M_i, M_j). By directly estimating D_j beforehand, multi-purpose site attractiveness can be more thoroughly characterized, and dimensionality of the interaction model will be maintained.[10] Furthermore, the estimation of both O_i and D_j allows the use of more elegant and accurate doubly-constrained

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[10] Trip interchanges are a function of trip ends and trip lengths rather than of mass and trip lengths.

models. Whether mass is used directly in the model or exogenously to estimate trip ends, the operational definition of mass depends on which variables most closely approximate observed travel behavior. Data availability and reliability are also considerations. One example is the use of census tracts for data collecting which has a significant potential for bias caused by the separation of retail districts into several census tracts with distant centroids. These issues are collectively the focus of trip generation modelling, which is reviewed by K. Webb (1974) and Stopher and Meyburg (1975, Ch. 7) among others.

The measurement of travel impedance is also fraught with problems. As with measures of site attractiveness, the specific variable for spatial impedance and the form of the cost function depends on the availability of data and their ultimate fit with observed behavior. Consideration must also be given to the control of potential distortions inherent to intercentroidal distance measurements, as previously outlined for interzonal distance measures. Wilbanks (1970) raises the additional problem of route selection: if multiple routes are available, which is used to measure distance? Wilbanks asks the same question for mode selection.[11] While least-

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[11] The use of traveltime on public modes causes another problem: how are scheduled headways incorporated into the interzonal traveltime? Dacarett (1975) answers this problem specifically with a "Latest Possible Departure Time" algorithm. The usefulness of this algorithm is unknown for trips other than longer distance journeys-to-work.

time, least-cost criteria seem most appropriate for mode and route assignment of interzonal impedances, the local population may choose modes and routes by other criteria. "Rational" and actual selection may differ, particularly for social-recreational trips and for travellers who are sensitive to barriers not specified in the impedance function.[12] Differences in selection may also be caused by distorted perceptions (cf. Lansing and Hendricks [1967], Neuburger [1971], Gould and White [1974], and Burnett [1976a]).

Care must also be exercised in the calibration of the β parameter in the impedance function. Whichever cost function is used, two additional biases must be considered. The first problem, noted by Wilbanks (1970), is a boundary distortion caused by prematurely truncating the region in which a significant number of interactions takes place. Greater truncation will decrease the trip lengths considered, biasing the β parameter upwards. The second problem is a density bias, analytically examined by Fisk and Brown (1975), who determined that β is sensitive to the proximity of surrounding destinations. A greater variety of nearby facilities leads to shorter trip lengths and a higher β. This sensitivity to density challenges the interpretation of β as the elasticity of travel to cost (be it

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[12] Mode selection also depends on the number of mode options available to the submarket. Some of the differences between captives of a mode and users who can exercise choice are outlined by Ferreri and Cherwony (1971).

monetary, time, or distance), and obscures the role of travel cost in measured accessibility. Fisk and Brown recommend using origin-specific values of β to overcome the latter problem, but this greatly increases calibration problems.

The problem of sensitivity to the density of destination opportunities indicates that the measures based on opportunity space may be more valid characterization of accessibility than distance-attraction measures. In spite of their many drawbacks, however, the distance-attraction measures are currently the most often recommended indicators of accessibility (as documented in Chapter 4).

The published alternatives to the preceding measures are aggregate-opportunity measures. These measures, based on opportunity space, are direct characterizations of the choice among destinations exercised by or at least available to members of a transportation market segment. Spatial impedances, represented by distance or traveltime, are utilized only to bound the range of opportunities considered relevant. This approach is advocated most strongly by Daccarett (1975), who presents the general form of the measure as:

$$A(r)_i = \sum_j D_j \epsilon_{ij} \tag{3.10}$$

where:

$A(r)_i$ = accessibility of zone i to all relevant locations.

D_j = number of destination opportunities in zone j.

$$\varepsilon_{ij} = \begin{cases} 1 \text{ if connectivity is adequate} \\ 0 \text{ otherwise} \end{cases}$$

Accessibility is simply the aggregation of all destinations within a range of travel considered reasonable. Operational forms of this approach have been developed by Tomazinis (1967), Wickstrom (1971), Wachs and Kamagai (1973), and Wyatt (1974).

Aggregate-opportunity indices are simpler in computation and are perhaps more intuitively appealing than distance-attraction measures, but they also are less appropriate for the following reasons. First, the definition of a traveltime range cannot be rationalized beyond arbitrary judgement, as suggested in the previous discussion of locational relevance. Second, the model implicitly assumes that spatial impedances play an insignificant role in determining accessibility within a given range.[13] Without such consideration, the boundary distortions such as Wilbank's (1970) centrality bias are inevitable. Third, destinations are considered accessible regardless of their relationship to other potential users. While capacity constraints are not explicit in the distance-attraction models, their resulting effects on accessibility are adequately characterized in doubly-constrained and implicitly captured in a singly-constrained models. Aggregate-opportunity

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[13] The case for this assumption is embodied in the "frictionless area" hypothesized by Getis (1969).

measures are useful only when inadequate resources and data are available for distance-attraction models and a distinct range of travel is empirically discernible.

AN ALTERNATE MEASURE OF ACCESSIBILITY

While the published aggregate-opportunity measures characterize accessibility in opportunity space, they relate implicitly spatial interaction to physical space. A more direct approach has been proposed for modeling spatial interaction entirely in opportunity space.[14] Known as the intervening opportunities model, this approach counters the arguments about locational relevance by Wilbanks (1970) and Daccarett (1975) and relaxes, without eliminating, the role of distance. The latter point is particularly useful in small-area transportation studies.

Surprisingly, the intervening opportunities model has not been considered in the literature as the basis of an accessibility measure. This is perhaps due to the decline in the model's use for predicting the distribution of trips between zones prior to the recent interest in accessibility. Furthermore, the accessibility interpretation of the model is not readily apparent, and therefore

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[14] In other words, a distance per se does not affect interaction; rather, it is merely a ranking mechanism.

requires careful consideration of the model's derivation.

The intervening opportunities model of spatial interaction is usually derived under the assumption that potential destinations are distributed continuously in space.[15] Recent derivations by Wilson (1967)[16] and Stopher and Meyburg (1975, pp. 159-163) begin with a discrete form of the model, but revert to the continuous case before the discrete version has been completed. In the process, an approximation is used which is inconsistent with the theoretical basis of the model, adds to the complexity of the derivation, and obscures interpretation of measured accessibility.

A complete derivation of the discrete intervening opportunities model which avoids the above-mentioned inconsistency has been developed by Schmitt and Greene (1978). This derivation is now presented to clarify the model's use for measuring accessibility. The discrete model is shown to become the continuous version in the limit as opportunities go to zero in size and infinity in number. The notation is as follows:

O_i = number of origins in zone i.

D_j = number of potential destinations in zone j.

L = probability of one randomly selected destination

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[15] These derivations are authored by Stouffer (1940), Schneider (1959), Harris (1964), and Ruiter (1967).

[16] This derivation is repeated in Wilson's books (1970, App. 3; 1974, App. 2), as well as his other articles.

fulfilling the given trip purpose.

P_{ij} = probability that a trip which starts in zone i will end in zone j.

U_{ij} = probability that a trip which starts in zone i will pass beyond zone j.

T_{ij} = number of trips starting in zone i and ending in zone j.

All zones j are ranked by increasing centroidal distance from each zone i so that j=1 for the nearest zone to i, j=2 for the next nearest, and so forth.

Consider first the case of one destination in each zone. The probability that the closest zone to i will satisfy the trip purpose is:

$$P_{i1} = L \tag{3.11}$$

The probability that the trip purpose is not satisfied and the traveler continues his search is:

$$U_{i1} = 1-L \tag{3.12}$$

The probability that the trip terminates in the next zone is conditional on both the traveler passing beyond zone 1 and satisfying his trip purpose in zone 2.

$$P_{i2} = (1-L)L \tag{3.13}$$

For zone 3, the probability is conditional on passing zones 1 and 2, and on the trip purpose being satisfied in zone 3.

$$P_{i3} = (1-L)(1-L)L = (1-L)^2 L \qquad (3.14)$$

In general, the probability of a traveler from *i* stopping in *j* is:

$$P_{ij} = (1-L)^{j-1} L \qquad (3.15)$$

and the probability of his passing *j* is:

$$U_{ij} = (1-L)^{j-1}(1-L) = (1-L)^{j} \qquad (3.16)$$

Consider now the case of variable numbers of destina

each zone. The probability of passing beyond zone 1 is conditional on all the probabilities (1-L) that each opportunity in zone 1 does not satisfy the trip purpose. Since there are D_1 opportunities to stop in zone 1:

$$U_{i1} = (1-L)^{D_1} \qquad (3.17)$$

The derivations by Wilson (1967) and Stopher and Meyburg (1975) approximate Equation 3.17 with $U_{i1} = (1-LD_1)$. This binomial approximation[17] is acceptable only when $D_1 \leq 1/L$. If for any zone *j*, D_j

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[17] The binomial approximation is obtained from the binomial expansion of $(1-L)^D$.

is greater than 1/L, then the probability of a trip terminating in that zone will be greater than one. This is an obvious violation of the model's probabilistic basis. By avoiding the use of this approximation, the derivation of the model can remain consistent and be simplified appreciably.

Continuing, the probability of passing zone 1 is conditional on both the probabilities of passing the opportunities in zones 1 and 2.

$$U_{i2} = U_{i1}(1-L)^{D_2} = (1-L)^{D_1+D_2} \qquad (3.18)$$

In general:

$$U_{ij} = U_{ij-1}(1-L)^{D_j} = (1-L)^{\sum_{k=1}^{j} D_k} \qquad (3.19)$$

It should be noted that the probability of passing j once all previous zones have been passed is $(1-L)^{D_j}$. To simplify notation, D is now defined as the sum of potential destinations between origin i and zone j.

$$D = \sum_{k=1}^{j-1} D_k \qquad (3.20)$$

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[17]

$$(1-L)^D = 1 - LD + \frac{D(D-1)L^2}{2!} - \frac{D(D-1)(D-2)L^3}{3!} + \ldots$$

Where L is very small, all higher order terms in L can be neglected so that:

$$(1-L)^D \approx 1 - LD \ .$$

In general, the probability that a trip originating in zone i will end in zone j is conditional on the probability that intervening opportunities did not satisfy the trip and on the probability that the trip will not continue beyond j once all previous destinations have been passed.

$$P_{ij} = U_{ij-1} [1-(1-L)^{D_j}] = (1-L)^{D} [1-(1-L)^{D_j}] \qquad (3.21)$$
$$= [(1-L)^{D} - (1-L)^{D+D_j}]$$

Equation 3.21 is simply the cumulative density function of a geometric probability distribution evaluated over the interval $[D, D+D_j]$. The mean of this distribution is 1/L; thus, L may be interpreted not only as a probability but also as the inverse of the average number of opportunities passed in a trip.

To convert Equation 3.21 into the more common, continuous form of the intervening opportunities model, an analogy can be made to the calculation of present value in economics (Chiang, 1967 , pp. 275-277). In this analogy, the probability of traveling to a given zone is discounted over intervening opportunities just as future dollars are discounted over time. The number of times a decision is made to stop or continue becomes infinite, as does the number of compounding periods.

The usual assumption for transfering from the discrete to the continuous intervening opportunities model is made: that zone size goes to zero. The number of zones, and thus the number of times a decision to continue is made, therefore becomes infinite. If x is an integer representing the number of decisions made by the traveler per unit of opportunity, then L/x is the probability of a trip being satisfied by an opportunity once it is reached. Substituting for L in the discrete model:

$$U_{ij-1} = (1 - \frac{L}{x})^{xD} \qquad (3.22)$$

This form is equivalent to the discrete case above when x=1. Equation 3.22 can be rewritten as:

$$U_{ij-1} = [(1 - \frac{L}{x})^{\frac{x}{-L}}]^{-LD} \qquad (3.23)$$

As x goes to infinity, the traveler makes an infinite number of decisions per unit opportunity regarding infinitely small destinations. The probability of selecting a given destination becomes zero, as does the probability of a given event in any continuous distribution. In other words, the decision to proceed as well as the distribution of opportunities in space becomes continuous. It can be shown that:

$$\lim_{x \to \infty} (1 - \frac{L}{x})^{\frac{x}{-L}} = e \qquad (3.24)$$

Using this result, the limit of Equation 3.23 as x → ∞ can be evaluated.

$$U'_{ij-1} = \lim_{x \to \infty} U_{ij-1} = e^{-LD} \qquad (3.25)$$

Equation 3.25 is simply the cumulative density function of the exponential probability distribution evaluated over the interval $[D,\infty)$. Evaluated over the interval $[D,D+D_j]$, this cumulative density function gives the probability of stopping at j as:

$$P_{ij} = [\, e^{-LD} - e^{-L\,(D+D_j)} \,] \qquad (3.26)$$

To convert the spatial choice model in Equation 3.26 into a trip distribution model, the probability of traveling to zone j is multiplied by the number of origins in i to give the number of trips T_{ij}.

$$T_{ij} = O_i \,[\, e^{-LD} - e^{-L(D+D_j)} \,] \qquad (3.27)$$

Equation 3.27 is the common form of the intervening opportunities model documented in the transportation literature (Pyers, 1966).

The intervening opportunities model introduces aspects of optimizing behavior into an essentially probabilistic trip distribution model.[18] The rationale for this is as follows. In its discrete

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[18] This interpretation of the model is extracted from Schmitt and Greene (1977).

form, the model postulates that a tripmaker will consider all possible destinations for a given trip purpose in strict order of their proximity to him. However, the model is stochastic in that there is a constant probability that any given destination opportunity, once arrived at, will satisfy the purpose of the trip.

The constant probability of satisfaction, the L-factor, is most simply estimated as the inverse of the mean number of opportunities passed for all trips. This estimator is based on the exponential distribution of trip lengths anticipated by the model. Once the opportunity distance of trips has been measured, the estimator can be calculated very easily.

While the L-factor is the inverse of the mean number of opportunities passed in a trip, it can also be interpreted in light of the intervening opportunities model as the constant probability that any arbitrarily small unit of opportunity, once reached, will satisfy the traveler's trip purpose. A small L-factor indicates that the tripmaker considers a wide range of opportunities to be accessible and is not likely to be satisfied at the closer-by destinations. A large L-factor, conversely, is indicative of a more limited range of spatial choice. Assuming that well-being is related to the availability of destination choices,[19] then the L-factor is a direct

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[19] Greater choice increases competition for patrons by social and economic enterprises, and reduces the possibility of abuse of captive markets.

measure of accessibility-related benefits of transportation.

The intervening opportunities model provides a theoretical basis for evaluating accessibility. It measures the amount of spatial choice exercised by the population (which can comprise either individuals, households, or zonal aggregates of people). In conjunction with more frequent travel, greater spatial choice reflects a fuller participation in the activities and services scattered throughout the community. The model thus provides an indicator of the contribution which transportation can make to the monitored population's quality of life. Furthermore, the intervening opportunity model recognizes that distance alone is not necessarily the determinant of spatial choice. Proximity of potential destinations with respect to each other may be more important, particularly in areas of high density and unevenly distributed destinations. Such conditions are common in micro-scale studies such as for Northeast Baltimore.

The L-factor of the intervening opportunities model has been shown to have excellent promise for evaluating transportation developments for disadvantaged groups. The proof of this measure's usefulness can be determined only in field settings, however, where many problems will occur which are related either to the model's calibration with actual data or to unanticipated clientele behavior. The calculation and interpretation of the L-factor is therefore attempted for evaluating the NECO Mini-bus Service.

No matter how appropriate the form or how easy the calculation of any accessibility measure appears to be, the success of its use is highly dependent on the process by which information is collected and the measure's results are employed. As a consequence, attention is focused on the evaluation process before the L-factor is tested in actual practice.

CHAPTER IV

EVALUATION FRAMEWORKS: THE PROCESS ISSUES

Evaluation includes a wide variety of endeavors whose common denominator is "the notion of judging merit" (Weiss, 1972, p. 1). In the planning context, the need for "judging merit" arises in selecting future courses of action and in learning from past actions for improved future decisionmaking. This need is frequently answered by judgements based on intuition and unstructured ad hoc experience, rather than a formal process of collecting and weighting evidence to evaluate the proposed or consummated action (Mandelbaum, 1975). The situation in transportation planning is no exception (Harris, 1973; Institute of Public Administration, 1975b, Ch. 7).

The often cited failure of formalized evaluation procedures to affect decisionmaking is most commonly attributed to the sociology and politics of bureaucratic planning and administration. This emphasis on the environment surrounding evaluation efforts reflects the disciplinary interests of sociologists, social psychologists, and political scientists who developed the literature on evaluation research following their involvement in the social action programs of the Sixties (Caro, 1971, pp. 1-34). Institutional resistance and related problems with evaluation efforts have been documented by Suchman (1967), Schulberg and Baker (1968), Campbell (1969; 1973), Rossi and Williams (1972), Shaver and Staines (1972), Weiss (1972), Wholey (1972), and others.

In contrast, difficulties with evaluation procedures are usually attributed in the planning literature to the investigative techniques employed. Simple descriptive or narrative accounts for use as tools for evaluating an action's impacts are most quickly dismissed. While adequate for administrative monitoring,[1] this approach has been shown by Wholey (1972) and others to be adequate for judging the effects of a program, project, or action. A variety of specific evaluation techniques, such as benefit-cost analysis, have been scrutinized in the literature and used extensively. Much has been written about the capacity of these techniques to capture all the measured impacts of a program in a comparable format; however, little attention has been given to the actual sources of information which are used by these comparative techniques.

Information is developed in two stages: raw data is collected and then transformed into an evaluation measure. The transformation generally involves the use of a model to describe or explain past and present conditions, or to predict future conditions. In the present case, trips are sampled and destination characteristics are tabulated. These data are transformed into an accessibility

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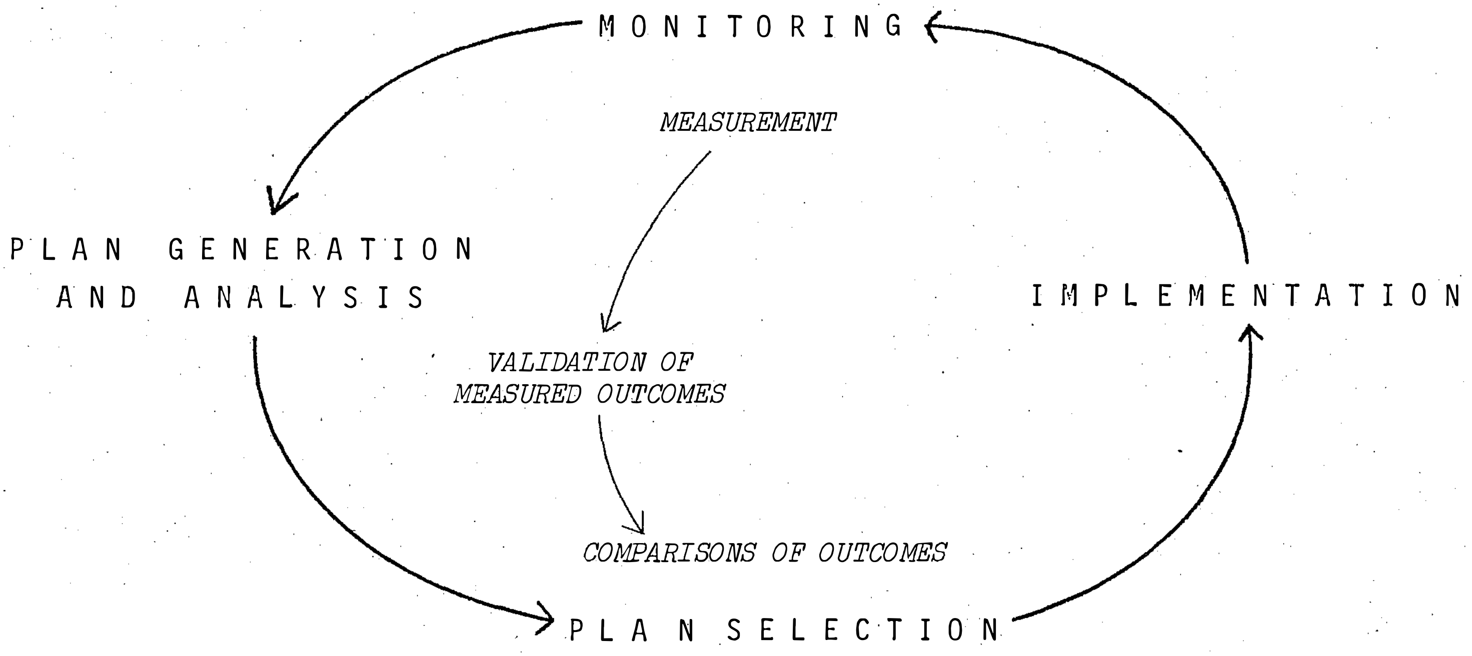
[1] This includes assessments of a program's compliance with specified organizational procedures and standards of internal operation (Suchman, 1967; Cain and Hollister, 1972).

measure using a spatial interaction model. The accessibility measure describes changes if the data are collected at different points in time and the model is estimated separately for each set of data. If the model is estimated with present or historic data, accessibility changes can be predicted by hypothesizing future trip costs and destination characteristics.

The collection and transformation of data are susceptible to three problems. First, the raw data may have been collected in poorly controlled or biased manner. Second, the evaluation measure may be based on a poorly specified or inappropriate model (as was discussed in the last chapter). Third, the type of model (descriptive, explanatory, or predictive) may be inappropriate. To have confidence in any measurement of change, the evaluation measure, its underlying model, and the data collection procedure must be validated as reflective solely of the outcomes of the transportation development under consideration. Only then can the measured outcomes be compared with confidence to those of alternative actions, often including a "do nothing" option.

As defined by Hawkridge (1970), a credible evaluation process should contain three basic steps: measurement (the collection and transformation of data), validation, and comparison of the measured outcomes. Since these steps provide the basic information for planning decisions, as illustrated in Figure 4-1, pitfalls in



The PLANNING PROCESS provides information for the *EVALUATION PROCESS*.

The *EVALUATION PROCESS* validates and interprets information, providing guidance for the PLANNING PROCESS.

Figure 4-1: THE PLANNING AND EVALUATION PROCESSES the measurement and validation stages must be scrutinized as well as the comparative techniques if evaluation research is to provide useful information to conscientious decisionmakers. Otherwise, as Dyckman (1967) and D. Harvey (1973, Ch. 7) imply, the practice of evaluation examined by the sociologists et al. and the particular measures and techniques discussed in the planning literature are of little consequence.

As defined in Chapter 1, three operational forms of the evaluation process have been or can be applied to transportation developments. Most commonly used is the predictive model framework, in which outcomes are predicted and evaluation takes place prior to implementation of the planned action. Demonstration projects provide a more recently developed framework for evaluating transportation innovations on a smaller scale prior to implementing similar or larger developments. The third framework, based on experimental and quasi-experimental designs, has been used in the evaluation of social action programs, but has rarely been applied to transportation projects. Descriptive and explanatory models are generally relevant to the latter two frameworks.

Each framework is examined with the intention of establishing its applicability to the evaluation of transportation developments for disadvantaged groups. Each framework's development and applications, its relationships to planning theory,[2] and its use of accessibility measures are explored. Criteria for determining the framework's applicability are based on the sensitivity of its structural and mechanical characteristics to the substantive issues outlined in Chapter 2.

THE PREDICTIVE MODEL FRAMEWORK

Evaluations structured by the predictive model framework are based on the "measurement" of outcomes prior to their occurrence. Such measurement is accomplished through the use of predictive models. Validation of the measured outcomes is based on acceptance of the model's theoretical underpinnings. Comparisons of the proposed action's outcomes are made to those of alternative actions (including the null or "do nothing" alternative) by altering the policy-sensitive variables in the model to reflect each alternative's characteristics.

The predictive model framework has been the dominant form of evaluation in contemporary transportation planning. According to W. B. Allen and Boyce (1974), this reliance stems from an emphasis on producing capital-intensive, physical transportation infrastructure. Predictive models are needed for the evaluation of present

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[2] Planning theory is concerned with the process of planning rather than particular tools employed by planners (Faludi, 1973).

Plans with measures of future conditions, so that estimates of further costs and benefits can be included in the evaluation.

In response to this need, a sequential system of models was developed with federal assistance in the 1950's for major metropolitan area transportation studies (Garrison, 1966). The sequential system of models, currently labeled the UMTA Transportation Planning System (UTPS), was adopted, refined, standardized (or rigidified in the view of some), and diffused throughout the United States by the Bureau of Public Roads[3] for local application (W. B. Allen and Boyce, 1974). The UTPS has substantial input requirements and generates extensive and detailed estimates of travel behavior for evaluation, all of which has been formally organized under federal auspices as the Urban Transportation Planning Process (Roberts, 1973). Illustrated in Figure 4-2, this process is driven by the UTPS and establishes the specific, predictive model framework of evaluation currently endemic to transportation planning.[4]

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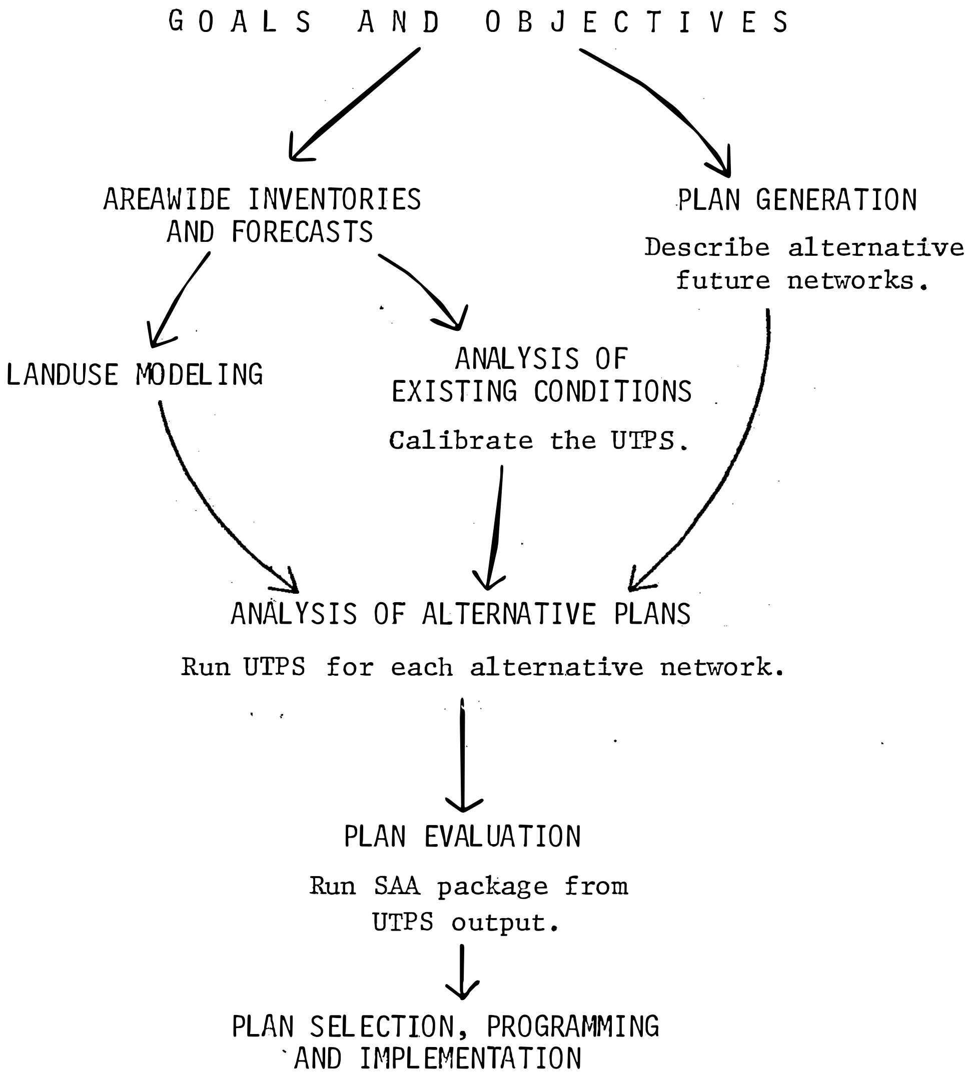
[3] The Bureau has subsequently been reorganized as the Federal Highway Administration (FHWA).

[4] The UMTA Transportation Planning System (UTPS) is documented by the U. S. Urban Mass Transportation Administration (1974). The UTPS includes four basic steps (trip generation and attraction, trip distribution, mode split, and trip assignment) which are described in detail by U. S. Federal Highway Administration (1972), K. Webb (1974), Wilson (1974, Ch. 9), and Stopher and Meyburg (1975, Ch. 7-10). Once calibrated to existing patterns, the UTPS predicts future travel demand for highways and line-haul public transit. Planning software for the latter has been refined recently by UMTA. Output from the UTPS is summarized in evaluation



UTPS = UMTA Transportation Planning System

SAA = Special Area Analysis

Figure 4-2: THE URBAN TRANSPORTATION PLANNING PROCESS

Measures of accessibility were developed in conjunction with the trip distribution stage of the UTPS. Both intervening opportunities and distance-attraction models of spatial interaction were used initially to distribute trips, but the former was not applied extensively after The Federal Highway Administration included only the latter in their generally available UTPS packages (W. B. Allen and Boyce, 1974).[5] The role of accessibility was limited as an input for predictions of future travel demand, with only occasional and inconsistent reference to interzonal travel-times in the evaluation of proposed systems (such as Ockert and Pixhorn [1968]).[6]

Accessibility was developed as an evaluation criterion following the increase in successful resistance to urban freeway construction (as documented by Geiser [1970], Lupo, Colcord, and Fowler

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measures by the Special Area Analysis (SAA) package (U. S. Department of Transportation, 1973), which includes measures of accessibility. Alternatives to the UTPS are discussed by The Highway Research Board (1973b) and Stopher and Meyburg (1975, Ch. 12-16). While the specific, alternative models may differ significantly from the UTPS, these alternatives do not affect the structure of the Urban Transportation Planning Process, nor do they change the general form or role of accessibility measures developed for the UTPS.

[5] The rationale for this selection is not entirely clear since assessments of both measures were equally favorable as reported by Heanue and Pyers (1966) and Jarema, Pyers, and Reed (1967).

[6] The relationships between evaluation measures and the UTMS are particularly evident in Ockert and Easler (1970).

[1971], and the Highway Research Board [1973a]). Emphasis shifted from evaluation of systemwide performance to evaluation of local transportation service and non-user impacts (Highway Research Board, 1973b; Hirten, 1973). While consideration of local impacts of highways had been required since the Federal-Aid Highway Act of 1958 (72 Stat. 902), coordination of transportation planning with local planning goals — and the subsequent development of evaluation measures which were to be sensitive to location conditions — was not required until the late Sixties (23 U.S.C., § 128; 49 U.S.C., § 1659a). The Special Area Analysis package was developed (as described by the U.S. Department of Transportation [1973]) and tested (as documented by the Massachusetts Executive Office ... [1973], and Sherman, Barber, and Kondo [1974]), to fulfill this requirement without disrupting the Urban Transportation Planning Process (as illustrated in Figure 4-2). Utilizing information estimated by the standard UTPS software, the package tabulates mode-specific traveltimes among various facilities, subareas, and subpopulations for proposed metropolitanwide transportation networks. Accessibility indices are simply the values of singly constrained distance-attraction models derived from the trip distribution phase of the UTMS (Cohen and Basner, 1972).

This reliance of evaluation measures on the structure of a predictive model is consistent with the framework's links to the rational comprehensive planning process.[7] This process has been defined by Banfield (1959) as the consideration of all alternatives and their consequences before taking a course of action, and is the major accepted tradition in planning theory (cf. Meyerson and Banfield [1955], Meyerson [1956], Harris [1960], Robinson [1965], Harris [1967] and Faludi [1973]). As illustrated by Altshuler (1965), this approach is practiced widely by transportation planners. Evaluation techniques, such as Hill's (1973) "Goals Achievement Matrix", are subsequently based on predicted, future conditions. Accessibility measures derived from the UTPS are another example.

Given the uncertainty of the future, the confidence in a model's predicted outcome is principally derived from the soundness of its theoretical base (Kaplan, 1964, Ch. 5). Lowe and Moryadas (1975) concur in the transportation context, stating that: "... a model provided with a theory is completely interpretable while one without a theory is subject to several different interpretations, each of which may be valid under different circumstances" (p. 196). This statement assumes that the theory adequately reflects changes in behavior following the implementation of an innovation. In neither the general case of transportation (as argued by Charles River Associates [1972, p. I-2 and App. E], the Highway Research Board [1973b, pp. 6-7], K. Webb [1974] and Dacey [1975]), nor the present context

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[7] This link is particularly well illustrated by Perraton (1974).

of the disadvantaged has a complete theory for interpreting changes in behavior been developed.

The Lowe and Moryadas statement also assumes that the predictive models based on those theories are adequately sensitive to parametric shifts in travel behavior. K. Webb (1974) and W. B. Allen and Boyce (1974) have noted that transportation demand models are largely dependent on currently observed travel patterns, and thus are only able to project the status quo. The predictive use of spatial interaction models and their concomitant measures of accessibility are particularly dependent on stable travel behavior, (Taaffe and Gauthier, 1973, p. 98). While such consistent travel behavior may be true of groups who are dependent on relatively unchanging and inflexible transit service, these models are not necessarily sensitive to innovations in service or user-oriented educational efforts.[8] Generally, behavior in self-learning environments is susceptible to parametric shifts (Mandelbaum, 1975; Burnett, 1976b).

For all its shortcomings, the predictive model framework necessarily remains the principle means of evaluating many planned actions. These actions, according to Etzioni (1967), require substantial investments of time and capital, are inflexible once

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[8] The latter includes instructions on use of the transportation service and information about opportunities which can be reached by the service, both of which significantly affect user demand in the inner city (California Business and Transportation Agency, 1971; Chicago Mayor's Committee ...., 1972).

established, and cannot be implemented piecemeal. In contrast, most innovative social programs and many physical improvements (such as the transportation services described by R. Kirby et al. [1974] and Perloff and Connell [1975]) are relatively inexpensive developments of existing technology and infrastructure. The fates of these innovations should not be tied to the predictive model framework of evaluation which is very likely insensitive to changes induced by them.

THE DEMONSTRATION PROJECT FRAMEWORK

Most innovations in public transportation, such as para-transit developments, do not require a major commitment of resources to an inflexible service prior to measuring the innovation's actual outcomes. The effectiveness of these innovations can be demonstrated in the restricted setting of one city or a part of the city prior to their widespread implementation. Evaluating innovations with such pilot tests is thus done by the demonstration project framework.

Demonstration projects are "usually short-term [endeavors] made to establish or demonstrate the feasibility of a theory or approach" (U.S. Public Health Service, 1974, p. 4). If the evaluation of a demonstration project is favorable, then the theory or approach to a problem can be applied in similar situations. This strategy has been legislated as the means for evaluating new forms of urban public transportation service since 1964 (49 U.S.C., § 1605), and follows the planning tradition of disjointed incrementalism.[9] Several hundred demonstration projects have been initiated to develop transportation service for the elderly alone (Institute of Public Administration, 1974).

The increasingly widespread use of demonstration projects to evaluate transportation and other social action programs has been frequently criticized in the literature. Charles River Associates (1972) offers the most charitable criticism, citing that transportation evaluations have lacked generalizability. Smerk (1974) faults the Urban Mass Transportation Administration's demonstration projects for testing only conservative innovations. Cain and Hollister (1972) go farther, charging that the entire demonstration project framework is inadequate for evaluating most social programs. Wholey (1972) agrees, suggesting that "the typical demonstration projects demonstrate only that it is possible to spend public funds in a particular way" (p. 364). A similar conclusion is reached in Hilton's (1974) review of the Urban Mass Transportation Administration's research, development, and demonstration program.

The ability of the demonstration project framework to achieve consistent advances in the solution of a problem has been particularly

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[9] Disjointed incrementalism was first proposed by Lindblom (1959) as a process of developing policy through successive, incremental, categorical change.

questioned. Cain and Hollister (1972) challenge the ability of individual demonstration projects — which they label the "pilot model" — to generate adequate experience for evaluating alternative innovations. "The present state of our theories of social behavior does not justify settling on a unique plan of action, and we cannot, almost by definition, learn much about alternative courses of action from a single pilot project" (p. 133). Perloff and Connell (1975) implicitly respond to this criticism by suggesting the simultaneous implementation of several demonstrations at different scales in the metropolitan area. This approach fails to answer the deeper problem: that evaluations of demonstration projects are restricted to justifying a preconceived idea or supporting the null hypothesis (that the innovation did not improve a specified condition). "Certainly it is useful to note that an agency's program is better than doing nothing, but it may be more important for social policy to ask whether something still better could be done" (Hyman and Wright, 1967, p. 764).[10] For this issue to be addressed, the causes of the innovation's measured outcomes must be understood.

The need to determine causality is central to the validation of measured changes following demonstration projects. The project must be carefully designed to control for a host of possibly

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[10] Demonstrations of feasibility "must be given low marks as sources of generalized knowledge about the behavior of transit users" (Hilton, 1974, p. 13).

conflicting, extraneous forces which distort the measured outcomes. These forces are examined at length by Campbell and Stanley (1963), Suchman (1967), and Cook and Campbell (1976), and are shown in Chapter 6 to be relevant to the Northeast Baltimore example. The designs used in one-shot demonstration projects are shown by Cook and Campbell to be inadequate to this task. A more powerful framework of evaluation must therefore be considered if the incremental approach to developing innovations such as the NECO Mini-bus Service is to be systematic and effective.

THE EXPERIMENTAL DESIGN FRAMEWORK

Experimental designs provide an alternative to demonstration projects for the incremental development and evaluation of innovations. The latter framework is actually a primitive version of the former, as suggested by Cook and Campbell's use of "pre-experimental designs" to label demonstration projects.[11] Control is the critical difference.

> "Experiments differ from typical demonstration projects in that those responsible exercise control over inputs and process variables — and carefully measure outputs to determine the extent

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[11] These specific designs are outlined in Appendix A.

> to which the project reaches its objectives" (Wholey, 1972, p. 365).[12]

Unlike demonstration projects, experimental designs explicitly address the validity of measured changes to determine whether the outcomes are actually attributable to the program or action being tested, and whether similar impacts can be expected in general applications of the treatment.[13] These designs, which are simply explicit procedures for implementing a treatment and collecting data, provide a sounder basis for the treatment's evaluation.

The use of experimental designs is usually associated with scientific investigations rather than with the development of social programs. In the former context, experimentation provides the means for evaluating specific questions by establishing "the rules whereby we may define, classify, and measure the [relevant] variables" (D. Harvey, 1969, p. 35). As a continuing process of hypothesis testing, experimentation also serves to increase or reduce confidence in the

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[12] Given this definition, the word "experiment" is frequently misused. Many demonstration projects based on pre-experimental designs are officially (and incorrectly) labeled experiments, as repeatedly illustrated by Benjamin et al. (1975) and the U.S. Department of Transportation (1976). The term is also used for multiple runs of a predictive model under different scenarios (e.g., Alder and Bottom [1973]). These "simulation experiments" (Kaplan, 1964, pp. 150-151) are dependent on synthetic data rather than on actual observations, and are thus not experiments in the present context.

[13] In the present case, the "treatment" is the NECO Mini-bus Service.

general model from which the hypotheses were drawn.

The applied context of social program evaluation is analogous to the scientific perspective. The experimental design framework, outlined by Riecken and Borouch (1974, pp. 13-14), is presented here in a modified form:

1. Program objectives are defined as measurable conditions.
2. A treatment (program or other planned action) is implemented under a carefully designed monitoring procedure which may or may not be initiated prior to the treatment, depending on the specific experimental design used.
3. Controls on and results of the measurement procedure are analyzed to assure that the measured impacts are attributable solely to the treatment.

4a. If the measured impacts are considered to be desirable, modifications to the treatment are implemented with concurrent experimentation until the objectives are maximized within the constraints of available resources.

4b. If the measured impacts are considered to be undesirable, program objectives are reviewed to determine whether they were appropriately defined. New or modified objectives and/or treatments are developed, and the process restarts at Step 2.

As intended by Riecken and Boruch (1974), this framework has been applied to pilot tests prior to the full-scale implementation of a program. The modified form above can also be applied to a flexible program such as the citywide LSS mini-bus service during its full implementation. Although the process can be repeated continually, most existing applications have been terminated at the third step above (cf. Caro [1971], Rossi and Williams [1972]).

While experimental designs have been used to evaluate a number of social action programs, they have rarely been applied to transportation services. Geographic proximity of potential clients to the service usually precludes the use of randomization techniques to assign individuals to treatment and control groups (Stanley, 1972).[14] In the absence of random assignment, quasi-experimental designs must be utilized.[15] Threats to the validity of evaluation measures are inherently more difficult to control in quasi-experiments (as will be discussed in Chapter 5), and techniques of statistical analysis are less well developed (Cook and Campbell, 1976). One transit ridership study by Louviere (1973) and highway safety programs described by Campbell (1969), Kaestner and Ross (1974),

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[14] Random assignment is the simplest and most effective means of guaranteeing equivalence between groups in all respects other than exposure to the treatment.

[15] Quasi-experimental designs use methods other than random assignment to approximate equivalence between treatment and control groups. Either true or quasi-experimental designs can be used within this framework.

and Griffin, Powers, and Mullen (1975), offer the only examples of fully developed quasi-experiments in transportation.[16]

Several issues have been raised which challenge the use of experimental design framework for evaluating transportation service innovations. Methodological problems relating to the control of validity can be resolved and are explored by Campbell and Stanley (1963), Fairweather (1967), Boyce (1970), Charles River Associates (1972, Chs. 3-4), Glass, Wilson, and Gottman (1975), Cook and Campbell (1976), and the following chapter. Other issues to be faced when using the experimental design framework include:

1. unrepresentative patron reaction to being "studied" or specially treated,
2. ethics,
3. administrative fear,
4. evaluator objective,
5. the development of program objectives,
6. systematic progress toward ameliorating the social condition, and
7. the complexity and timeliness of requisite techniques.

Many of these issues are common to the other frameworks of evaluation as well.

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[16] Accessibility was not an issue in those programs, and has thus not been used to date as an evaluation measure in the experimental design framework.

Patron Reaction. When cognizant of the experimental setting, patrons often react to being "studied" in their response to an innovative service. These unrepresentative reactions can be minimized by the use of unobtrusive measures, such as those described by E. Webb et al. (1966) and Cook and Campbell (1976, pp. 319-321). Similarly, reactions biased by temporary appearance of experimental services are lessened by an explicitly permanent commitment to alleviate the local condition in question.

Ethics. The issue of ethics includes safety and equity. The former aspect occurs when a social experiment entails threats to life, limb, psychic well-being, or property, and is rare in the transportation context.[17] Equity is the more common aspect of ethics, raised every time an ameliorative treatment is tried on only part of the community. The usual response is to focus the treatment on the groups having the greatest need. The division of patrons into two categories of scheduling priorities for the NECO Mini-bus Service is an example. A commitment to widespread applications of successful programs may also lessen the equity problem. The issue of ethics, however, remains an unavoidable tightrope to be negotiated by the program administrator and evaluator together.

Administrative Fear. Problems with experimentation are not

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[17] While safety can be a problem in trauma-responsive service experiments, any acceptable design should adhere to minimum performance standards that preclude loss of life greater than that experienced prior to the experiment.

raised by the community alone. Suchman (1967) and Weiss (1972) among others suggest that public officials resist experimentation and thorough evaluations, fearing both failure in clear view of the public and the appearance of political indecision.[18] The fear of failure is valid when public officials advocate an innovation as a solution rather than as one attempt to alleviate a local condition.[19] According to Mandelbaum (1975), only an untenable status quo is politically worse than the failure of a proclaimed solution. Campbell (1969) suggests a strategy to be used by the officials: emphasize the local condition's importance as an untenable status quo, thus justifying the trial of various potential solutions. A specific failure is rationalized as only one in an ongoing series of efforts to deal with a difficult and multi-faceted condition. This stance also counters charges of indecision, suggesting changes as constructive developments rather than as symptoms of a weak or short-term commitment to improving the condition.

Evaluator Objectivity. The practice of evaluation through applied experiments is no less political for the evaluator. Shaver

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[18] Fear can also be a cover for bureaucratic resistance to change, as noted by Weiss (1972) and Barndt (1975).

[19] This is particularly true if the performance levels of a "successful" service are specified before all the effects of the service can be evaluated. Such prespecified expectations, although recommended by Barndt (1975), are unnecessary liabilities. This does not preclude the establishment of minimum performance standards.

and Staines (1972) warn that the evaluator who claims to have totally objective judgement may cause public disenchantment and subsequent mistrust if a declared success later proves unviable. Campbell's response (following Shaver and Staines, 1972, p. 164) posits a dual role of the evaluator, both of which reject this notion of omniscience. The evaluator is first of all a critic, challenging the treatment's measured effects with every validity threat he knows. In this way, his evaluation is more likely to catch problems with the treatment, and can be accepted as the base line of experience from which the innovation can be developed further. While thorough self-criticism may breed confidence in his evaluation, it does not remove the basic assumptions and biases from which he works. By carefully revealing his assumptions and biases, particularly in the form of detailed program objectives, the evaluator assumes an advocate role, following somewhat the tradition established by Davidhoff (1965). By revealing as best he can the basis of his judgements, the evaluator's results are more readily accepted as honest approximations of a perceived reality rather than questionable pronouncements from a "black box". This is particularly important for the NECO Mini-bus Service, which must justify requests for support before recalcitrant, local officials who are skeptical of the service's value.

Development of Objectives and Systematic Progress. Campbell's advocate role of the evaluator presupposes exogenously specified goals from which the more immediate program objectives (and thus the condition to be evaluated) are drawn. Once these goals are stated, can both the program goals and objectives be evaluated and refined with experience, as Suchman (1967, pp. 39-42) deems necessary? Certainly the objectives can be changed through a political process as the external forces affecting ideology evolve and alter community values. Change in response to the experience gained through experimental designs, however, is dependent on the evaluation framework's own feedback mechanisms. These mechanisms are also necessary for systematically improving the condition under attack.

The previously discussed frameworks have shown little potential for making systematic progress towards the solution of substantive problems. Predictive models are restricted by exogenously developed theories, often reenforcing a status quo view of the world (as W.B. Allen and Boyce [1974] evidence in the field of transportation). The demonstration project framework is limited to investigating an innovation's feasibility rather than areas in which the innovation can be improved.[20]

The potential of the experimental design framework is more promising when applied to continuous program development. As specific

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[20] Even this restricted question is poorly addressed by the primitive designs used in demonstration projects. See Cook and Campbell (1976, pp. 246-249).

actions or treatments are implemented and tested, those which improve the conditions specified through the program's objectives are further developed. The direction of these developments is based on the patterns of causality uncovered by the experimental design, already required to establish the validity of measured changes. The result is greater understanding of the problem, pointing the way to improved strategies and suggesting the general applicability of the treatment in other contexts.[21] Even the experience gained from failures is useful, uncovering inappropriate strategies for solution of the problem, and encouraging a reconsideration of the program's basic formulation.[22] Development of the innovation continues until

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[21] For basic program objectives to be questioned, the experimental design framework must be able to uncover contradictory evidence through the invalidation of key hypotheses. Shaver and Staines (1972) charge that this source of evidence is a function of more of haphazard luck than systematic investigation, and is adequate for revealing systematic biases of the specific experiment but not the flaws of its underlying ideology. The practice of multiple hypothesis testing, advocated in the last century by Chamberlin (1890), provides a more reliable source of potential contradictions. Rather than testing an idea or innovation against the null hypothesis (that it does not work), it is pitted against competing hypotheses (that other forces are coming into play). Each plausible explanation of an innovation's impact is investigated in turn through the experimental design, and the resulting patterns of causality reveal the underlying dimensions of the condition to be ameliorated. Multiple innovations, likewise evaluated in a directly competitive framework, reveal each innovation's relative worth.

[22] For example, the NECO Mini-bus Service may prove to be far less effective than increased police protection at destinations or other approaches for ameliorating the mobility problems of the local elderly and handicapped. In such a case, the NECO governing board would divert its resources to the more effective means.

the conditions are satisfactorily ameliorated or until the problem is redefined in more relevant terms.

Complexity and Timeliness. As noted by Suchman (1967), experimental designs allow both rigor and flexibility in dealing with a variety of spatial, temporal, and problematic contexts. The fullest deployment of this power and versatility is not without its costs, however, requiring the use of sophisticated designs which entail substantial time to implement and occasionally require complicated analytical techniques to interpret. Simplified quasi-experimental designs often must be used instead, each with particular time and analytical sophistication requirements and each with specific weaknesses for uncovering threats to validity of the measured outcomes.

No single experiment — particularly in the field — can hope to cover all conflicting explanations of causality and address all validity threats, but recursive applications of the experimental design framework makes this unnecessary. As strongly advocated by D. Allen (1969), an innovation can be evaluated through several limited experiments, each addressing different validity threats and program attributes. Multi-faceted and controversial programs require more reiterations of the innovation-evaluation process. While this process may take a long period of incremental tinkering to fully test and develop an innovation, the innovation is serving the public. Experimentation and action thus need not be exclusive as long as something can be learned from the action taken.

The preceding concerns with the experimental design framework have been transformed into strengths of the approach.[23] A general case for using the framework when little is known a priori about patron reaction to a flexible innovation is summarized by Riecken and Boruch (1974, pp. 9-10). Experimentation:

1. provides more dependable inferences about causes and effects over simpler observational or retrospective studies;
2. allows comparisons of equally plausible kinds of treatment;
3. forces better problem and program definition; and
4. develops knowledge about human responses to various forms of intervention.

In contrast to the a priori theoretical and data requirements of the predictive model framework, experiments can build knowledge of a substantive problem's characteristics during attempts to ameliorate it. Consistent progress toward program objectives is encouraged and a means is provided for questioning the objectives themselves. Also, experimental designs can be tailor-made to meet client needs and to take into account the innovation's specific characteristics and the local geography. This insures the

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[23] Even the substantial range of criticisms lodged by Barndt (1975) against rigorous evaluation efforts have been answered or turned into strengths. For example, he notes that program objectives are often incompatible, yet this very problem can give rise to the competing hypotheses which truly challenge the program's value. Likewise, his problem with the evolutionary nature of program objectives has been addressed by their dynamic interplay with the results of experiments.

sensitivity often lacking in other evaluation frameworks. Experimentation is thus suited for a wide range of planning needs, including assessment of a concept or claim credited to a treatment, estimation of critical parameter values for predictive models, development of project elements, and development of comprehensive programs.

A general case has been made for the use of the experimental design framework to evaluate flexible innovations when patron response cannot be predicted beforehand with confidence. These conditions are evident in the substantive context developed in Chapter 2; therefore, this framework is the obvious choice for evaluating the NECO Mini-bus Service and innovations of similar nature.

WHEN AND HOW LONG TO EXPERIMENT

The experimental design framework is not a panacea for all evaluation needs, even in the case of transportation developments for disadvantaged groups. Questions of when and how long to experiment must be addressed.

The first question — when to experiment — is addressed by four considerations to be made before experimentation is attempted. These considerations, outlined by Riecken and Boruch (1974, pp. 27-

38), include:

1. Political considerations. Has policy been inflexibly committed? Is the cost of delaying full implementation less than the cost of a full scale faux pas?
2. Ethical considerations. Are adverse impacts harmful to individuals? Is experimentation just an excuse for delaying action or distributing treatments unequally?
3. Technical considerations. Can the substantive questions asked be answered without resorting solely to "black box" explanations?
4. Administrative-Managerial Considerations. Can a working, knowledgeable team be gathered or trained to execute the study? Can they develop credibility?

If any questions are answered "yes" in the first two considerations or "no" in the remainder, then experimentation will most likely be a fruitless or counterproductive exercise which should probably not be attempted.[24]

It has been argued in the preceding section that experimentation should continue beyond one iteration once the decision to

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[24] Obviously, experiments should not be conducted for the abusive purposes noted by Weiss (1972, pp. 11-12). These purposes include postponement of major reforms, ducking of responsibility, creating public relations "cannon fodder", and merely fulfilling grant requirements, none of which asks whether a program should rationally be continued, expanded, or modified.

experiment is made. As noted, however, iterative applications of the experimental design framework to an ongoing development of transportation (or any other) service are nonexistent. Experiments are considered by planners to be one-shot tests of an idea (such as the New Jersey Income Maintenance Experiment).[25] As shown in the following chapter, no experimental design can control all threats to validity or explore all possible consequences at all variations of an ameliorative action. A process of recursive experimentation, as illustrated in Figure 4-3, is necessary if innovations such as the NECO Mini-bus Service are to be confidently evaluated and developed beyond their initially conceived form.

In a process of recursive experimentation, any number of situations and variations on the basis innovation can be tested by building knowledge from comparable, experimental designs. Innovations are tested incrementally, but they are not restricted to being incrementally different from previous experiences. Furthermore, recursive application of the experimental design framework promotes the systematic, evolutionary development of a solution. Even the final, full implementation of a tested innovation can be designed as an experiment to monitor the program's ultimate effectiveness.

The greatest strength of the recursive experimentation is a

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[25] This attitude is particularly evident in Mandelbaum (1975).

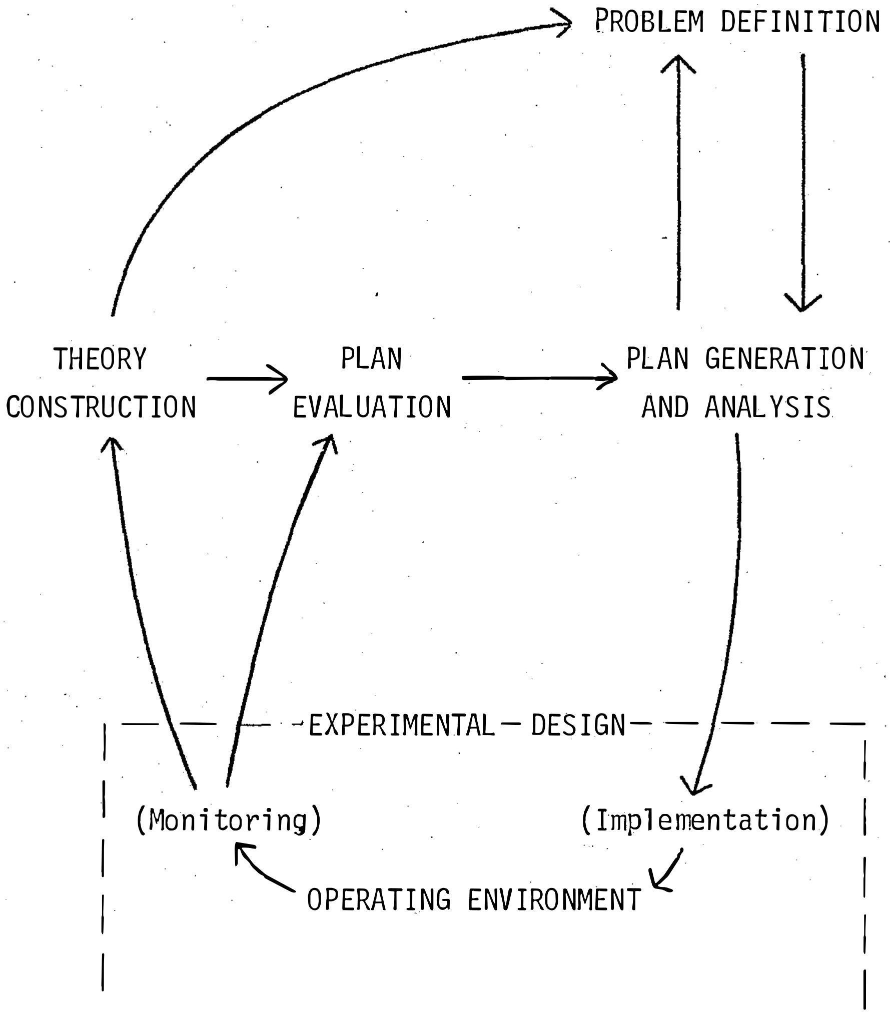

Figure 4-3: "RECURSIVE EXPERIMENTATION": A PROCESS OF EVALUATION

greater sensitivity to conditions surrounding even a radical innovation. This is not to say that the framework provides a clear vision of future conditions, for:

> "Even a successful experimental program does not eliminate our radical ignorance of the future. It may, however, increase the general confidence that what is true and workable today will persist into tomorrow" (Mandelbaum, 1975, p. 189).

The development of transportation innovations for disadvantaged groups is a suitable application for the experimental design framework of evaluation. To make this framework operational, attention is now shifted from process issues to the design of experiments, and then to the use of accessibility measures within those designs for evaluation.

CHAPTER V

EXPERIMENTAL DESIGNS IN TRANSPORTATION RESEARCH

A process based on experimental designs has been proposed for the evaluation of flexible transportation developments for disadvantaged groups. To make this process operational, the issues of selecting and implementing experimental designs in transportation research are now explored.

The experimental design, as formuled by Riecken and Boruch (1974 , p. 31), is a three-part plan which includes:

1. selecting the treatment and control groups,[1]
2. administering the treatment, and
3. making observations.[2]

Campbell (1963) notes that an experiment can be "designed" after the fact, provided relevant conditions have been adequately monitored and the event under study is distinct (to act as a treatment). Whether premeditated or post hoc, the experimental design is a monitoring process carefully tailored around an implemented treatment which provides data for that treatment's evaluation.

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[1] The former group is exposed to the innovation (treatment) while the latter, which is similar in all other relevant characteristics, is not.

[2] Observations made before initiating the treatment are usually called pretests, and observations made after implementation are called posttests.

Given the sparse experience with attempted experiments in transportation research, it is not surprising that experimental designs have received little attention in the transportation literature. A major source for such designs is provided by Campbell and his associates (Campbell, 1963; Campbell and Stanley, 1963; Glass, Wilson, and Gottman, 1975; Cook and Campbell, 1976), who have developed comprehensive reviews of validity threats and a general typology of true experimental and quasi-experimental designs which can be adapted to the transportation context.[3]

To make the experimental design framework of evaluation operational in the transportation context, the present chapter is focused on the selection of available designs, measuring instruments, and sampling techniques. Campbell's typologies of validity threats and experimental designs are reviewed first to establish the range of problems and methods for countering those problems. Criteria for selecting a design and its constituent measuring instruments are then developed. Because evaluations are often based on sampled data, special attention is given next to the spatial units and techniques of sampling useful in transportation research. Finally, an illustrative example is used to synthesize the many considerations

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[3] The only previous attempt to develop experimental designs for transportation research, a review of before-and-after designs by Charles River Associates (1972), is entirely based on Campbell and Stanley (1963).

in this chapter.

VALIDITY THREATS IN TRANSPORTATION RESEARCH

The results of transportation research and evaluations are susceptible to numerous threats to their validity. Control of these threats is a central purpose of experimental designs, and a major criteria in the selection of a design; therefore, these validity threats are examined first.

For a measured change to be valid, it must represent the phenomena and the actual magnitudes of the phenomena which it purports to represent. Both Kaplan (1964, § 23) and Suchman (1967, Ch. 7) divide this definition of validity into two basic questions:

1. Are the measure and measurement technique reliable?
2. Does the measure and measurement technique actually address the phenomena in question?

For a measure and measurement technique to be reliable, results must be replicated under separate but identical situations (Kaplan, 1964, p. 200). The measure and measurement technique must therefore be precise and adequately sensitive to change at the desired level of detail. Reliability, however, does not include the requirement that a measure address the phenomena in question. Systematic biases can consistently distort a "reliable" measure, which eventually can result in a misguided evaluation. The issues of reliability and systematic biases must therefore be considered together in establishing the validity of a measured change. Unfortunately, transportation research is usually limited to a myopic view of reliability; validation is based either on the ability of one set of estimates to match another or on the ability to predict present conditions from recent conditions (cf. Heanue and Pyers [1966], Klein et al. [1971], and Cantanese [1972]).[4] As demonstrated through this chapter, neither ability is an adequate criterion for validity.

Cook and Campbell (1976, pp. 224-227) argue that four conditions must be met to validate a measurement of change and its relevance to other situations. These conditions are the basis of Cook and Campbell's four generic classes of validity threats.

One condition is that the action taken and the condition to be ameliorated actually covary. Covariance is not always obvious when sampling is involved. "Statistics are used for testing whether there is covariation ... (and) function as gatekeepers. Unfortunately, they are fallible gatekeepers even when they are properly used, and they fail to detect both true and false patterns of covariation" (Cook and Campbell, 1976, p. 225). Problems of correctly determining covariation are called threats to *statistical validity*.

Another condition is that the experiment itself did not bias

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[4] The former criterion is explicitly illustrated by Liou et al. (1974).

change. Does the measured change reflect differences between participants that have little to do with the ameliorative action? Might the data collection procedure — rather than the action taken — have caused the change? These questions are answered by considering rival hypotheses to determine *internal validity.*[5]

In social settings, change is rarely determined from raw data alone. The data must be interpreted, often with the aid of a theoretical construct. Problems of interpretation are called threats to *construct validity,* "and these should be understood as threats to correct labeling of the cause and effect operations in abstract terms that come from common linguistic usage or formal theory. Actually, the problem of construct validity is broader than this and obviously applies to attempts to label any aspect of an experiment including the nature of the setting, the nature of the persons participating, and so forth" (Cook and Campbell, 1976, p. 226).

For purposes of evaluating transportation service and other social programs, an experiment has little value if the results cannot be generalized beyond the specific time or place of the innovation. The conditions for generalizability are addressed as threats to *external validity.*

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[5] The use of competing hypotheses was advocated in the last century by Chamberlin (1890).

Within the four generic classes, Cook and Campbell discuss 34 specific validity threats. Any of these threats, listed on Table 5-1, can systematically bias measurements in evaluation research.

The Cook and Campbell typology of validity threats is based on experience in education, criminal justice, and industrial management. Very little of this experience includes research in which geographic space plays a major role, such as transportation.[6] The Cook and Campbell typology can be placed in a spatial context through two themes: spatial differentiation and geographic proximity.

Spatial differentiation is the division of human activity among specific locations on the earth's surface. People of similar backgrounds tend to live in the same neighborhoods. Symbiotic enterprises are often located together. Zoning ordinances generally allow only one land use for a given set of adjoining properties. Whether encouraged by social ties, economic linkages, localized resources, or legal mandates, the result is a varied landscape in which no two places are exactly alike, and in which most localities

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[6] Any nonarbitrary definition of geographic space would open a pandora's box of argumentation which has frequently sidetracked the discipline of geography for over seventy years. For purposes of this exposition, geographic space includes any functionally related area which is larger than an average city block but not contained by physically linked structures.

TABLE 5-1

THE COOK AND CAMPBELL TYPOLOGY OF VALIDITY THREATS

THREATS TO STATISTICAL CONCLUSION VALIDITY

Statistical power
Fishing and error rate problem
Reliability of measures
Reliability of treatment implementation
Random irrelevancies in the experimental setting
Random heterogeneity of respondents

THREATS TO INTERNAL VALIDITY

History
Local history
Maturation
Testing
Instrumentation
Statistical regression
Selection
Mortality
Interactions with selection
Ambiguity about the direction of causality
Diffusion or imitation of treatment
Compensatory equilization of treatment
Compensatory rivalry
Resentful demoralization of respondents receiving less desirable treatment

TABLE 5-1 — (Continued)

THREATS TO CONSTRUCT VALIDITY

- Inadequate pre-operational explication of constructs
- Mono-operation bias
- Mono-method bias
- Hypothesis-guessing within experimental conditions
- Evaluation apprehension
- Experimenter expectancies
- Confounding levels of constructs and constructs
- Generalizing across time

THREATS TO EXTERNAL VALIDITY

- Interaction of the treatment and treatments
- Interaction of the treatment and testing
- Interaction of the treatment and selection
- Interaction of the treatment and setting
- Interaction of the treatment and history
- Generalizing across effect constructs

are internally homogeneous. In short, spatial differentiation is the basis of a complex stratification of cultural and environmental phenomena.

As with any method of stratification, spatial differentiation is a source of selection biases and related validity threats. An example of selection bias is the use of on-board interviews during rush hours to measure the quality of regular transit service for the elderly, very few of whom ride at that time. More subtle biases occur when monitoring sites are selected for previously measured, extreme conditions. For example, the extreme accident rate at an intersection measured in a short time period may be due to local conditions or random variation. If the extreme rate is due in part to the latter, then fewer accidents will probably occur in a subsequent period, whether or not safety improvements are made (Griffin, Powers, and Mullen, 1975). Comparisons of the rates are thus susceptible to the bias of statistical regression, which can distort the evaluation of ameliorative actions. Evaluations can also be confused by multiple actions in the same locality, such as effects of simultaneous changes in local transit service and fares on ridership.

Validity threats which stem from spatial differentiation underlie the failure of many transportation impact studies to generate useful insights.[7] In these studies, impacts are measured from comparisons between sites adjacent to the new facility and "control" sites of similar circumstances yet far enough removed to supposedly be unaffected. Finding a distant yet comparable monitoring site is difficult at best; finding a distant control site in which local history does not cause distortions during the study is even harder.

To reduce the biases which stem from spatial differentiation, areas in closer geographic proximity are often selected for control sites. Social and economic interactions between nearby areas reduce their differences. Unfortunately, those same interactions aid the diffusion of impacts into the control area. Impacts of fixed facilities or service changes can physically diffuse or be imitated by compensatory activity in the surrounding area.[8] Whether labeled "externality", indirect impact", "John Henry Effect", or otherwise, the result is a distorted comparison between treatment and control areas.

Geographic proximity also usually precludes the use of true experimental designs for evaluating changes in spatially contiguous services such as transportation. For example, it is

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[7] This failure is documented by Charles River Associates (1972).

[8] Compensatory activities are incorporated by the last four threats to Internal Validity in Table 5-1.

nearly impossible to assign at random individual eligibility for a fixed-route transit service as it passes through the neighborhood. Without random assignment, spatially contiguous services can be evaluated only with predictive models or quasi-experimental designs. The former often lack sensitivity to innovations. The latter often require interarea comparisons , and are less effective in controlling the biases inherent to spatial differentiation.

The role of geographic space in the Cook and Campbell classification of validity threats can be summarized as a conflict between the effects of spatial differentiation and of geographic proximity. This conflict was evident during the design of the NECO Mini-bus experiment. In order to factor out seasonal variations and other extraneous factors, the traditional approach of comparing changes in the service area to changes in a control neighborhood was considered. The only comparable neighborhoods were not far enough removed to preclude residents in the control area from altering their travel behavior to match that of friends in the service area. Changes attributable to the service would then be indeterminant. More distant neighborhoods of similar social and economic characteristics had vastly different locational attributes, such as distance to downtown Baltimore and other potential destinations of travel. Differences in such attributes distort the comparison of local travel patterns. A quasi-experimental design was eventually selected in which controls were not based on inter-neighborhood comparisons. The validity of any evaluative conclusions is thus restricted to the particular locality and time. In general, external validity is assured mainly through comparisons of areas, but such comparisons are possible only if the conflicting validity threats stemming from spatial differentiation and geographic proximity can be controlled.

The geographic aspects of validity discussed so far are readily subsumed by the Cook and Campbell classification. Their concern with the timing of observations and interpersonal diffusion of the treatment are directly analogous to the preceding concern with the degree of spatial separation among monitoring sites. However, these aspects are only a portion of the threats to validity which arise in a spatial context. The Cook and Campbell inventory in Table 5-1 must be expanded to include eight additional threats. These additional threats are included in Table 5-2 and are now examined in that order.

Boundary Distortions

Boundary distortions, which affect both statistical and internal validity, arise in the definition of the study area. Its

TABLE 5-2

GEOGRAPHIC VALIDITY THREATS NOT INVENTORIED BY COOK AND CAMPBELL

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1. Boundary Distortions
    a. Overextension
    b. Truncation
2. Partition Distortions
    a. Spurious location or diffusion
    b. Excessive heterogeneity within zones
    c. Density bias
3. Scale Distortions
4. Interaction of Scale and Constructs
5. Interaction of Scale and Statistical Validity
6. Generalizability across Scales
7. Interaction of Space and Time
8. Confusion of Spatial and Aspatial Issues

boundaries can overextend and dilute the phenomena under study, or the phenomena can be prematurely truncated. Measures of density are particularly susceptible to this problem. Population density, for example, can be altered merely by increasing or decreasing the amount of surrounding, unsettled land encompassed by the study area. Of course, many boundaries can be defined by physical barriers or by discrete spatial changes in the amount or nature of the phenomena.[9] Such is rarely the case, however, for small-area studies such as in Northeast Baltimore.

In transportation studies, boundary distortions are especially difficult to avoid in the calibration of trip distribution models. When characterizing local travel, trips ending beyond the local area are usually classified as external and excluded from the calculations. The number and length of these external trips will affect the values of the model's parameters (Wilbanks, 1970). Biases can subsequently occur both in predicted intra-area travel volumes and in comparisons of the effects of distance on local trip frequencies.

Boundary distortions can be mitigated. If possible, the study area should be defined by the region's functional linkages or by a characteristic which has greater within-region variance than between-region variance. If the use of less appropriate boundaries

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[9] For example, the rapid change in land values and density of development often define a precise urban boundary, as demonstrated by Barden and Thompson (1970).

is required by the data or the political context, then a measure of the degree to which the desired and utilized boundaries differ should be included with the study's results.

Partition Distortions

Partition distortions are a potential threat to internal validity whenever the study area is subdivided into analysis zones. These distortions include spurious location or diffusion, excessive heterogeneity within zones, and the density bias.

Spurious location or diffusion can occur when the spatial incidence of a phenomenon is located by centroids of analysis zones. If the phenomenon actually occurs peripherally in a large analysis zone, its location is distorted by its arbitrary assignment to the zone centroid. Should the phenomenon be divided by the boundaries of large zones, its location is falsely split and spuriously diffused among the distant zonal centroids. An example is the use of census tracts to measure the attractiveness of retail centers. Retail centers are usually partitioned by major traffic arteries which frequently demarcate census tracts. Since census tracts are designed for population rather than transportation or retail studies, the retail center is assigned to several distant centroids. This problem is more severe in suburban areas where census tracts are larger.

The obvious answer to the spurious location or diffusion problem is to minimize the size of each analysis zone. Partitioning the study area into smaller zones, however, magnifies computational difficulties as the number of zones increases.

Complications also occur when partitions allow too much heterogeneity within zones. If within-zone variance of a phenomenon exceeds its between-zone variance, then the areal units provide a basis for neither precise descriptions nor adequately sensitive predictions. An example is the excessive variance of travel behavior observed within census tracts by McCarthy (1969) and Wachs (1973). This variance has been attributed by Aldona, deNeufville, and Stafford (1973) to the mismatch between observational units and the spatial distribution of causal factors. Mismatches are more prevalent when an arbitrary grid or constant area is used to define the subdivisions.

When the size and shape of zones are allowed to vary and more accurately reflect functional units, a density bias can occur. For example, monitored increases in the zonal concentration of new suburban activities may be overrepresented by the larger sizes of census tracts outside the central city (Greene, 1977).

There is no panacea for partition distortions. The amount of potential bias, requisite observational or model sensitivity, and computational capabilities must all be considered if the number, size, shape, and uniformity of subdivisions are not predetermined.

These considerations have been examined recently by Cliff et al. (1975, Ch. 2), Batty (1976, pp. 111-113), and Coulson (1978).

Scale Distortions

Several validity threats which arise in geographic space are related to scale. In this context, scale refers to the relative magnitude of the study. Micro-scale transportation studies usually involve individuals or households in a neighborhood setting. Macro-scale studies deal with larger aggregates, such as interzonal travel flows throughout an entire city or region.

While scale is an issue to each of the four generic classes of validity, scale distortions specifically affect internal validity. Scale distortions occur when a measure is applied to different scales without careful recalibration. Local conditions, which are usually averaged out in aggregate studies, will often cause parametric shifts in a measure of travel behavior.

Scale distortions are an unnoticed yet relevant threat to the distance-attraction measure of accessibility. Recalling from Chapter 3, a zone's accessibility increases with the attractiveness or size of surrounding zones and decreases exponentially with distance to each zone. The rate of exponential decay is taken from a gravity-type trip distribution model calibrated from regionwide travel surveys. The regionwide parameter is used to calculate the accessibility of specific facilities to zones within transportation corridors, ignoring the strong possibility that regionwide travel behavior is not simply mirrored by local residents. The effect of distance on local accessibility is thus distorted because the measure is calibrated at a different scale. Likewise, the use of a locally calibrated measure for larger aggregates of travel behavior is also susceptible to scale distortions.

Interaction of Scale and Constructs

More than parametric shifts can occur between scales, in which case completely different variables assume importance. To investigate this threat of interaction between scale and constructs, the question must be asked: does the operational form of the construct hold for varying distances, densities of activity, or degree of areal aggregation? These questions of construct validity would be relevant, for example, if a travel demand model for interurban, rail passenger service was applied to an intraurban subway system. Availability of air transportation would be an important variable in the former application, but hardly relevant to the intraurban case.

Interaction of Scale and Statistical Validity

Scale is an important issue when establishing statistical validity. In order to establish covariance between policy inputs and indicators of the condition to be ameliorated, the scale of the analysis must not be reduced beyond the ability of the data base to provide adequate inferences. Discrepencies in the data are magnified by increasing disaggregation because they are less likely to be averaged out. Statistical validity depends on the level of detail available in the data base. Data can be aggregated above — but rarely disaggregated below — the scale at which it is collected. Inferences about larger populations may be drawn from representative samples, but inferences about subgroups require their adequate representation in the same as well. Any of these factors will affect the consistency of measured results, and are explored further by Alonso (1968).

Generalizability Across Scales

The final scale problem is one of external validity. The conclusions reached for one scale may not be generalizable to another. For example, activity patterns in a medium-size city are not always analogous to those in the largest metropolitan areas. Similarly, a door-to-door transit service covering a six square kilometer area may not be comparable with one serving 100 square kilometers, even if the intended clientele have similar characteristics.

As with the other validity threats related to scale, control of this threat is not readily accomplished with an analytical device.

The best "control" is an awareness of scale-related problems and the need to avoid them by matching the scale of the study to the scale of the particular research question. The expediency of using tools and results from one scale to another will most likely cause more problems than it is worth.

Interaction of Space and Time

The seventh validity threat in Table 5-2 is the interaction of space and time. It should be obvious that "the use of space involves movement, and movement consumes time" (Cullen, 1972, p. 459), yet this point is occasionally forgotten in transportation studies. This is particularly true for estimates of latent travel demand, in which frequencies of travel are often compared without consideration of the trip lengths. Trips of similar frequencies but differing lengths do not represent equivalent amounts of travel. Furthermore, similar trip lengths in physical distance may be radically different in traveltime and thus not truly the same. In short, equivalent patterns of behavior must be equal in their respective consumption of both time and space.

Confusion of Spatial and Aspatial Issues

The confusion of spatial and aspatial issues is the last and perhaps most fundamental validity threat inherent to research at geographic scales, and stems from the misattribution of a spatial effect to a spatial rather than aspatial cause. Rapid suburbanization in the late 1960's is an example of one spatial effect that has been commonly attributed to a spatial cause (the development of high-speed transportation facilities). Consideration must also be given to aspatial causes, such as changing income and tax laws, housing subsidy programs, and the national economic climate, all of which have spatial expressions but are not necessarily applied to specific, spatial domains.[10]

The excessive within-zone variance of travel behavior previously mentioned may have its roots in the confusion of spatial and aspatial issues. The use of areal units to explain travel behavior assumes that a spatial process such as residential differentiation affects the observed spatial behavior (i.e., travel), although the effect is unclear. Yet excessive within-zone variance of travel behavior is evidence of heterogeneity within the areal units, stemming either from the previously discussed partition distortions or from the aspatial nature of causal factors. Kutter (1973) argues the latter: that travel behavior responds more to individual characteristics than to spatial settings.

The confusion of spatial and aspatial issues can often be

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[10] This concept is examined at length by D. Harvey (1973; 1975).

attributed to disciplinary turf. Overemphasis of spatial factors is common for geographers and their allies, while economists and their allies tend to underemphasize space (if only for theoretical tractibility). In either case, the construct validity of a measured or predicted change is left in doubt unless both spatial and aspatial interpretations are considered.

The Cook and Campbell typology and geographic validity threats have been presented in a cursory fashion to provide a set of problems against which experimental designs can be matched. These threats are developed more completely in the context of an actual experiment later in this and the following chapter.

SELECTING EXPERIMENTAL DESIGNS AND DATA COLLECTION INSTRUMENTS IN TRANSPORTATION RESEARCH

The diversity of validity threats is no greater than the variety of experimental designs from which the evaluator can choose. Of the numerous and varied designs which have been developed for research in social psychology, most can be applied to the transportation context. The candidate designs are included in the reviews by Campbell and Stanley (1963) and Cook and Campbell (1976), whose inventories of designs are merged and summarized in Appendix A.

There are no hard-and-fast rules for matching specific designs with given sets of evaluation problems. It can be seen that the number of permutations of both designs and previously outlined validity threats is enormous, and that specifications for a design can be tailor-made to fit the problems at hand. This flexibility in coping with diversity underscores the rejection by Suchman (1967, Ch. 2) of evaluation "cookbooks". Rather than attempt to capture the range of possible problems and solutions, attention is now focused on the criteria which should be considered in selecting a design.

Most of the experimental designs listed in Appendix A are useful for evaluating transportation developments. Already noted exceptions are pre-experimental designs, which are completely inadequate and not considered beyond this point. Selection from the remaining designs is based on several criteria, including complexity, timeliness, applicability to recursive development of an innovation, validity threats, applicability at geographic scales, and availability of appropriate data collection instruments.

Complexity

The criterion of complexity is primarily an issue of interpretability by lay persons. As in the case of large-scale predictive models cited by D. Lee (1973), Carver (1970) notes that the credibility of an evaluation is diminished if its measures or design cannot be explained in non-technical terms. Regression-correlation designs are particularly difficult to portray other than as a "black box", which reduces their effectiveness in comparison to simpler designs.

Complexity is also a problem for the analyst if large quantities of data must be processed without computer assistance. Both the probability of error and the requisite staff-hours are increased by increasingly complicated designs.

While complexity is an important criterion, it is the least critical. If the other criteria are reasonably met, the selection of a design can finally be resolved by Occam's razor: the least complicated, viable design to implement and explain is the best.

Timeliness

While basic research often can be afforded the luxury of long-term data collection, the evaluation of services already on the street requires more immediate results. This criterion may preclude time-series and cross-lagged panel designs for evaluating just-implemented innovations. The separate-sample, pretest-posttest design with two before measures may also be eliminated if the time between a proposal for service and its implementation are inadequate for both pretests.

Applicability to Recursive Innovation Developments

A strong case has been made in Chapter 4 for the application of experimental designs in a recursive process of evaluation and development. The multiple-treatment designs are particularly suited for this approach, although reimplementing one-treatment designs is also possible. If space and population size permit, the application of one-treatment designs in different locales for each incremental development is desirable. This approach lessens the threats of patron reactivity and testing-induced change which are inherent to multiple-treatment designs.

Validity Threats

The types of validity threats addressed and the degree of their control vary for each design. Selection is largely a problem of matching a design's strengths and weaknesses with the threats inherent to a particular service evaluation. For example, Boyce (1970) raises a validity issue in fixed-facility impact studies by asking when to observe facility-induced change. If the facility is locally anticipated before the pretest measures are taken, or if the full impact of the facility is yet to be consummated before the posttest is taken, then the measured change is underrepresented. Longer periods between observations, however, increase the validity threat of history. This problem is avoided by the use of time-series designs in studies of long term change. In studies of short term change, such as driver adjustment to route modifications (examined by Yagar [1973]), this problem is relatively minor, and less complicated before-and-after designs are viable.[11]

The importance of a design's inherent strengths and weaknesses is largely a function of the evaluation's purpose. Designs which emphasize control of threats to external validity, for example, are very desirable for federally funded pilot projects which attempt to provide generalized information for a nationwide spectrum of clients. This emphasis is far less important to a locally based effort to improve local transit service.

Applicability to Geographic Scales

As suggested earlier in this chapter, validity threats inherent to research at geographic scales are little studied and potentially the most difficult to control. Since transportation experiments are almost always implemented at geographic scales, these threats are particularly important to consider in the selection of a design. Several tried-and-true experimental designs are of limited value in the spatial context, although only the institutional cycle design

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[11] Care with these designs must be exercised, however, if changes in travel behavior involve the patron's learning about more than how to use the service. Particularly when accessibility measures reflect destination choice, changes will not occur until the patron learns about new spatial opportunities.

is completely excluded (given the previous definition of geographic space) in addition to the pre-experimental designs.

True experiments are championed by Cook and Campbell (1976) as the most powerful designs, but they are often impossible to implement in geographic settings. It is usually impossible to select patrons of a spatially defined service such as transportation and exclude other potential users by a random process.[12] Even if random assignment is possible, the ethical problems raised in Chapter 4 challenge the acceptability of true experiments, particularly in smaller jurisdictions. These designs are also relatively weak when attempting to control threats to external validity and generalize across geographic scales.

Of the quasi-experimental designs, those with either separate treatment and control groups or multiple treatments with separate groups are more susceptible to spatial validity problems. These designs require the definition of several groups in non-interacting, areal units. Such spatial disaggregation is usually difficult to achieve without incurring scale and partition distortions. There are often not enough areal units which are adequately separated to counter the treatment's diffusion. When enough areal units are available, their spatial separation will probably affect their

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[12] The alternative of randomly sampling users and nonusers does not assure equivalence of the groups — indeed, it exaggerates their differences — and cannot be considered a true experiment.

comparability given the tendency of urban activities to differentiage by area along social and economic dimensions (cf. Timms [1971], Charles River Associates [1972], D. Harvey [1973], and Schwirian [1974]).

While separate-group designs are difficult to utilize in urban areas, they are potentially useful in rural area transportation experiments. Separation of observation groups is more easily achieved in areas of low density, and the process of residential differentiation is not as pervasive.

The designs which suffer least from threats at geographic scales are those which allow all groups to be exposed to the treatment. Because treatment diffusion is unimportant, the difficulties of finding similar yet separated areas are eliminated. The nonequivalent dependent variable design, the first four sample-group, one-treatment, before-and-after designs, the one-group, interrupted time-series designs, and the one-group, multiple-treatment designs are thus most useful in urban transportation experiments.

Data Collection Instruments

Selection of a particular design depends in part on the availability of appropriate instruments with which observations are made.

Data collection instruments can be divided among four categories:

1. involuntary-obtrusive (interviews),
2. voluntary-obtrusive (questionnaires),
3. nonmechanical-unobtrusive, and
4. mechanical-obtrusive.

The resource requirements for each category are now reviewed and the designs for which they are appropriate are mentioned.

Involuntary-obtrusive data collection instruments include interviews made at the subject's home or on board a transit vehicle. Whether administered in person or by telephone, interviews entail the most direct confrontation of the researcher and his subject. Warwick and Lininger (1975), suggest that his confrontation entails a high potential for biased reactions. To control for reactivity, the interview must be skillfully prepared and executed, and numerous, specially trained personnel are usually required as interviewers.[13] Furthermore, the potential for subject reactivity increases with repetition of exposure (Cook and Campbell, 1976), which restricts the use of these instruments in designs which require repeated observations of the same group.

In spite of their many limitations, on-board and home-based

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[13] A substantial literature exists on the design of interviews and questionnaires, including Backstrom and Hursh (1963), D. C. Miller (1970), and Warwick and Lininger (1975) among others. The range of flexibility is succintly summarized by D. C. Miller (1970), pp. 66-67).

interviews are very commonly used data collection instruments in transportation studies. Transit demonstration projects have heavily utilized on-board interviews in one-shot case studies and static-group comparisons. Metropolitanwide transportation studies have utilized both on-board and home-based interviews to develop origin-destination matrices.[14] While it is difficult to collect rigorous evaluation data with on-board interviews alone,[15] they have been shown by the Cleveland Transportation Action Program (1970b) to be a useful public relations device which may provide timely patron suggestions and testable hypotheses. Home-based interviews have far greater potential as a data collection instrument for evaluative experiments. Interviews can generate more detailed and extensive information about travel behavior than any other single data collection instrument, because greater flexibility and availability of time improves the quality and quantity of responses.

When expertise and financial resources are available, the home-based interview is a suitable data collection instrument for studies in which information is needed about individual respondents. The problems of expense and reactivity limit this instrument to designs

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[14] Oi and Schuldiner (1962) explain and Brant and Low (1967) critique this traditional use of interviews in transportation studies.

[15] On-board interview data are difficult to analyze rigorously without supplemental information since only users of the service are observed.

in which no group is observed more than once. Home-based interviews are most effective instruments for designs with only one round of observations, such as the posttest-only, control group design and the one-observation, regression-correlation designs.

A voluntary-obtrusive instrument is usually the written questionnaire, in which the confrontation between researcher and subject is indirect. Since questionnaires are more easily ignored by the subject, participation in the study is more voluntary. Responses thus tend to be less reactive (without the presence of an interviewer) but more selective than interview data. As with interviews, the preparation of questionnaires requires skill; however, their collection is usually far less expensive.[16] General comparisons of questionnaires and interviews are presented by D. C. Miller (1970, pp. 76-88) and Warwick and Lininger (1975, Ch. 6).

The voluntary-obtrusive data collection instrument most commonly used in transportation studies is the mail-back questionnaire. While this instrument is easily diffused (i.e., passed along to unanticipated respondents), it is relatively inexpensive to distribute and collect. It is thus possible to obtain larger samples, although questionnaires share with interviews the weakness of increased

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[16] Detailed examples of questionnaire preparation for transportation studies are presented by Urban Transportation Systems Associates (1972).

validity threats when repeatedly administered to the same groups.[17] As a consequence, mail-back questionnaires are appropriate for any design in which no one group is sampled more than once. Care must be taken, however, not to overextend the jurisdiction's ability to generate an adequate number of samples. The multiple separate-sample, pretest-posttest design is particularly susceptible to this problem.

The desirability of collecting data by unobtrusive means has been argued previously herein and extensively by E. Webb et al. (1966). Such data are usually derived from nonmechanical sources such as a research staff observer or a public record keeper (e.g., the city title recorder).[18] On-site observations by the researcher, however, are usually time consuming and may require training if supplemental manpower is utilized, although these problems are usually reduced by observing only samples. Reliance on the archival records of other sources lessens the requisite field work, but often

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[17] For questionnaires, validity threats include greater levels of reactivity, re-testing-induced reactions (i.e., respondents learning how to answer the questions), and mortality.

[18] The advantages of direct observation are argued by Kloeber and Howe (1975), who demonstrate the greater precision of sampled "head counts" in comparison to frequency-of-use questionnaires for estimating transit ridership. Different techniques for direct observation of transit ridership are examined by Ungar (1974).

raises the problems of instrumentation and reduced accuracy.[19]

While any design can make use of archival data and on-site observations, the most common and effective match is between time-series designs and archival data. Boyce (1970) recommends this match and attempts its use in his study of rapid-rail transit impacts on land values (Boyce et al. 1972), although his length of record is limited.[20] Whether or not a time-series approach is used, the design selected will depend on the amount, completeness, and reliability of the data collected.

The time, expense, and probability of error incurred in the tabulation of on-site observations and in the transcription of archival data can be minimized if the observations themselves are mechanized. The least obtrusive and most reliable measuring instruments used in studies of travel patterns are automatic traffic counters. Mechanized ticket collection and automated, transit-patron billing systems, such as outlined by Nelson (1976), can supply a wealth of information useful in any number of experimental designs.[21]

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[19] For example, transit ridership records based on fare collection are shown by Schwartz (1967) to be less accurate than estimates based on sampled observations.

[20] More powerful time-series designs have been used by Gaurdy (1975) and Harmatuck (1975) for ridership studies, but these require greater amounts of data. See also Kemp (1974).

[21] If automation provides more direct monitoring of behavior, simpler designs can be employed with greater confidence. For example, exact origin-destination data are collected in Nelson's (1976)

Because designs and data collection instruments have specific strengths and weaknesses, the actual design selected depends on the resources and data collection instruments available to the evaluator, the population and area involved, and the relevant threats to validity requiring attention. Cook and Campbell advocate selecting the design which controls the most validity threats within the evaluator's constraints. They also recommend the use of "patched up" designs, improvising with one or more of the designs presented in Appendix A, to deal with peculiar situations otherwise uncovered.

SAMPLING WITH SPATIAL UNITS

Many of the experimental and quasi-experimental designs appropriate to transportation research utilize sampling techniques either to reduce extensive monitoring activity or to randomly assign membership in treatment and control groups. Techniques for sample selection have been developed in the fields of sociology, agricultural research, and physical ecology, and are tabularly summarized in those contexts by Ackoff (1953, p. 124), Haggett (1966, p. 195), and D. Harvey (1969, p. 358). Sampling from spatial units is extensively reviewed by Haggett (1966, pp. 191-200), Berry and Baker

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[21] system, which are far more reliable than the same data synthesized from more commonly monitored link volumes. The latter approach, outlined by Robillard (1975), requires questionable assumptions and many generate indeterminate biases.

(1968), D. Harvey (1969, pp. 356-369), and King (1969 , pp. 61-67).

This literature is now extended to transportation research. A variety of appropriate spatial units and a typology of sampling schemes are developed. The strengths and weaknesses of each approach are reviewed in the transportation context, and those which are particularly useful for evaluating innovations for disadvantaged groups are highlighted.

Spatial Sampling Units

As illustrated in Table 5-3, there are five basic spatial units derived from points, lines, and areas. Points are generally called nodes, and may be street intersections, access-egress points for transit service, or housing structures. In contrast to points, lines and areas are each divided between regular and functional types. When data is collected along a continuous line segment, whether defined by a straight line or circle, the sampling unit is called herein a regular transect. One example is a cordon line established at a constant radius from the central business district. In contrast, functional transects reflect an activity unit, and need not conform to straight lines or circular arcs. Examples are cordon lines which follow political boundaries and cross sections along highways. Sampling units based on area are called quadrats. Although usually defined in geographic literature by a square grid or

TABLE 5-3

BASIC SPATIAL SAMPLING UNITS

Node	Location defined as a point
Regular transect	Line segment defined by straight line or circle
Functional transect	Line segment defined by human activity
Regular quadrat	Conterminous areas of equal size and shape
Functional quadrat	Area defined by human activity

hexagonal lattice (i.e., a regular quadrat), Krebs (1972, p. 141) notes that regular shapes are not required in the original definition of quadrats. Because irregular shapes can cause analytical problems, nonregular quadrats are used only to bound functionally related or similar areas. These functional quadrats, including traffic zones, census tracts, and political jurisdictions, are more commonly used than regular quadrats in transportation studies.

The use of only one spatial unit for sampling is rare in transportation research. Units are more commonly employed in tandem, drawn from the relevant pairs listed in Table 5-4.[22] Examples are given for each pair. The first pair, "node on functional transect", is somewhat unusual in that the point itself may be mobile. This is suggested by Schwartz (1967), who determines transit ridership by sampling vehicles on a sample of lines. All other pairs of sampling units are generally fixed in space.

A wide variety of techniques classified in Table 5-5, are available for sampling with these spatial units. Two categories in the table are irrelevant to sampling in transportation research. Nonstratified-nonprobability sampling, in which data are collected without plan, yields ungeneralizable information at best and represents a squandering of evaluation resources. Purposive-stratified

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[22] While 25 possible pairs exist, all but nine are exceedingly rare, redundant, or undefinable.

TABLE 5-4

COMBINATIONS OF SPATIAL SAMPLING UNITS USED OR USABLE IN TRANSPORTATION RESEARCH

Combination	Example
Node on functional transect	Access-egress points on transit lines
Node in regular quadrat	Households in square grid cells
Node in functional quadrat	Households in traffic zones
Functional transect from functional transect	Block faces perpendicular to transit lines
Functional transect in regular quadrat	Routes through square grids
Functional transect in functional quadrat	Routes in transportation corridors
Regular quadrat in functional quadrat	Square grid within political jurisdictions
Functional quadrat in regular quadrat	Political jurisdictions within square grid
Functional quadrat in functional quadrat	Census tracts within political jurisdictions

TABLE 5-5

ENUMERATION TECHNIQUES

	NONPROBABILITY	PROBABILITY
NON-STRATIFIED	Complete Enumeration Uncontrolled Selection of Samples	Simple Random Sample Weighted Random Sample Nested Simple Random Sample Nested Weighted Random Sample
SYSTEMATIC STRATIFIED	Aligned Stratified Sample	Unaligned Stratified Sample
PURPOSIVE STRATIFIED	Complete Enumeration of Sample "Typical" Case Study	Functionally Stratified Random Sample

nonprobability sampling, commonly presented as the "typical" case study, likewise generates information of indeterminate value according to D. Harvey (1969, pp. 359-361) and Cook and Campbell (1976). The remaining four categories are potentially useful, and are now examined.

Nonstratified Probability Samples

This category includes several techniques for randomly selecting a sample from the entire study area. The best known technique is the simple random sample, in which all units have an equal probability of being selected. Weighted random samples differ in that probabilities of selection vary by some criterion. If one set of units are randomly sampled within another set of randomly selected units, the technique is called "nested random" and "weighted nested random" respectively for samples of equal and unequal probabilities of selection. Nested random sampling of points is illustrated by D. Harvey (1969, p. 364, Figure 19.2:e,f). Weighted random and both nested sample techniques are also known as cluster sampling in sociological literature. Whether nested or not, weighted random samples are employed to approximate a simple random sample of an unevenly distributed variable, and to reflect a stratified sample. The former purpose occurs in the sampling procedure devised for the NECO Mini-bus evaluation effort. Households with elderly and handicapped members are to be sampled, but their locations are aggregated to census blocks and larger units. In the sampling procedure, the probability of selecting a block is weighted by its elderly and handicapped population, and the measuring instrument is then applied to all of the elderly and handicapped in the selected block. The probability of selecting a given individual is thus approximately equal.[23] This technique does not guarantee that all neighborhoods, classes of residential density, or other stratified units are represented in the sample. If such representation is deemed important, then the selection technique can be modified to reflect the stratification by adding constraints to the weights.[24] The constrained technique is presented by Rogers (1974, Ch. 9) under the title of "quadrat spatial sampling", which he uses to control a density bias in his sample of low-order retail activity.[25]

Nonstratified probability samples have two major strengths. First, they are the simplest yet accurate approach to sampling populations with known frequency distributions in space. Second, they require the least judgement in classification, reducing a major

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[23] CENSAM, a computer program for implementing this technique, is presented in Appendix B.

[24] According to Rogers (1974, p. 132), this constrained approach is used rather than purposive stratified probability sampling when an inadequate sample size is available for the latter technique.

source of error noted by Ackoff (1953).[26]

Systematic Stratified Samples

The nonprobability and probability categories of systematic stratified samples are labeled "aligned" and "unaligned" respectively in the geographic literature. Both categories guarantee that the entire study area is represented, which is particularly important when little is known about the spatial distribution of the variable under investigation. While simple random sampling has the more desirable statistical properties for population inferences, systematic stratified samples have been shown by studies cited in Haggett (1966, p. 198) to be more efficient in uncovering spatial patterns.

Aligned samples are taken at regular spatial intervals, such as the centroids of regular quadrats or regular transects with equidistant spacing. This sampling technique is very susceptible to misrepresenting variables whose occurrence in space is cyclical, and is thus inappropriate for many empirical investigations. Testing the fit of theoretical to actual distributions is perhaps the

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[26] The error reduction is not as great for weighted random samples if the variables under investigation have greater variance between sampled units than within. Warwick and Lininger (1975, pp. 98-101) recommend increasing the sample size 1.5 times over that used in simple random samples to obtain approximately the same level of error.

only effective use for aligned samples.

Unaligned samples are less sensitive to the bias of cyclically occurring variables, and maintain regionwide representation of the study area. The technique involves simple random selection within each regular quadrat. Berry and Baker (1968) strongly recommend this technique as the most efficient means of uncovering spatial patterns which are not known *a priori*.

Purposive Stratified Random Samples

Purposive or functionally stratified random samples comprise the most commonly used class of sampling defined by stratification. The technique is simply to draw a random sample from a functional quadrat or functional transect. Haggett (1966, p. 300) presents a classic example in which he samples nodes from functional quadrats. The quadrats are defined by a cartographic Venn diagram of relevant factors. The sample by Schwartz (1967) of vehicles on routes defined by mode and transportation corridor is another example of purposive stratification.

If the stratification is carefully defined, this sampling technique provides the most accurate representation of the phenomena under study. Purposive stratification is also very flexible, allowing a variety of controls. For example, an employment-accessibility study by the Chicago Mayor's Committee (1972) controlled for labor skill requirements by stratifying traffic zones by employment mix. Stratification also allows the use of different procedures (e.g., measuring instruments) for different groups.

For purposive stratification to work, several criteria must be met. Warwick and Lininger (1975, pp. 96-98) note that the proportion of the universe in each stratum must be known, and that the boundaries between strata must be clear. Each variate must be assigned to a unique strata. There must also be enough observations to represent each strata adequately.

In contrast to simple, random samples, purposive stratification requires the most judgement. Threats to construct validity must be considered in the definition of each stratum. Similarly, strata defined by extreme values are sensitive to the internal validity threat of statistical regression. Obviously, purposive stratification is not appropriate for sampling phenomena with poorly understood spatial characteristics.

Selection of a Sampling Technique

The main criterion for selection of a sampling technique is the degree of knowledge about the spatial distribution of the phenomena under investigation. Purposive stratified sampling is best if the phenomena are adequately understood. For less thoroughly developed subjects, such as travel behavior of disadvantaged groups, weighted random samples are more appropriate. If very little is known at all, unaligned-systematic-stratified samples provide the best investigative approach.

AN EXAMPLE: THE NECO MINI-BUS EXPERIMENT

Many of the general issues explored herein have been considered specifically during the design of an experiment to evaluate the NECO Mini-bus Service. The needs, resources, and constraints addressed in this experiment are presented to illustrate the issues of design selection and geographic sampling. This section will describe the intended procedures, leaving the discussion of the experiment's actual implementation and findings for the next chapter.

The NECO situation is quite amenable to experimentation because little is known *a priori* about the unsatisfied travel needs of the area's elderly and handicapped, and the service is quite flexible. While limited in funds available for personnel-intensive survey techniques (e.g., in-house interviews), NECO does have a substantial, literature-distribution system for its community newspapers. This resource is particularly effective for areally distributed, mail-back questionnaires. As a consequence, this data collection instrument was selected to provide the principle data for analyzing outcomes impacts of the service.

The questionnaire is reproduced in Figures 5-1 and 5-2, with the cover letter in Figure 5-3. Although Straus and Peterson (1972) discount the importance of length on questionnaire response rates, the need to prepare a return acceptable to the U. S. Postal Service without the added expense of envelopes restricted questionnaire length to one page, printed on both sides. Questions about personal information beyond travel behavior were limited to improve the response rate and reduce the selection bias caused by obtrusiveness. The questionnaire was designed in a relatively open form to encourage detailed responses without overwhelming the respondent with specific questions.

The selection of a design for the questionnaire's use was based on two considerations. First, the transportation service is required to cover the entire NECO area, precluding the use of never treated control groups.[27] Second, the area's large population makes sampling necessary.[28] These considerations restricted possible selections to the sample-group, one-treatment, before-and-after design category.

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[27] Local politics require that the service cover the entire NECO area. Untreated control groups cannot be selected from adjacent areas because the NECO literature distribution system is limited to the NECO area, and proximity effects would be difficult to control.

[28] The sampling technique is mandated by the section preceding the discussion of this example. A weighted random sample is developed with the computer program presented in Appendix B.

1 HOW MANY PERSONS WHO LIVE IN THIS HOME ARE:

____ over 60 years of age

____ handicapped in a way that effects their travel

____ both handicapped and over 60 years of age

2a THIS HOME IS (CHECK ONE):

☐ a single family house

☐ an apartment in a house

☐ an apartment in an apartment building

b AND IS LOCATED ON ________________ STREET.

3 WHERE DO YOU TRAVEL IN THE BALTIMORE AREA? (FOR EACH PLACE, ANSWER AS MANY OF THE FOLLOWING QUESTIONS AS POSSIBLE.)

	Where do you travel to now?	Where is this place? (nearest street corner)	What do you do there?	How often do you usually go there? (a week or month)	How do you go there? (walk, MTA bus, your car, friend's car, etc.)	How long do you usually stay there?	How do you return home?
a.	____________	____________	__________	___times a______	________________	_____hours	___________
b.	____________	____________	__________	___times a______	________________	_____hours	___________
c.	____________	____________	__________	___times a______	________________	_____hours	___________
d.	____________	____________	__________	___times a______	________________	_____hours	___________
e.	____________	____________	__________	___times a______	________________	_____hours	___________
f.	____________	____________	__________	___times a______	________________	_____hours	___________
g.	____________	____________	__________	___times a______	________________	_____hours	___________
h.	____________	____________	__________	___times a______	________________	_____hours	___________
i.	____________	____________	__________	___times a______	________________	_____hours	___________

Figure 5-1: NECO QUESTIONNAIRE - 50 PERCENT REDUCTION OF SIDE 1

FOLD HERE FOLD HERE FOLD HERE

4 WHERE WOULD YOU LIKE TO TRAVEL IN THE BALTIMORE AREA (EITHER PLACES WHERE YOU DO NOT GO NOW OR PLACES WHERE YOU DO NOT GO AS OFTEN AS YOU WOULD LIKE)?

	Where would you like to go?	Where is this place? (nearest street corner)	What would you do there?	How often would you go there? (a week or month)	Why can't you go there now (or go there as often as you would like)?
a.	________	________	________	___times a___	________
b.	________	________	________	___times a___	________
c.	________	________	________	___times a___	________
d.	________	________	________	___times a___	________
e.	________	________	________	___times a___	________
f.	________	________	________	___times a___	________

5 DO YOU HAVE ANY COMMENTS OR SUGGESTIONS?

6 WHEN YOU HAVE COMPLETED BOTH SIDES OF THIS QUESTIONNAIRE, JUST FOLD THE PAPER ALONG THE DOTTED LINES SO THAT THE RETURN ADDRESS IS SHOWING, STAPLE OR TAPE CLOSED, AND DROP IN ANY MAILBOX. NO POSTAGE IS NECESSARY.

THANK YOU FOR HELPING US BEGIN TO SERVE YOU AND THE COMMUNITY.

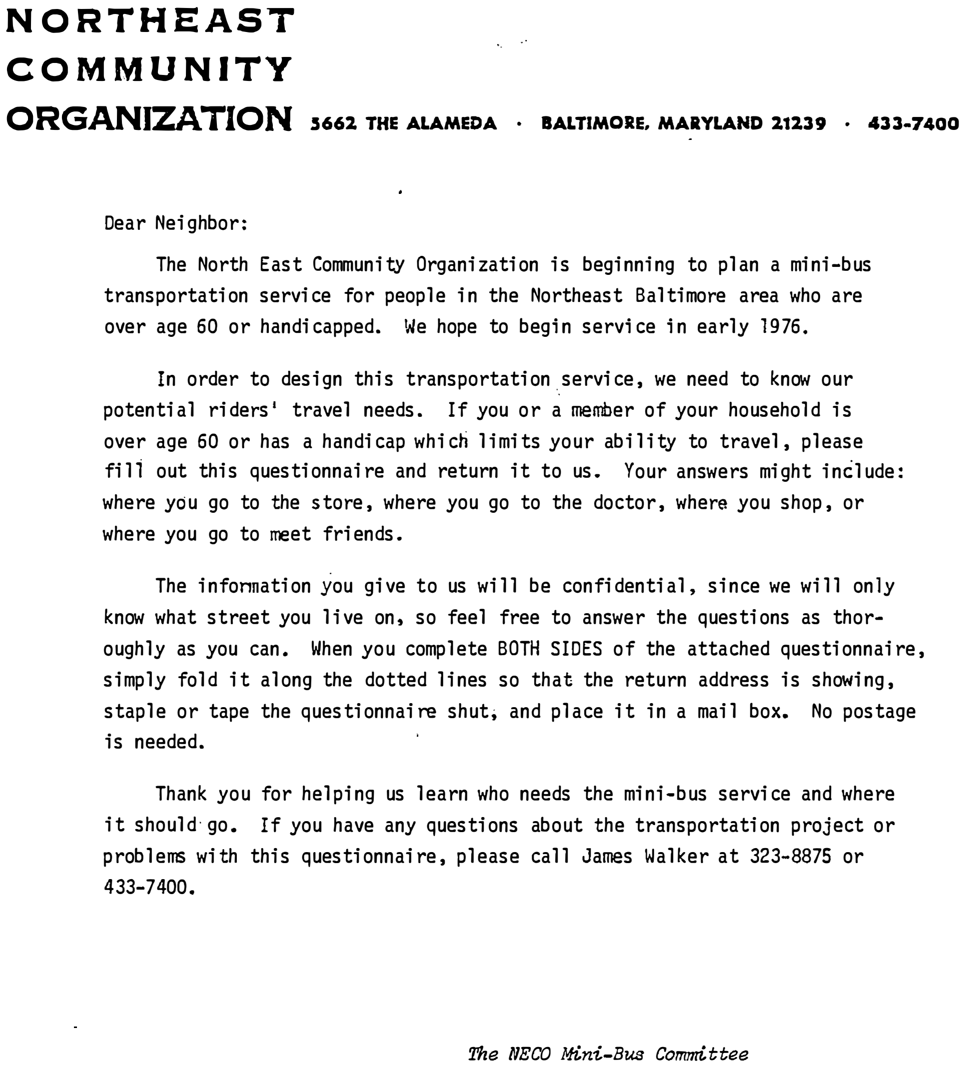
BUSINESS REPLY MAIL
NO POSTAGE NEEDED IF MAILED IN THE UNITED STATES

POSTAGE WILL BE PAID BY:

NORTHEAST COMMUNITY ORGANIZATION
5662 THE ALAMEDA
BALTIMORE, MD 21239

FIRST CLASS
PERMIT NO. 16374
BALTIMORE, MD

Figure 5-2: NECO QUESTIONNAIRE - 50 PERCENT REDUCTION OF SIDE 2



**NORTHEAST
COMMUNITY
ORGANIZATION** 3662 THE ALAMEDA · BALTIMORE, MARYLAND 21239 · 433-7400

Dear Neighbor:

The North East Community Organization is beginning to plan a mini-bus transportation service for people in the Northeast Baltimore area who are over age 60 or handicapped. We hope to begin service in early 1976.

In order to design this transportation service, we need to know our potential riders' travel needs. If you or a member of your household is over age 60 or has a handicap which limits your ability to travel, please fill out this questionnaire and return it to us. Your answers might include: where you go to the store, where you go to the doctor, where you shop, or where you go to meet friends.

The information you give to us will be confidential, since we will only know what street you live on, so feel free to answer the questions as thoroughly as you can. When you complete BOTH SIDES of the attached questionnaire, simply fold it along the dotted lines so that the return address is showing, staple or tape the questionnaire shut, and place it in a mail box. No postage is needed.

Thank you for helping us learn who needs the mini-bus service and where it should go. If you have any questions about the transportation project or problems with this questionnaire, please call James Walker at 323-8875 or 433-7400.

The NECO Mini-Bus Committee

Figure 5-3: NECO QUESTIONNAIRE - 65 PERCENT REDUCTION OF THE PRETEST COVER LETTER

Of the six options listed in Figure A-4 in the first appendix, the separate-sample, two-pretest — one-posttest design was selected for the NECO transportation experiment. Major delays in vehicle purchase by the Mass Transit Administration noted in Chapter 2 allowed adequate time for two pretests. With one survey distributed in the winter and a second in late summer, seasonal variations in travel patterns and desires could be controlled. The weaknesses in this design tabulated by Campbell and Stanley (1963) are maturation and mortality, both noted previously to be of limited importance.

Particularly in field settings, even the most carefully designed experiment can go awry. Problems with the evaluation measures used, unanticipated validity threats, and policy fluctuations can all affect the success or failure of an evaluative experiment. The actual experience gained from the Northeast Baltimore example using the mean opportunity distance measure of accessibility is examined in the following chapter.

CHAPTER VI

EVALUATING MEASURED CHANGES IN ACCESSIBILITY: A CASE STUDY

Two facets of a general approach to evaluating service innovations for the transportation disadvantaged have been developed in the preceding chapters. First, improving accessibility was defined as the major substantive goal, and an operational measure of this goal was specified. Second, the framework in which the measure is applied to evaluate transportation innovations was explored. This framework, based on recursive experimentation, was illustrated with a design for evaluating the NECO Mini-bus Service for the elderly and handicapped in Northeast Baltimore.

The NECO Mini-bus experiment is now used to synthesize these facets. To measure changes in accessibility, the L-factor of the intervening opportunities model in Chapter 3 is calculated through the experimental design from Chapter 5. This case study serves to test the L-factor as an evaluation tool, to gain insights into its use for monitoring travel behavior, and to uncover problems with implementing experimental designs.

The present chapter includes four sections. Implementation of the experimental design is examined first to outline problems which occurred and the resulting data base. This data base is then used in the following sections to calculate the evaluation measures.

Since the frequency as well as length of trips must be considered for the evaluation of changes in accessibility, the measurement of each is detailed in the second and third sections respectively. In these sections, emphasis is given to statistical issues. Other validity issues are raised in the fourth section.

IMPLEMENTATION OF THE EXPERIMENTAL DESIGN

Before data are manipulated and an evaluation is made, the implementation of the experimental design must be reviewed. Obviously, failure to implement the experiment in strict accordance with its design can raise additional problems with interpretation and evaluation of the results. Implementation problems are common when experiments are done in the field, as the NECO Mini-bus experiment poignantly illustrates.

The two pretests were made as planned. The first pretest, hereafter called "Sample 1", was taken in December, 1975. While 10,000 questionnaires were distributed to doorsteps in the selected blocks, only about 2,000 households were estimated to be eligible recipients (i.e., have elderly and/or handicapped members).[1] Of these eligible households, 64 responded with usable questionnaires

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[1] CENSAM, the program outlined in Appendix B, was used to generate both samples with one questionnaire going to each housing unit in the selected census blocks.

for a response rate of 3.2 percent. The second pretest, "Sample 2", was taken in August, 1976. The same procedure resulted in 176 usable responses, which is a rate of about nine percent. From these 240 combined responses, information was obtained for 1,254 trips differentiated by purpose and destination. The tabulation procedure for the pretest data and the resulting pretest data base are reviewed in Appendix C.

Diffusion is a problem with the pretests which was raised in Chapter 5. A few questionnaires were returned from blocks which were not assigned to that particular sample. These questionnaires were probably redistributed to acquaintances of the original recipient, some of whom may have responded in both samples. Since less than one percent of the questionnaires were found to be from the wrong blocks, they were easily discarded.

A potentially more serious problem with the pretests is suggested by the disparity in response rates. A spot check of Sample 1 blocks revealed several blocks from which no questionnaires were returned. It can be surmised that the first set of questionnaires was not entirely distributed.[2] Visual inspection of the spatial distribution of returns indicated that coverage, although spotty,

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[2] The questionnaires were placed on doorsteps by local residents who volunteer their time to distribute the NECO community newspapers and local association newsletters. Since only one NECO staffperson was available to supervise the volunteers, their compliance with the distribution plan could not be guaranteed.

was adequately representative of the neighborhoods within the study area.[3]

Other than the low response rate, difficulties with the pretests appear to have had an insignificantly deleterious effect on the data base; far worse, external problems, which developed during the summer of 1977, were encountered for the posttest. First, the Mini-bus Service operating deficit was substantially higher than expected, forcing NECO to divert funds from its general budget to the project. This diversion was questioned by major contributors to NECO. Second, staff positions for the Mini-bus Service were threatened by cutbacks in a state employment program. Third, the relatively low initial ridership (less than 100 one-way rides per week) made the service difficult to justify, particularly given its high operating costs relative to other NECO projects.[4] NECO administrators feared that a thorough evaluation might provide evidence fatal to the service. If the Mini-bus Service were terminated:

1. NECO would probably loose the vehicles and suffer a large financial loss; and

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[3] When disparities in representation exist between samples, comparisons are tainted by the threat of instrumentation. See Cook and Campbell (1976, p. 227).

[4] The ability of the NECO Mini-bus Service to meet local needs has not been questioned. Concern has been raised, however, that a small number of people are being served relative to NECO's non-transportation projects.

2. there would be nothing to replace the service.[5]

Local travel needs would be left completely unserved and a poor climate for future efforts would be created. Since a follow up questionnaire might have provided fatal evidence and exacerbated local backlash,[6] the posttest was postponed indefinitely. In short, the evaluation was halted because little would be learned (without the chance to tinker with service characteristics) at great cost.

With the posttest virtually cancelled, the NECO Mini-bus case study is a failure as an evaluative experiment. On the other hand, the case study serves to illustrate pitfalls in the current practice of evaluating transportation developments for disadvantaged groups. These problems and the lessons learned are discussed in the following chapter. Fortunately, the posttest is not crucial to testing the L-factor and investigating its interpretation.

TRIP GENERATION CHARACTERISTICS

As noted in Chapter 3, a measure of travel frequency is a

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[5] Beyond grants for purchasing vehicles, there are at present no federal programs for directly subsidizing specialized, areawide transit for disadvantaged groups. A myriad of individual programs provide travel subsidies only for specific trip purposes, and cannot be tapped feasibly by a small, general-purpose service.

[6] If the posttest was followed shortly by cancellation of the

necessary supplement to the L-factor of the intervening opportunities model to characterize travel behavior fully. The frequency of travel by household, known more commonly as household trip generation rates, is readily calculated from each pretest sample. These rates are now examined to determine whether seasonal or other variations were captured by the questionnaires.

Before household trip generation rates are considered, careful attention should be given to the definition of household used in this study. A household is usually defined as including "all the persons who occupy a group of rooms or a single room which constitutes a housing unit".[7] In this study, a household refers only to the elderly and/or handicapped members of the group that occupies the unit. For instance, the travel behavior recorded in this study for a family which includes an aged grandparent applies only to that one person over age 60. While that person's recorded trips may be made in conjunction with other family members, their travel made without the elderly person is not counted. In the case of the NECO pretests, most of the respondents appeared to live alone or

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[6] service, then local patrons would likely believe that the service existed only for an academic study and not for them. NECO's credibility would be damaged as a result.

[7] This definition and the more lengthy definition of a housing unit are published in numerous volumes of the 1970 Census of Housing. For example, see *1970 Census of Population and Housing, Census Tracts, Baltimore SMSA,* PHC(1)-19, Appendix B.

with one other person of similar age or handicap.

Average household trip generation rates are presented in Table 6-1 for all trips, four major categories of trip purposes, and one subcategory. The major categories include all retail trips, trips for medical services, trips for services other than medical and social-recreational trips.[8] Because they were so infrequently recorded, school and work trips are included only in the rates for all trips. Low-order retail trips, which include regular trips to the grocery, drug store, and other outlets of everyday necessities, are reported separately as well as within the retail category. This subcategory is singled out for more detailed study in the following section.

A *t*-test is used to infer whether differences in the average rates between samples are real or due to sampling error. This test requires two assumptions to be made: the data are normally distributed; and, the samples are drawn from the same population. The first assumption is supported by the central limit theorem, which states that the distribution of sample means is asymptotically normal. Successful implementation of the pretests according to the experimental design assures the second assumption. The precise null

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[8] In all cases, trips actually taken at known frequencies are counted. Trips which are desired but not taken and trips at unknown frequencies are not included. The detailed trip purposes which comprise each category are listed in Appendix C.

TABLE 6-1

HOUSEHOLD TRIP GENERATION RATES: DIFFERENCES IN PRETEST MEANS

Trip Purpose	Sample 1 Mean	Sample 2 Mean	Sample 1 Mean	Sample 2 Mean	Est. $\sigma_{diff.}$	*t*-statistic
All Trips*	182.37	175.99	62	162	21.00	0.304
Retail Trips	112.79	108.54	56	125	13.91	0.306
Low-order Retail Trips**	8.62	8.08	43	102	1.13	0.477
Medical Trips	24.52	29.66	29	76	12.22	-0.421
Non-Medical Service Trips	46.20	64.34	20	68	14.47	-1.254
Social-Recreational Trips	104.08	85.35	26	83	15.74	1.190

Note: *t*-statistic and est. $\sigma_{diff.}$ (pooled estimate standard error for normal distribution of difference in sample means)calculated from William L. Hayes, (1973, pp. 406-408).

* All trips also include school and work trips.

** Sample mean values for low-order retail trips are based on monthly rates. All other mean values are for annual rates.

hypothesis to be tested, $H_0:\mu_1=\mu_2$, states that the trip generation rates (mean trip frequencies) for each sample are actually the same. None of the *t*-statistics recorded in Table 6-1 are significant, even at the ten percent level; therefore, the null hypothesis cannot be rejected. In other words, variations in average household trip generation have not been found, even when rates are disaggregated by trip purpose.

Since travel behavior is commonly thought to vary with season, the lack of variation is at first disturbing, but readily explained. Seasonal variations were suppressed because no time period was specified for the trips to be recorded on the questionnaires. People recorded a greater variety of infrequent trips, and indicated the "usual" frequency for the trips included. Had respondents been asked to record only trips taken in the preceding week, frequencies would strongly reflect that particular season. While then-usual frequencies undoubtedly had some influence on the responses in the prettests, the questionnaire's design apparently suppressed any significant differences between the samples. Whether due to the questionnaire's insensitivity or the less likely explanation that seasonal variations in fact do not exist, the pretest results indicate that any subsequently measured change will unlikely be due to seasonal variation.

MEAN OPPORTUNITY DISTANCE: STATISTICAL ISSUES

The L-factor of the intervening opportunities model of spatial interaction is now calculated to characterize trip lengths in the study area as mean opportunity distance. In this section, three statistical issues are considered. First, the method for computing the L-factor for each sample is reviewed in detail. Second, the ability of the L-factor to characterize the data is tested and revisions in the computation of the L-factor are made as necessary. Third, the change in L-factors between samples is tested as was the change in trip generation rates. The results of these statistical manipulations are then interpreted and critiqued in the following section.

The Initial Computational Procedure

As developed in Chapter 3, the L-factor is most readily estimated as the inverse of the mean opportunity distance of sampled trips.[9] In order to calculate this average, trips to be considered are identified and a method for ranking destination opportunities is specified. The ranked destination opportunities passed by each recorded trip in the sample are then totalled and divided by the

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[9] Note that mean opportunity distance is averaged over trips rather than over households.

the number of sampled trips. The inverse of this average is the estimated L-factor of the sample.

Trips are identified for inclusion in the L-factor's calculation by two criteria. First is purpose. In this study, low-order retail trips are used because they are most universally reported and homogeneous category of trips. The second criterion is geographic incidence. Occasional trips may be made to distant locations for reasons not germaine to the study. Recent migrants to a locality, for example, may shop in the distant areas from which they moved until they become familiar with local opportunities. Such infrequent but extremely long trips can be considered to be statistical outliers and subsequently should be excluded. In this initial computational procedure, inner city or crosstown destinations are eliminated from the samples.

The method for ranking destination opportunities in the initial computational procedure is straightforward. Destinations are first defined by nodes, each representing a shopping center or other retail cluster (destinations 1 through 22 in Figure 6-1).[10] From each trip origin, all destinations closer than the trip's end by rectilinear distance are considered to be intervening opportunities. Rectilinear distance is used because the streets and public transit

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[10] Since all but one low-order retail outlet in the study area are located in these clusters, zonal aggregations or individual locations need not be.

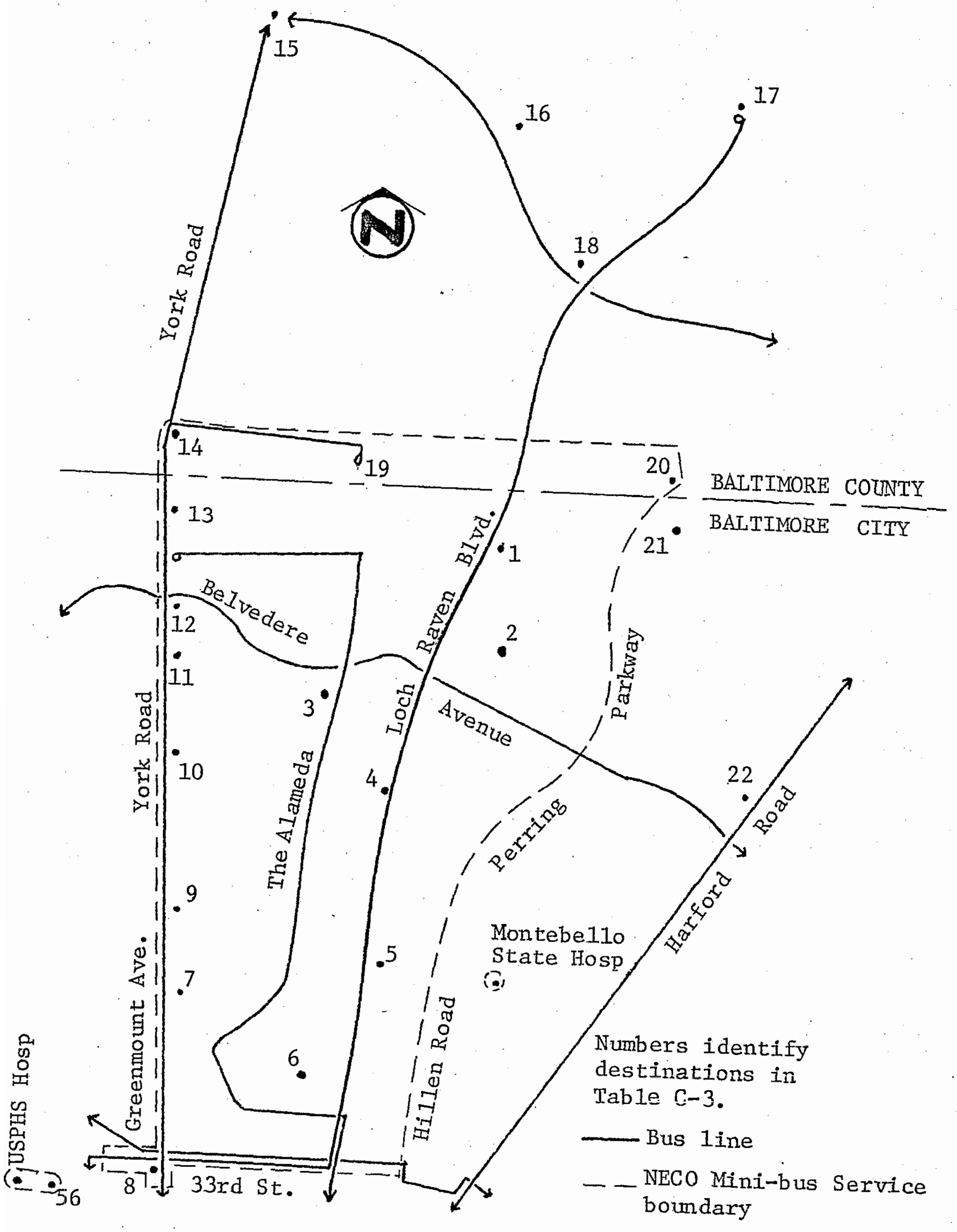

Figure 6-1: PUBLIC TRANSIT AND DESTINATIONS IN NORTHEAST BALTIMORE

routes follow a rectangular grid and velocities are relatively constant throughout the area. The retail floorspace of the intervening opportunities is added to half of the floorspace of the destination reached to indicate the site attractiveness of the opportunities passed.[11] Only Waverly (destination 8) and destinations north of 33rd Street in Figure 6-1 are included in these totals because a strong directional bias is assumed to preclude destinations to the south from consideration in the sampled population's spatial choices. This assumption is based on the major socio-economic and racial transition at 33rd Street and the complete absence of trips which end in the area south of that street. Inclusion of these destinations would bias the L-factor as an indicator of spatial choice.

Goodness-of-fit Tests and Revised Computations

The ability of the L-factor to characterize the sampled travel behavior can be tested to indicate the adequacy of the computational procedure. Since the intervening opportunities model specifies an exponential distribution of trips in opportunity distance, expected trip frequencies for each range of distance can be calculated with

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[11] It is assumed that the traveller goes to the center, or expected location, of the retail cluster which he reaches.

the estimated L-factor.[12] These expected frequencies can then be compared with observed frequencies using a Chi-square (χ^2) goodness-of-fit test.

The statistical fit of the model using combined-sample data in ten intervals of opportunity distance is rejected by an order of magnitude (χ^2 = 328.5). As illustrated in Figure 6-2, the distribution of trip lengths hardly resembles the anticipated, exponential distribution. From this situation, it can be suggested that either an extraneous variable is causing the distortion, the computational method is causing the distortion, or the model is fundamentally wrong.

Variations in travel patterns by mode were considered as the most likely extraneous elements. L-factors were estimated separately for frequent users of automobiles, infrequent or nonusers of automobiles, car drivers, bus users, and walkers. While minor improvements in χ^2 values were achieved, none of the statistical fits were substantially better. It was noticed, however, that walkers seemed to account for the greater numbers of short trips, and bus users tended to go much farther than anticipated.

Since the model overestimated medium-distance trips and underestimated at either extremes of opportunity distance, it was thought

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[12] A procedure for calculating expected frequencies on pocket calculators using Reverse Polish Notation is documented in Appendix D.

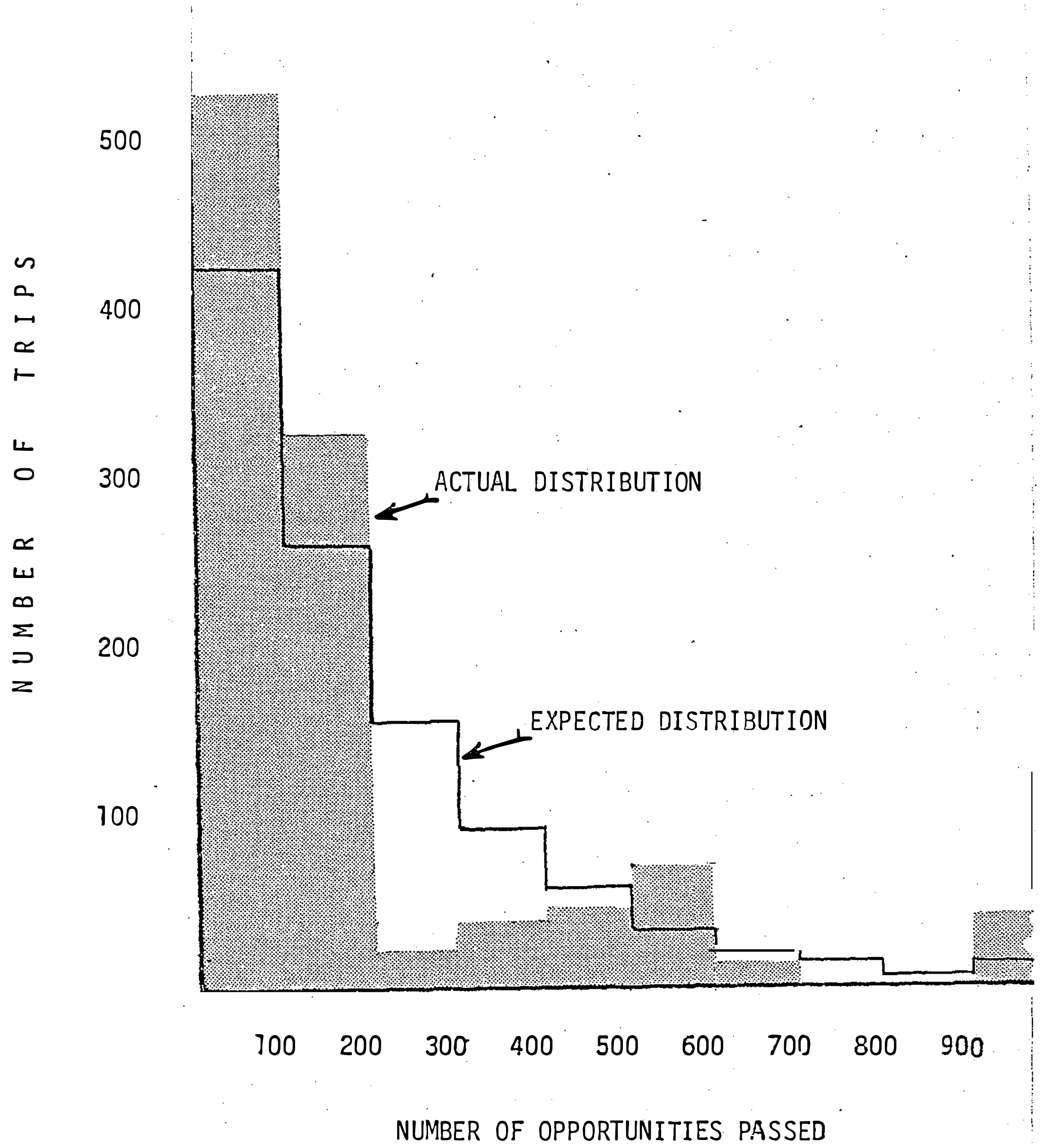

Figure 6-2: COMBINED PRETEST TRIP DISTRIBUTION FOR LOW-ORDER RETAIL TRIPS IN THE NECO AREA (All Modes)

that the destination ranking procedure or trips considered might be inappropriate. This was substantiated by actually mapping the origin-destination flows in Figure 6-3. As can be seen by comparing this figure with Figure 6-1, most trips follow a southwest-northeast trend, which coincides with a major transportation corridor (33rd Street-Loch Raven Boulevard) straddled by the study area. A few trips extend north-south along a peripheral corridor (Greenmount Avenue-York Road), and almost no trips cross between the corridors. Destinations in one corridor are apparently perceived as farther away than suggested by physical distance. Possible reasons for this include greater traveltime, requisite transfers, physical and monetary costs, and a variety of other social factors which are not easily combined into a method of ranking destination opportunities.

To compensate for this corridor bias, the distribution of trip lengths has been recalculated, eliminating the few trips which do not fall within the diagonal corridor.[13] The results are shown in Figure 6-4. While the χ^2 test still fails to prove exponentiality (χ^2 = 49.4), the fit is vastly improved, as is the shape of the actual distribution. Once again, disaggregated estimates by mode fail to improve the fit substantially. The model continues to overestimate the middle range of trip lengths.

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[13] In other words, trips starting or ending in the York Road corridor north of Waverly (destination 8) are eliminated from the calculation.

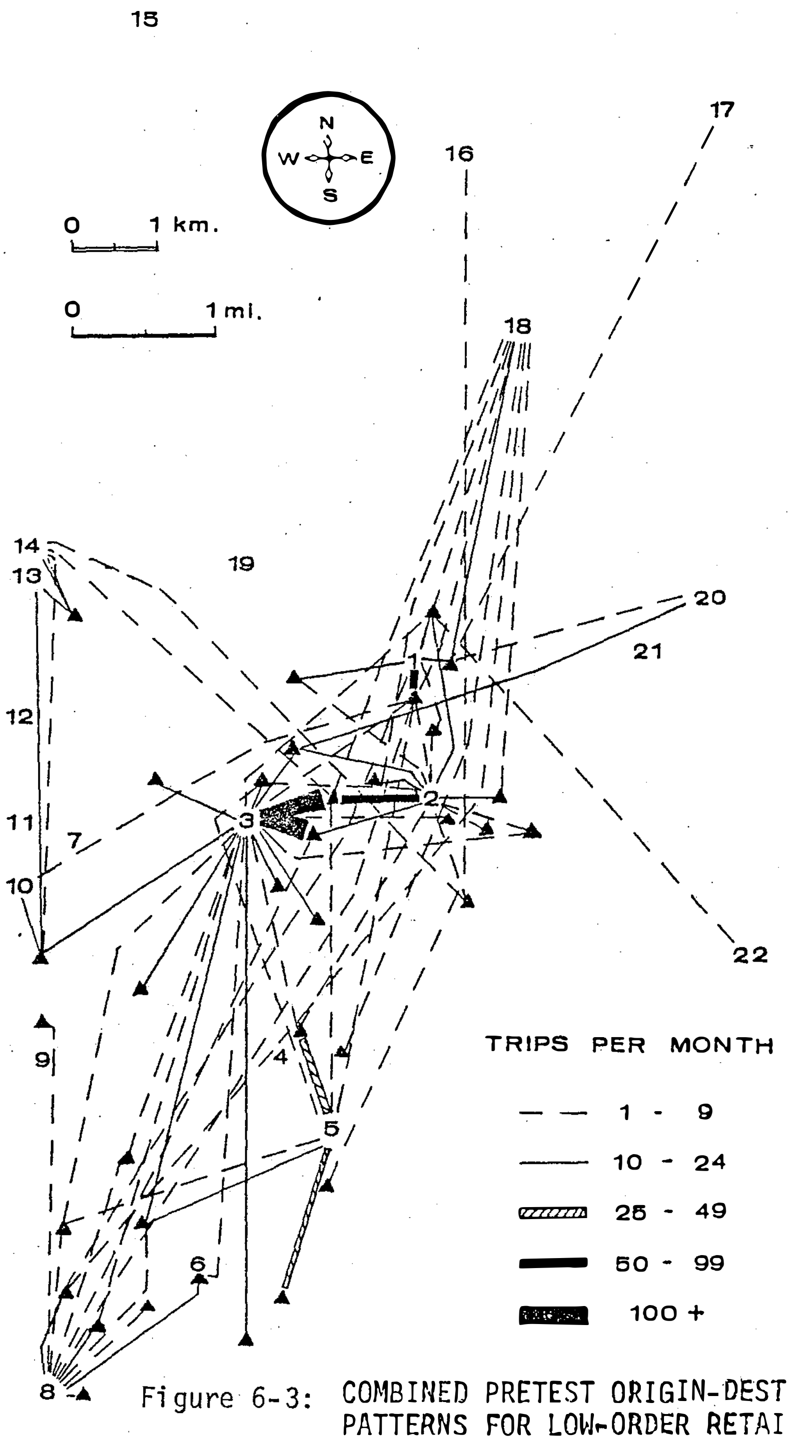

Figure 6-3: COMBINED PRETEST ORIGIN-DESTINATION PATTERNS FOR LOW-ORDER RETAIL TRIPS IN THE NECO AREA

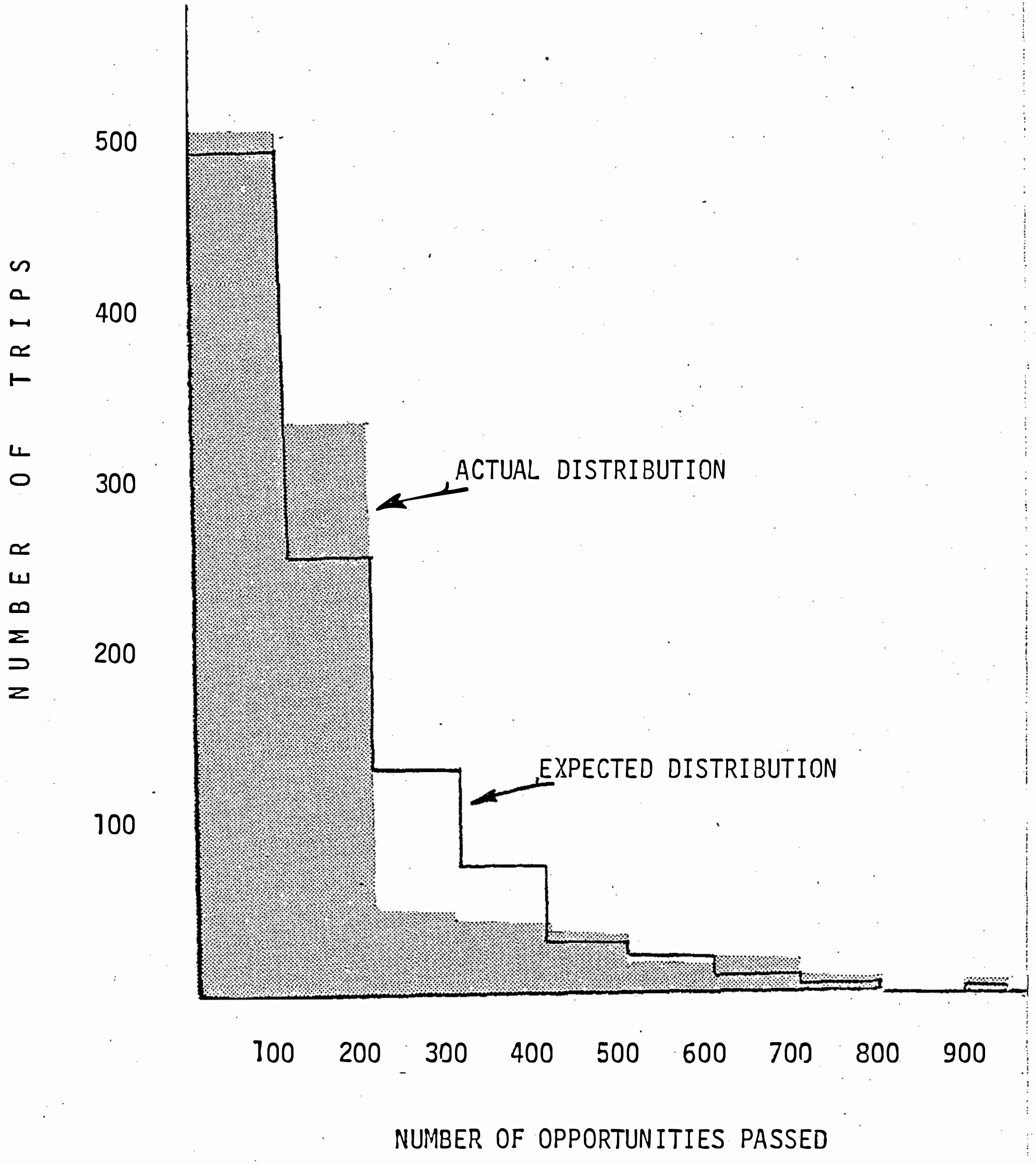

Figure 6-4: COMBINED PRETEST TRIP DISTRIBUTION FOR LOW-ORDER RETAIL TRIPS IN THE NECO AREA EXCEPT THE YORK ROAD CORRIDOR (All Modes)

An explanation of the model's overstated middle range of trips is revealed by investigating the recorded trips which are desired but not taken. These trips were expected to be to more distant (and thus harder to reach) destinations. As shown in Table 6-2, this expectation is not necessarily correct. When measured in physical, rectilinear distance, desired trips are nearly the same or shorter on the average than actually taken trips. The desired but unreached destinations are beyond walking range and not directly linked to the origin by public transit. It can be surmised that the middle-range trip lengths are actually more difficult to overcome than more distant but directly served travel.

This explanation indicates the need for a destination ordering procedure which weights distances by requisite transfers or public transit traveltime; however, such a procedure is difficult to implement in an accurate and nonarbitrary form. The increased complexity of computations seems unnecessary at this stage given the general agreement between the calibrated model and the actual distribution of trip lengths. This point is considered further after other validity issues are explored.

Testing for Change

The third statistical issue, which is most important in an evaluative context, is the need to test for differences between

TABLE 6-2

AVERAGE TRIP LENGTHS IN RECTILINEAR DISTANCE

	Average Rectilinear Distance W Kilometers		
Trip Purpose	Combined Samples	Sample 1	Sample 2
Actual Retail Trips	2.37	2.42	2.34
Desired Retail Trips	3.60	3.52	3.63
Actual Medical Service Trips	4.06	5.60	3.58
Desired Medical Service Trips	3.81	3.20	3.83
Actual Nonmedical Service Trips	2.60	3.21	2.47
Desired Nonmedical Service Trips	1.88	1.45	1.92
Actual Social-Recreational Trips	4.10	2.95	4.19
Desired Social-Recreational Trips	5.08	4.48	5.17

Actual trips are all trips recorded with known frequencies.
Desired trips are all trips recorded as desired but not taken.

sample L-factors. In short, are differences in L-factors estimated from the samples due to real change or sampling error? While this question is identical to that raised for average household trip generation rates, the *t*-test used in the preceding section is inappropriate here. Although asymptotic normality of sample L-factors (as mean opportunity distance inverted) can be assumed, the exponential distribution of the population of trip lengths implies that the sample variance is the inverse of the product of the mean-squared and the number of trips. This violates the requirement of the *t*-test that the mean and variance are independent. Another test is necessary.

A confidence interval test can be used for the hypothesis, $H_0:L_1=L_2$. This interval is delineated such that:

$$P(\beta_L \leq \beta \leq \beta_U) = 1-\alpha \qquad (6.1)$$

where β is the mean opportunity distance ($\frac{1}{L}$) of the sample, now labeled $\overline{X}$. Given that the opportunity distance of trips is distributed exponentially:

$$E(\overline{X}) = \frac{1}{L} \qquad (6.2)$$

and:

$$VAR\ (\overline{X}) = \frac{1}{n} * \frac{1}{L^2} \qquad (6.3)$$

where n is the number of trips in the sample. It follows from the Central Limit Theorem that:

$$\frac{\overline{X} - \frac{1}{L}}{\sqrt{\frac{1}{n} * \frac{1}{L^2}}} \sim AN\,(0,1) \qquad (6.4)$$

Let $\frac{1}{L} = \beta$. We now wish to find the $\frac{\alpha}{2}$ point of the standard normal distribution.

$$P\,[\, Z_{\frac{\alpha}{2}} \leq \frac{\overline{X} - \beta}{\beta/\sqrt{n}} \leq Z_{1-\frac{\alpha}{2}}\,] = \alpha \qquad (6.5)$$

Equation 6.5 can be rearranged so that:

$$\frac{\overline{X}}{1 + \frac{Z_{\frac{\alpha}{2}}}{\sqrt{n}}} \leq \beta \leq \frac{\overline{X}}{1 - \frac{Z_{1-\frac{\alpha}{2}}}{\sqrt{n}}} \qquad (6.6)$$

forms a (1-α)*100 percent confidence interval for β. If the mean of one sample falls within the confidence interval of the other, then the null hypothesis is not rejected (i.e., the difference in L-factors is attributed to sampling error).

The confidence interval test in Equation 6.6 was applied to the sample L-factors which were computed by the revised procedure for low-order retail trips. As summarized in Table 6-3, differences were not significant at the 95 percent level of confidence. This

TABLE 6-3

CONFIDENCE INTERVAL TEST FOR DIFFERENCE IN PRETEST SAMPLE L-FACTORS

	Sample 1	Sample 2
Number of trips	318	700
Sample mean	164.5	150.3
Approximate variance of mean	85.1	32.3
Approximate 95% confidence interval	[148.2,184.9]	[139.9,162.3]

finding is consistent with the previous test for differences in trip generation rates, and can be explained with the same rationale. Either seasonal differences do not exist or they are suppressed by the questionnaire. In either case, evaluation of changes subsequently measured will be more confidently attributable to the transportation service.

INTERPRETATIONS AND OTHER VALIDITY ISSUES

The preceding sections have emphasized statistical issues in determining whether or not a change in trip generation rates or in average trip lengths has occurred. Threats to the validity of measured changes (or lack of changes) stemming from the collection and computation of pretest measures have been examined.

Attention is now shifted to other confounding factors which can bias the evaluative interpretations of measured changes in accessibility. These factors have been reviewed in the preceding chapter as threats to internal, construct, external, and geographic validity (Tables 5-1 and 5-2). The specific threats relevant to the NECO Mini-bus experiment are now considered.

History, a threat to internal validity, refers to the occurrence of any event which affects the entire population but is extraneous to the service being evaluated. In the present case, one such event occurred between the pretests. Time-of-day restrictions were eliminated on the reduced-fare program for elderly users of the citywide MTA bus service. This resulted in a general increase in bus usage by the elderly, and could have affected both their trip generation rates and distances travelled. As shown in Tables 6-1 and 6-2, some average household trip generation rates and distances travelled by respondents to the questionnaires actually declined. Either seasonal effects or shifts between modes negated the expected increase, or the elderly in the study area are not particularly sensitive to the event.

Local history, another threat to internal validity, refers to the occurrence of any extraneous event which effects portions — but not all — of the sampled population. Changes in the spatial distribution of the elderly and handicapped and of potentially desirable destination opportunities are the major threat of local history in this experiment. The time period between pretests is short enough to disallow significant shifts in population or activity centers. Furthermore, major construction or abandonment of housing stock or destination facilities have not taken place recently which otherwise might cause shifts in the spatial distribution of the intended clientele. One exception is the completion of a subsidized housing project for the elderly which was not included in the sample blocks. This facility may cause a shift in social-recreational trip destinations not related to the NECO Mini-bus Service.[14] Subsequent trip

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[14] There have been a number of rides carried by the Mini-bus from

origins from this block will not be comparable with pretest travel patterns for all trip purposes. As a consequence, all trips originating or ending in this block should be eliminated from calculations of any sample L-factor.

The most difficult internal validity threat to examine in this study is selection, which is exacerbated in the present case by the low response rate. As noted in the discussion of voluntary-intrusive data collection instruments in Chapter 5, those who respond to mailback questionnaire may be different from persons who do not, resulting in a selection bias. In this experiment, the number of questions related to characteristics other than trips taken or desired was limited to increase the response rate and reduce the chance that only active members of the community would respond. As a consequence, specific characteristics of the respondents are unknown and thus cannot be compared with known population characteristics from the 1970 Census or other archival sources, which might otherwise indicate the degree of selection bias.

Although not a problem with the pretests, the interaction of selection and history can be a threat to measured changes between the pretests and the posttest. As the NECO Mini-bus Service becomes available, more households in subsequent posttest samples may perceive the importance of responding to the questionnaire. The resulting increase in the response rate would include a more diverse

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[14] this facility to a similar housing project in Homewood (destination 56) which had not previously been anticipated.

group, which may be more representative of the intended clientele but less comparable to the pretest sample groups.

If a posttest is finally made, subsequently measured changes must be interpreted as an indicator of relative success or failure for the innovation to be evaluated. Confidence in this interpretation requires the establishment of both construct (and to a lesser degree) external validity. In the present context, questions of construct validity are raised when changes in trip generation rates or trip lengths are interpreted as benefits accruing to the intended clientele. Comparability of the innovative service's impacts on its clientele to the impacts of other options is addressed by questions of external validity. These options include maintaining the status quo, modifying the innovation, replacing the innovation, or supplementing the innovation. Simply terminating the service is not considered an alternative if the social condition to have been ameliorated is still present. External validity is more confidently assured if the alternatives are implemented as comparative experiments.

The presence or absence of change is usually interpreted by the latent demand construct (cf. Hoel et al. [1968], T. Harvey [1971], Anderson and Hoel [1974], Yukubousky and Politano [1974], and Falcocchio [1977]). Benefits of travel are assumed to be directly related to the frequency of travel; therefore, benefits of an innovative service to its intended clientele are proportionate to changes in their trip generation rates. If the rates do not change, then the innovation is considered to be ineffective.

An absence of change in trip generation rates does not necessarily preclude the existence of benefits under an alternative construct. If the costs of travel are assumed to reduce the benefits of a trip as well as the frequency of trips, then increased benefits will accrue to the user who travels at the same rate for reduced costs. This alternative interpretation is particularly important for nondiscretionary travel, such as low-order retail trips.

Changes in trip lengths measured as mean opportunity distance (the inverse of the L-factor) have a straightforward interpretation from Chapter 3. Increased mean opportunity distance indicates greater choice of destinations being exercised by the sampled population. Since captive reliance on few destinations is reduced, the population benefits from increased accessibility. However, mean opportunity distance can also decline when greater choice is being exercised under the current method of computation. As previously noted, the average trip length in physical distance for desired trips can be less than that of trips actually taken. If a new, door-to-door transit service is used to reach otherwise inaccessible destinations in lieu of more distant locales, average physical trip distances will decline. The same reduction will most likely occur in a mean opportunity distance measure for which destinations are ranked solely by physical distance. This problem is illustrated by a hypothetical example in Figure 6-5.

Simple rebounding of the study area, while adequate for improving the characterization of travel patterns in a pretest, does not solve the contradiction in evaluating comparisons of pretest and posttest measurements. The mean opportunity distance still declines in the hypothetical example when simple rebounding is done, as illustrated in Figure 6-6. While destination B may have been dropped from consideration by the hypothetical population, its past inclusion signifies that spatial choice has in fact been increased over time. Destination B may no longer be used, but only because destination C has been brought into reach. Nonetheless, the mean opportunity distance still declines in the hypothetical example.

The simplest method to maintain a proportional relationship between the mean opportunity distance measure and spatial choice (i.e., benefits to the intended clientele) is a combined rebounding and destination reordering procedure. In short, the study area is expanded as increasing choice is exercised by the intended clientele, and the new destinations are ranked and added beyond the existing order of destinations.[15] This approach is computed as follows:

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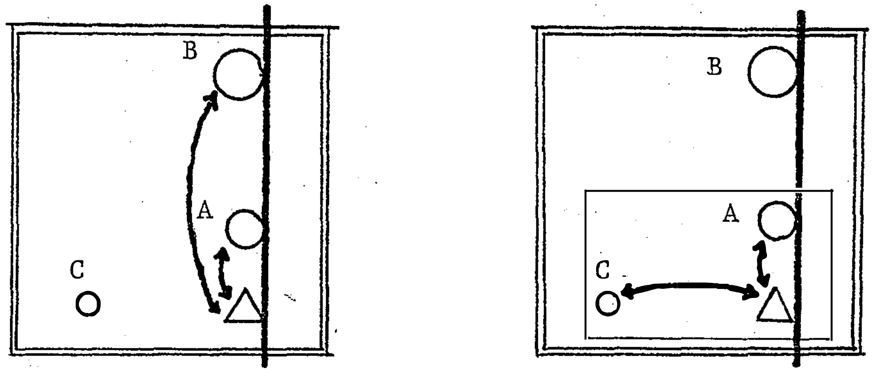
[15] Note that the study area is not contracted in size.



PRETEST

POSTTEST

RANKING OF DESTINATIONS FROM ORIGINS

A, C, B

RANKING OF DESTINATIONS FROM ORIGINS

A, C, B

MEAN OPPORTUNITY DISTANCE

$$\frac{(A + C + \frac{B}{2}) + \frac{A}{2}}{n \text{ trips}} = \frac{60}{n}$$

MEAN OPPORTUNITY DISTANCE

$$\frac{(A + \frac{C}{2}) + \frac{A}{2}}{n \text{ trips}} = \frac{25}{n}$$

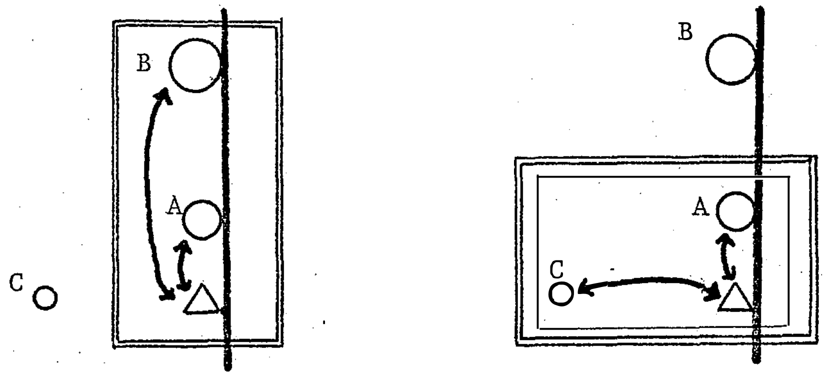
═	Boundary of study area
—	Boundary of door-to-door transit service
▬	Regular bus route
→	Trips
△	Location of origins

Destination A is 10 square units.

Destination B is 50 square units.

Destination C is 20 square units.

Figure 6-5: CALCULATING MEAN OPPORTUNITY DISTANCE BY THE SIMPLE ORDERING METHOD



PRETEST

POSTTEST

RANKING OF DESTINATIONS FROM ORIGINS	RANKING OF DESTINATIONS FROM ORIGINS
A, B	A, C

MEAN OPPORTUNITY DISTANCE

$$\frac{(A + \frac{B}{2}) + \frac{A}{2}}{n \text{ trips}} = \frac{40}{n}$$

MEAN OPPORTUNITY DISTANCE

$$\frac{(A + \frac{C}{2}) + \frac{A}{2}}{n \text{ trips}} = \frac{25}{n}$$

═	Boundary of study area
—	Boundary of door-to-door transit service
━	Regular bus route
↔	Trips
△	Location of origins

Destination A is 10 square units.

Destination B is 50 square units.

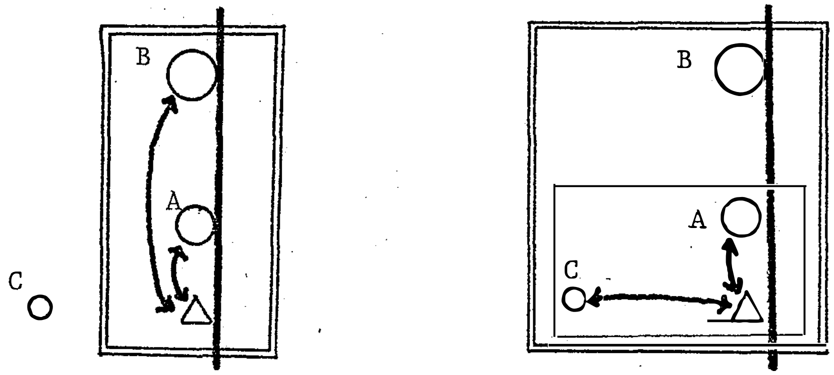
Destination C is 20 square units.

Figure 6-6: CALCULATING MEAN OPPORTUNITY DISTANCE BY THE REBOUNDING METHOD

1. Exclude all unvisited or very infrequently visited destinations from pretest calculations.
2. Measure physical distances between all pretest origins and the remaining destinations.
3. For each origin i, accumulate the sizes of all destinations closer than the destination j actually visited.
4. Add one-half the size of destination j to the total to get the opportunity distance between i and j.
5. If this is the last sample, then *stop*.
6. For the next sample, measure physical distances between all origins i and the newly visited destinations j.
7. Add each distance between origins i and the newly visited destinations j to the distance between that i and the most distantly visited j in the previous sample.
8. Return to *step* 3, using the revised distance matrix from *step* 7.

The results of this procedure are illustrated through the hypothetical example in Figure 6-7, in which the mean opportunity distance finally increases between the pretest and posttest.

For small-area studies such as the NECO Mini-bus experiment, a major threat to validity in research at geographic scales is the interaction between scale and constructs. Spatial interaction models have been applied most successfully to highly aggregated



PRETEST

POSTTEST

RANKING OF DESTINATIONS FROM ORIGINS

A, B

RANKING OF DESTINATIONS FROM ORIGINS

A, B, C

MEAN OPPORTUNITY DISTANCE

$$\frac{(A + \frac{B}{2}) + \frac{A}{2}}{n \text{ trips}} = \frac{40}{n}$$

MEAN OPPORTUNITY DISTANCE

$$\frac{(A + B + \frac{C}{2}) + \frac{A}{2}}{n \text{ trips}} = \frac{75}{n}$$

═ Boundary of study area

— Boundary of door-to-door transit service

━ Regular bus route

⟷ Trips

△ Location of origins

Destination A is 10 square units.

Destination B is 50 square units.

Destination C is 20 square units.

Figure 6-7: CALCULATING MEAN OPPORTUNITY DISTANCE BY THE REBOUNDING-REORDERING METHOD travel patterns, where particular boundary and partition distortions are generally averaged out. As noted by Isard (1960), disaggregation of these models to small areas and population subgroups causes "the systematic and pervasive influence of the distance variable [to disintegrate]" (pp. 512-513). In other words, the issues captured successfully by the model at higher levels of aggregation may be unreliably captured or irrelevant at smaller scales.[16] This is particularly true for accessibility measures based on physical space rather than opportunity space, none of which have the flexibility to accommodate the localized directional biases and other distortions of monitored travel behavior which have been examined in this study. In contrast, the mean opportunity distance measure of accessibility appears to have adequate flexibility in addressing local conditions in a straightforward manner that yields consistent results. In summary, the mean opportunity distance measure is superior for evaluating changes in accessibility in small-area studies.

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[16] Hartgen and Wachs (1973) strongly concur with Isard's view.

CHAPTER VII

CONCLUSIONS

The evaluation of transportation developments for disadvantaged groups has been explored in the preceding six chapters. Accessibility was first established as the concept which best represents the needs of the transportation disadvantaged. The diversity of the transportation disadvantaged and of flexible innovations to ameliorate their condition was examined next. Their condition was then characterized more precisely by an accessibility measure which was derived from the intervening opportunities model of spatial interaction. Three frameworks of evaluation were then considered, and the framework which best encouraged the development of effective, ameliorative services was developed further. The accessibility measure was next applied within the selected framework to a transportation service for the elderly and handicapped in Northeast Baltimore.

This study was motivated primarily to examine two major questions. First, what framework of evaluation is most appropriate for the evaluation of transportation developments for disadvantaged groups? Second, how should accessibility measures be structured and interpreted in a manner consonant with that framework? To answer these questions required consideration of four topics:

1. the condition of the transportation disadvantaged requiring amelioration;
2. the precise measurement of that condition as accessibility;
3. the role of evaluation in the process of planning for the amelioration of that condition; and
4. the design of transportation experiments.

While the diversity of these topics allowed only their initial exploration within the confines of this study, several conclusions and policy recommendations can be drawn from this effort.

Existing classifications of the transportation disadvantaged are inappropriate. It was argued in the second chapter that current research and ameliorative actions are designed for groups whose membership does not fall entirely within the transportation disadvantaged, while missing other persons in need. Furthermore, the existing classification does not readily provide a match between the transportation disadvantaged and the ameliorative actions proposed in their behalf.

The transportation disadvantaged include persons who are spatially isolated from opportunities considered generally available to the public. Reasons for this isolation can be summarized as readily correctable, physical and financial barriers to existing transportation, inadequate links between the person and his desired destination by otherwise available transportation, or a complete lack of transportation services. These problems can be ameliorated by modifications to existing vehicles, direct subsidies to users, and implementation of innovative, subsidiary or para-transit service. The approach of market segmentation can be used to classify the transportation disadvantaged by their problems in a way which is sensitive to these solutions.

A more appropriate classification, such as the one proposed in Chapter 2, is difficult to employ because requisite data are difficult to obtain, and because the allocation of public resources are based on the existing categories.[1] Until these conditions are changed, each evaluation effort must carefully examine the relative spatial isolation of the group who is intended to be served by the innovation.

Given the limited availability of local resources, *transportation services should be evaluated by their effects on the most spatially isolated individuals.* This follows from the ethical and political considerations raised in Chapter 4. Individuals with the fewest and least tenable options for travel are usually those in greatest need. Since the operating costs per client are high for many transportation innovations, the realization of increased accessibility for those in greatest need is far more important justification than merely expediting the existing travel patterns with a

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[1] See Falcocchio (1977) and Schmitt (1977).

new service.

None of the measures proposed on the existing literature for monitoring accessibility changes are particularly satisfactory when applied to subpopulation in small areas. Most of these measures are based on physical space, the effects of which on travel can often be distorted by social and economic aspects of local geography. Furthermore, these measures are only indirect surrogates of access to opportunities.

The effects of transportation services on spatially isolated groups are most directly characterized by the L-factor of the intervening opportunities model of spatial interaction when monitored in conjunction with trip generation rates. Of the many accessibility measures proposed in Chapter 3, trip lengths are measured explicitly and completely in opportunity distance only by the L-factor. Unlike previous measures, this method of measuring trip lengths can be modified to accommodate local geography and provide a consistent basis for temporal and spatial comparisons. It now remains to compare rigorously the spatial interaction indices in field settings.

Successful evaluations require more than appropriate measures. Indeed, *evaluations of transportation developments often fail to provide useful information because they are conceived within an inappropriate framework.* Reliance on the predictive model framework is neither necessary nor satisfactory.[2] The currently used

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[2] The latter point is due to the inadequate knowledge about travel behavior of the transportation disadvantaged noted in Chapter 2.

alternative, based on demonstration projects, also fails because results of the evaluation cannot be validated.

The experimental design framework of evaluation is the best approach for the development of effective transportation services for disadvantaged groups. As shown in Chapter 4, the experimental design framework:

1. provides more dependable inferences about the effects of an innovative service on its targeted clientele;
2. encourages greater attention to be given to the objectives of the ameliorative action, both before and after the action is taken; and,
3. provides a consistent basis for building knowledge about the problem and the intended clientele's reactions to various solutions.

Experiments should not be attempted, however, unless the political, ethical, technical, and administrative-managerial conditions are met such that decisionmakers are responsive to honest evaluations, and the evaluator is able to alter the service and monitor clientele reactions adequately. *This framework is generally more productive when applied in a recursive process of experimentation and evaluation.* In this manner, both the innovation and inferences about its effects can be refined in a consistent manner.

One of the principle strengths of the experimental design framework of evaluation is its explicit handling of validity threats. While many such threats have been catalogued previously, *several threats to the validity of research at geographic scales must be considered in addition for transportation studies.* These threats include:

1. boundary distortions,
2. partition distortions,
3. scale distortions (to internal validity),
4. interaction of scale and constructs,
5. interaction of scale and statistical validity,
6. generalizability across scales,
7. interaction of space and time, and
8. confusion of spatial and aspatial issues.

Boundary distortions include overextension and truncation; partition distortions include spurious location and diffusion, excessive heterogeneity within zones, and density biases. The abilities of various experimental designs to control these threats are examined in Chapter 5.

The discussions of evaluation, experimental design, and accessibility measures are merged in practice through the NECO Mini-bus experiment. While the experiment was not completed, several conclusions can be drawn from the interim analysis and from the circumstances which undermined the evaluation effort. These conclusions are discussed in turn.

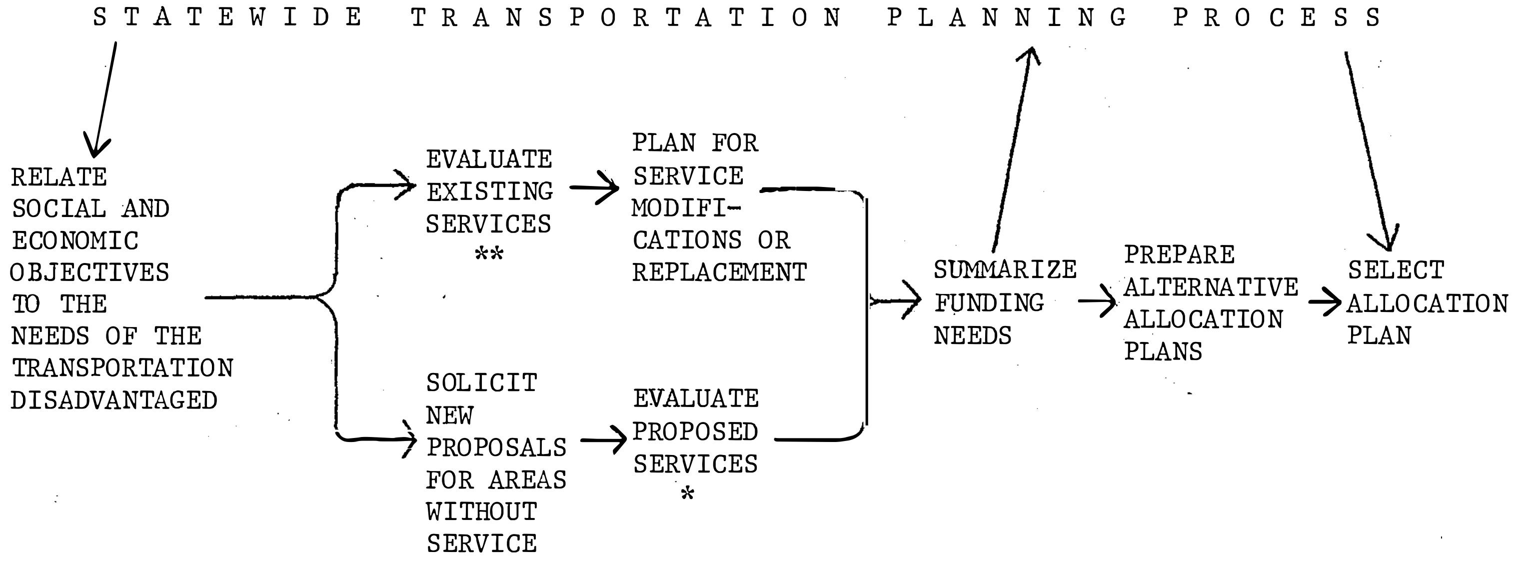
It was found in the trial application of the L-factor within an experimental design that the expected results did not match the actual distribution of trips monitored in Northeast Baltimore. This failure to fit statistical criteria was turned to advantage, in the spirit of addressing threats to validity, by exploring the model's inadequacies and subsequently revealing the community's needs more precisely. Since ".... the overall criterion for a successful evaluation technique must be its usefulness rather than its goodness of fit" (Houghton, 1974, p. 134), *the potential of the L-factor accessibility measure has been confirmed in its first evaluative application in an experimental design.*

Other methodological findings in the case study are two-fold. First, seasonal variations in both mean opportunity distances and trip generation rates were adequately suppressed by the data collection instrument. Direct comparisons between pretests and a posttest can thus be made. Care must be taken, however, not to interpret any subsequent lack of change in nondiscretionary travel as a failure of the service unless discretionary travel is also unchanged. Second, the major threat to validity which remains uncontrolled is selection bias, caused by the voluntary nature of the data collection instrument and the low response rate. If a recursive approach to experimentation is eventually followed in the continuing development of the NECO Mini-bus Service, a subsequent experiment can deal specifically with characteristics of the respondents and thus confirm the internal validity of changes measured in the first experiment.

The major, analytical finding related to the purpose of the NECO Mini-bus Service is that *a need for localized, door-to-door service has been supported by the analysis of pretest data.* This finding is based on the respondents' stated desire to reach nearby destinations which are neither within walking distance nor directly served by the citywide bus network.

Given these useful insights, why was the NECO Mini-bus experiment not completed to realize fully the touted benefits of the recursive-experimental approach to planning and evaluation? Most simply put, both NECO and the evaluator were not given adequate flexibility to consider other alternative services. *The failure to complete the NECO Mini-bus experiment is not due to a structural shortcoming of the evaluation framework; rather, the failure is a result of the funding mechanism.* As suggested in Chapter 4, recursive experimentation works only if there is an ongoing commitment to ameliorating the problem at hand. This commitment is difficult to maintain since funding enabled by Section 16(b) of the Urban Mass Transportation Act is restricted to vehicle purchases and does not provide for trade-ins. NECO was able to initiate a transportation service only because federal funds were available to purchase vehicles and staff positions were funded through a state employment program. There is no centralized source of funds for alternative approaches such as providing vouchers for taxi service, which may be cheaper and at least as effective. As a consequence, NECO's commitment to providing service is constrained to making the most of a perhaps inappropriate solution. *It is unreasonable and politically untenable to evaluate a transportation service when the only alternative to that service is to do nothing at all.*

Two actions are recommended to allow services for the transportation disadvantaged to be developed fully through recursive experimentation. *Funding enabled by Section 16(b) of the Urban Mass Transportation Act should be expanded to include uses other than for the purchase of vehicles.* This would allow for a wider variety of ameliorative actions to be attempted. Also a plan should be considered by which *vehicles purchased under Section 16(b) are placed in a motor pool controlled by a statewide transportation or human services agency.* The state would then lease the vehicles to local agencies and be able to shift vehicles among projects as local conditions change or service modifications require different equipment. Local agencies would include both public and quasi-public agencies such as NECO. Vehicles and operating funds could be administered through a process such as the one illustrated in Figure 7-1, which has been proposed for the Maryland Department of



* Obtain base-line data. Measure actual and desired trip patterns.

** Measure post-implementation trip patterns. Compare to pre-implementation conditions with the mean opportunity distance measure.

Figure 7-1: A PROPOSED STATEWIDE PLANNING PROCESS FOR THE TRANSPORTATION DISADVANTAGED OF MARYLAND (from Schmitt [1977]).

Transportation (Schmitt, 1977). These recommended changes in federal funding and state administration of projects for the transportation disadvantaged would provide flexible resources necessary for recursive experimentation at the local level.

While the desirability of coordinating these projects is an accepted common wisdom, rigorous examinations of the need for and approaches to coordination are lacking. What benefits can be realized by regional or statewide coordination? While reducing service redundancy is usually cited, the potential of coordination to create economies of scale, to improve maintenance, to increase flexibility in matching vehicles to changing needs, and to improve local-agency access to operating subsidies should be investigated. Different approaches to coordination have been tried, such as the Older Adults Transportation System (OATS) in Missouri, but their effectiveness in realizing these benefits is inadequately documented. Untested approaches, such as the one just proposed for a state motor pool, have yet to be compiled and their potentials considered.

A research effort should follow the present study, focusing on the question: can approaches to service coordination be matched with various bureaucratic and geographical conditions to improve the delivery of transportation services to local, disadvantaged groups? The proposed study would consist of three phases. In Phase I, existing mandates and enabling provisions in federal and state laws and regulations for the coordination of transportation services would be reviewed. Implications of recent judicial decisions on access to human services would also be examined. Phase I would then be summarized with a list of existing coordination efforts (classified by type of coordination, size of clientele, and extent of services), and a list of benefits which might accrue from coordination. These lists provide the basis for a survey of representative, service-providing agencies, which would be collected and summarized in Phase II.[3] Specific, alternative plans for coordinating transportation services would then be developed and evaluated in Phase III. This proposed effort should conclude with specific plans recommended for regions where coordination of transportation services for disadvantaged groups is needed.

Perhaps the most significant finding of the present study is that *there is a general lack of experience with the use of experiments in transportation planning and research.* This study has been a preliminary effort in gaining experience with the design of experiments and data collection instruments and with the interpretation of evaluation measures in the transportation context. Far more experience with the various measures of accessibility and the design issues surveyed in Chapter 5 must be accumulated before this

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[3] This survey would include questions on the type of explicit or *de facto* coordination and on the benefits and problems related to coordination.

framework of evaluation can be used to its greatest advantage. The mean opportunity distance measure should be compared more thoroughly with other indicators based on locally monitored travel behavior. Finally, a major, ongoing effort must be made to synthesize the experience gained in local efforts to serve the transportation disadvantaged. Reasons for a lack of change in travel behavior are as important as reasons for major changes induced by an experimental transit service. From such experience, more effective and appropriate transportation services can be developed so that eventually no local resident is involuntarily isolated from the necessities and amenities that support his or her quality of life.

APPENDICES

APPENDIX A

A TYPOLOGY OF EXPERIMENTAL DESIGNS

The experimental designs referenced in Chapters 5 and 6 are drawn from the inventories of designs by Campbell and Stanley (1963) and Cook and Campbell (1976). Using the typology of designs in Cook and Campbell, both inventories are summarized and merged in this appendix.

The notation employed in Figures A-1 through A-8 is taken directly from the above mentioned works. Let "O" be an observation and "X" be a treatment or an event. Observations made prior to the treatment are called "pretests" and those made after are called "posttests". The horizontal arrangement of these symbols indicates their sequence in time, each row referring to one group or area under observation. If the row is prefixed with the symbol "R", that group or area is selected by a random process. The exact references from which the design is taken are abbreviated as follows:

C+S	Campbell and Stanley (1963)
C+C	Cook and Campbell (1976)
CRA	Charles River Associates (1972)

Alpha-numerics following the abbreviation and separated by a colon identify the design in the given reference. Other notation is explained as it occurs.

These figures provide only a summary of the experimental designs available for transportation research. The given references should be consulted for a more complete discussion of each design.

Pre-experimental Designs

As illustrated by Figure A-1, pre-experimental designs provide the methodological basis of demonstration projects. Cook and Campbell (1976, pp. 247-249) discuss the inability of these designs to control internal validity threats, underscoring the failure of demonstration projects as an evaluation framework in transportation research.

True Experimental Design

In contrast to the preceding category, true experiments are the most powerful and desirable designs available. By randomly assigning individuals (or areas) to treatment and control groups, differences between the groups which are irrelevant to the innovation can be statistically removed. Measured changes are then attributable solely to the innovation being evaluated. The three basic designs are illustrated in Figure A-2.

<u>One-Shot Case Study</u>

X   0

(C+S: 1, C+C, CRA: a)

<u>One-Group Pretest-Posttest</u>

0   X   0

(C+S: 2, C+C, CRA: b)

<u>Static-Group Comparison</u>

X   0

0

(C+S: 3, C+C, CRA: c)

FIGURE A-1: PRE-EXPERIMENTAL DESIGNS

Pretest-Posttest Control Group Design

R	0	X	0
R	0		0

(C+S: 4, CRA: d)

Posttest-Only Control Group Design

R	X	0
R		0

(C+S: 6, CRA: e)

Solomon Four-Group Design

R	0	X	0
R	0		0
R		X	
R			0

(C+S: 5)

FIGURE A-2: TRUE EXPERIMENTAL DESIGNS

Quasi-Experimental Designs

As noted in the previous chapter, the ability to randomly select treatment and control groups is limited in transportation research, and often undesirable from political and ethical perspectives. Equivalence between treatment and control groups must be assured by other means. These varied means which do not employ random assignment are quasi-experimental designs.[1]

Six categories of quasi-experiments are illustrated in Figures A-3 through A-8, indicating the diverse range of options available — and necessary — to control validity threats. These categories are based on the number of groups observed, of treatments administered, and of observations made.

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[1] Randomization techniques can be used for sampling observations from treatment and/or control groups, but not to assign membership to either group.

Nonequivalent Control Group Design

0 X 0

0   0

(C+S: 10, C+C, CRA: g)

CRA refers to this as "the before-and-after design with control area."

Nonequivalent Dependent Variable Design

$$0_{m_2}^{m_1} \qquad 0_{m_2}^{m_1}$$

(C+C)

This design employs different sets of dependent variables (m_1 and m_2), one of which is not sensitive to the treatment and acts as the control.

FIGURE A-3: CLASSIC ONE-TREATMENT BEFORE-AND-AFTER DESIGNS

Separate-Sample Pretest-Posttest Design

R	0	X	
R		X	0

(C+S: 12, CRA: h)

This design is labeled the "before-and-after user study" by CRA.

Multiple Separate-Sample Pretest-Posttest Design

R	0	X		Subarea A
R		X	0	
R	0	X		Subarea B
R		X	0	

Either subareas or subpopulations from the study area can be used, and their number is not limited.

Separate-Sample Two-Pretest-One-Posttest Design

R	0		X	
R		0	X	
R			X	0

(C+S: 12b)

Separate-Sample Pretest-Inclusive-Posttest Design

R	0	X	0
R		X	0

(C+S: 12c)

FIGURE A-4: SEPARATE-SAMPLE ONE-TREATMENT BEFORE-AND-AFTER DESIGNS

FIGURE A-4: (Continued)

Separate-Sample Pretest-Posttest Control Group Design

R	0	X		Subarea A
R		X	0	
R	0			Subarea B
R			0	

(C+S: 13, CRA: i)

This design is labeled the "randomized before-and-after user study with control" by CRA.

Expanded Separate-Sample Pretest-Posttest Control Group Design

R'	R	0	X		Subarea A
	R		X	0	
	R	0	X		Subarea B
	R		X	0	
	R	0	X		Subarea C
	R		X	0	
R'	R	0			Subarea D
	R			0	
	R	0			Subarea E
	R			0	
	R	0			Subarea F
	R			0	

(C+S: 13a)

This design uses a nested sample. Sample units are randomly selected (R) from subareas which are themselves randomly selected beforehand (R').

Interrupted Time-Series Design

0 0 0 0 X 0 0 0 0

(C+S: 7, C+C, CRA: f)

The number of observations is not limited for this or any other time-series design.

Interrupted Time-Series Design with Nonequivalent Dependent Variables

$$0^{m_1}_{m_2} \quad 0^{m_1}_{m_2} \quad 0^{m_1}_{m_2} \quad 0^{m_1}_{m_2} \quad 0^{m_1}_{m_2} \quad 0^{m_1}_{m_2} \quad 0^{m_1}_{m_2} \quad 0^{m_1}_{m_2}$$

(C+C)

This is the time-series version of the nonequivalent dependent variables design described previously. Any number of dependent variables (m_1, $m_2 \ldots m_n$) may be used.

Interrupted Time-Series Design with Nonequivalent Control Group

0 0 0 0 X 0 0 0 0
0 0 0 0 0 0 0 0

(C+S: 14, C+C)

Interrupted Time-Series Design with Switching Replications

0 0 X 0 0 0 0 0 0
0 0 0 0 0 0 X 0 0

(C+C)

This design is used for treatments which are phased into implementation.

FIGURE A-5: BASIC TIME-SERIES DESIGNS
(See Glass, Wilson, and Gottman [1975])

Repeated Treatment Design

0 X 0 0 X 0

(C+C)

Removed-Treatments Pretest-Posttest Design

0 X 0 0 $\overline{X}$ 0

(C+C)

The second event "$\overline{X}$" is the removal of treatment "X". Returning the fare to its original amount is an example.

Equivalent Time Samples Design

$X_1$0 $X_0$0 $X_1$0 $X_2$0 ...

(C+S: 8)

Treatments are administered in different intensities (X_1, X_2, ...X_n), possibly including placebo dosages (X_0). Treatments are administered in a random sequence and not necessarily at regular time intervals.

Equivalent Materials Samples Design

X_{i1} o X_{j0} 0 X_i0 0 X_{j1} 0 ...

(C+S: 9)

Different treatments (subscripted i and j in this example) are administered in different intensities (subscripted 0 and 1) in a random sequence.

FIGURE A-6: ONE-GROUP MULTIPLE-TREATMENT DESIGNS

Recursive Separate-Sample Pretest-Posttest Design

R	0	X			
R		X	0		
R			0	X	
R				X	0

(C+S: 12a)

Reverse-Treatment Nonequivalent Control Group Design

0	X+	0
0	X-	0

(C+C)

This design applies dichotomous treatment, such as fare increases (X+) and decreases (X-), to different groups or areas.

FIGURE A-7: MULTIPLE-GROUP MULTIPLE-TREATMENT DESIGNS

FIGURE A-7: (Continued)

Counterbalanced Designs

X_1 0	X_2 0	X_3 0	X_4 0
X_2 0	X_4 0	X_1 0	X_3 0
X_3 0	X_1 0	X_4 0	X_2 0
X_4 0	X_3 0	X_2 0	X_1 0

(C+S: 11)

Subscripts in this design refer to different treatments or treatment intensities. Another label for this design is "rotation experiment".

Institutional Cycle Design

	X	0				Cohort 1
R		0	X	0		Cohort 2
R			X	0		
				0	X	Cohort 3

(C+S: 15)

Each group is a cohort observed while it experiences one stage of an institutional cycle.

Regression Discontinuity Analysis Design

0

0 X

0

(C+S: 16, C+C)

Groups are divided by pretest scores. Posttest scores are then regressed onto pretest scores for each group. Parametric discontinuities between groups are identified. The number of group divisions is not limited, although two is implied by both references.

Quantified Multiple Control Groups Posttest-Only Design

X 0

X 0

...

(C+C)

Groups are selected by classes of a quantified characteristic rather than a pretest score. Observations are regressed on the ordered characteristic and significant residuals are identified.

FIGURE A-8: REGRESSION-CORRELATION DESIGNS

FIGURE A-8: (Continued)

Posttest-Only Design with Predicted Higher Order Interactions

E X 0

E 0

(C+C)

Expected impacts (E) are compared with observed impacts.

Path Analysis Correlation Design

m_i

m_j X 0

m_k

(C+C)

Patterns of causality with intervening variables are prespecified and correlations among the variables (m_i, m_j, m_k...) are observed to test the model.

Cross-lagged Panel Correlation Design

m_i X 0 0 ...

m_j

(C+C)

This design differs from the previous one by utilizing multiple posttests and correlating the measures both longitudinally and in cross-section.

APPENDIX B

CENSAM: A PROGRAM FOR RANDOMLY SELECTING SAMPLES OF CENSUS AREAS

CENSAM is a program designed to select samples of census tracts or blocks. The number of tracts or blocks selected depends on several user-supplied constraints, such as the number of households in the areal units selected. This program was used successfully on the DEC-System 10 of The Johns Hopkins University Computing Center for the NECO Mini-bus experiment.

CENSAM is written in Fortran IV, and reads data from card input. The program deck, consisting of 436 cards, is listed following this explanation of user-supplied parameters. These parameters are entered into the program's INSTRUCTIONS section, which follows the variable names in the listing.

The Data

To run CENSAM, the user must supply the following information about the data:

1. the total number of census tracts from which the sample is taken (an integer > 0);
2. the total number of census blocks, (an integer $\geq$ 0); and,

3. the year in which the census data was collected (a 4-digit integer).

The user must also supply one format card each for the tract and block data decks. If blocks are not the sampling units and thus not included as input, a dummy format card is inserted.

At the minimum, data cards for census tracts must include entries for the following variables in order:

1. the census tract number,
2. the total population of the tract, and
3. the total number of housing units in the tract.

Between entries 2 and 3, up to four subpopulations can be included as decimal fractions of the tract population. All entries must be in floating-point format, and any suppressed data should be entered as zero. The tract data deck must be ordered by ascending census tract numbers.

If block data are included, entries must be made on each card for:

1. the census tract number,
2. the census block number,
3. the total population of the block, and
4. the number of housing units in the block.

Between entries 3 and 4, up to four subpopulations can be included as decimal fractions of the block population. All block entries except the block number must be in floating-point format,[1] and suppressed data should be entered as a negative real number.[2] The deck must be ordered by ascending tract and block numbers.

Up to four subpopulations can be included to specify a segment of the population to be used for weighting the sample. Tract percentages can be used to calculate the size of the subpopulation in each tract or estimate the subgroup's size in each block. If block percentages are available, the subgroup's size by block can be calculated directly. The number of population subgroups entered by tract percentages (NPSGT) must be specified as an integer between 0 and 4 inclusively. The number of population subgroups entered by block (NPSGB) must be specified in the same manner. For example, the percentage of elderly persons in each block is available from published Census Bureau reports. The percentage of handicapped is available by tract, as is in some cases the percentage of persons who are both handicapped and elderly. To calculate the population of elderly and handicapped by block, NPSGT = 2 and NPSGB = 1. The elderly and handicapped population for each block will then be estimated in CENSAM by adding the relevant percentages and multiplying

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[1] The block number is an integer.

[2] The negative values are manipulated as zeros, and the number of suppressions are tabulated.

them by the block population.[3]

Selecting the Number and Type of Samples and the Sample Size

The user must define the number and type of samples he wishes to generate. Samples can be selected with or without the selected areal units being allowed to appear in more than one sample. If tracts or blocks should not be selected for more than one sample, then the number of samples without replacement (NSWOR) is specified as an integer greater than zero. Similarly, the number of samples with replacement of areal units between samples (NSWR) is specified as an integer greater than zero. Any number of samples can be taken with replacement followed by any number of samples without replacement. If one type of sampling is not desired, the number for that type of sampling is set at zero; however, NSWR + NSWOR must be an integer greater than zero.

The sample size, or number of areal units in each sample, depends on constraints to the total sample population and the total number of housing units in the selected areal units. The sample population is defined by either the population or subpopulation, summed over all selected areal units. When either MAXTAP (the

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[3] The overlap between the elderly and handicapped is factored out if the tract percentages of persons who are both elderly and handicapped are negative in the tract data file.

maximum total population), MAXTSP (the maximum total subpopulation), or MAXTHU (the maximum number of housing units) is exceeded for any sample, the selection of areal units is terminated. All three constraints must be specified as positive, real numbers. If only one or two criteria are desired to establish the sample size, the remaining constraints should be specified at a value greater than the study area total. That value will thus be adequately high for the constraint to be ignored.

Two additional constraints on sample size must be specified. The maximum number of areal units selected for the sample should not contain more than a given fraction of the population or subpopulation of the study area. This is particularly important when areal units can appear only once in each sample.[4] In this case (i.e., for sampling without replacement), MAXCF2 is set at a positive real number less than one. MAXCF1 is for sampling with replacement, and can take any value greater than zero. These constraints act as a safety valve, in case the preceding constraints were set too high.

If the user wishes to select a specific percentage of tracts or blocks in the study area, that fraction can be specified by

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[4] As more units are preempted by selection, the range of usable random numbers diminishes, which increases the probable length of time consumed to generate numbers in that range.

MAXCF1 and MAXCF2. In this case, the values for tract or block populations must all be entered as a constant in the data deck.[5] MAXTSP, MAXTAP, and MAXTHU should be specified at adequately high values to be ignored.

Weighting the Sample

CENSAM can weight the probability of selecing an areal unit (either tract or block by its total population, a segment of its population, or both. To weight the selection of tracts by:

1. population, W1=1 and W2=0
2. subpopulation, W1=0 and W2=0
3. population plus subpopulation, W1=2 and W2=0.

To weight the selection of blocks by:

1. population, W1=1 and W2=0
2. subpopulation, W1=0 and W2=0
3. population plus subpopulation, W1=2 and W2=0.

To override these options and assign an equal probability for selecting each tract, specify W1=1 and W2=0 and replace each tract population entry in the data deck with a constant. For blocks, specify W1=0 and W2=1 and replace each block population entry with a constant.

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[5] This will automatically cancel the ability to weight the probability of an areal unit's selection, which is discussed next.

Output Options

CENSAM generates a listing of the data, a summary check of consistency between tract and block entries, and a listing plus summary of each sample. Each sample can be listed in the order by which the areal units were selected or by ascending order of tract-block numbers. While both listings may be useful, the user may want to reduce the length of output to save on line-printer charges. The OUTPUT must be specified for printing the unordered samples only (OUTPUT = 1), the ordered samples only (OUTPUT = 2), or both ordered and unordered samples (OUTPUT = any other integer). The data lists and consistency checks will be printed in all cases.

System-Specific Modifications

Modifications to the program deck may be necessary to use CENSAM on other computer systems. First, device numbers for input-output statements may have to be changed. In the following listing the card reader is unit 2 and the line printer is unit 3. Second, the library subroutine for generating random numbers may be called by a different name than "X = RAN (1.0)". These are the only items which are not elementary Fortran.

```
C   CENSAM IS A PROGRAM DESIGNED TO SELECT SAMPLES OF CENSUS AREAS
C   AT RANDOM, WEIGHTING THE PROBABILITY OF SELECTION BY THE POPULATION
C   OR POPULATION SUBGROUPS OF THE AREAL UNIT.  THIS WEIGHTING
C   APPROXIMATES AN EQUAL PROBABILITY OF SELECTING ANY GIVEN MEMBER OF
C   THE POPULATION OR SUBGROUP.
C
C   PROGRAMMED BY ROLF R. SCHMITT
C
C   VARIABLE LABELS...
C    ABX = BLOCK HAS/HAS NOT ALREADY BEEN SELECTED
C    BBP = NUMBER OF BLOCKS IN TRACT WITH POPULATION DELETED
C    BHUI= MANIPULATING VARIABLE FOR HUB
C    BHUD = NUMBER OF BLOCKS IN TRACT WITH HOUSING UNITS DELETED
C    BP = TOTAL POPULATION OF BLOCK
C    BPD = INDICATOR THAT BLOCK POPULATION HAS BEEN DELETED
C    BPOP = MANIPULATING VARIABLE FOR BP
C    CBN = CENSUS BLOCK NUMBER
CI   CFI= CUMULATIVE FREQUENCY OF SAMPLE POPULATION IN DATA LIST
C    CTNI= CENSUS TRACT NUMBER
CI   CUMFRE = CUMULATIVE FREQUENCY OF SELECTED SAMPLE POPULATION
C    FRE = FREQUENCY (FRACTION OF TOTAL SAMPLE POPULATION)
CI   G01-G04I= MANIPULATING VARIABLES FOR PSGT1-4 AND PSGB1-4
CI   HUB = HOUSING UNITS IN BLOCK
C    HUD = INDICATOR THAT BLOCK HOUSING UNITS HAVE BEEN DELETED
CI   HUTI= HOUSING UNITS IN TRACT
CI   I,J,K,L = INDEX VARIABLES
CI   MAXCF1 = MAXIMUM DESIRED CF FOR SAMPLING WITH REPLACEMENT
CI   MAXCF2 = MAXIMUM DESIRED CF FOR SAMPLING WITHOUT REPLACEMENT
CI   MAXTAP = MAXIMUM DESIRED TAP
CI   MAXTHU = MAXIMUM DESIRED THU
```

```
C     MAXTSP = MAXIMUM DESIRED TSP
C     NB = NUMBER OF CENSUS BLOCKS
C     NPSGB = NUMBER OF POPULATION SUBGROUPS ENUMERATED BY BLOCK
C     NPSGT = NUMBER OF POPULATION SUBGROUPS ENUMERATED BY TRACT
C     NS = NUMBER OF SAMPLES TAKEN
C     NSWOR = NUMBER OF SAMPLES TAKEN WITHOUT REPLACEMENT
C     NSWR = NUMBER OF SAMPLES TAKEN WITH REPLACEMENT
C     NT = NUMBER OF CENSUS TRACTS
C     OUTPUT = OPTION SWITCH FOR TYPE OF PRINTED OUTPUT
C     PBG1-PBG4 = PERCENT OF BLOCK POPULATION IN SUBGROUPS 1-4
C     PTG1-PTG4 = PERCENT OF TRACT POPULATION IN SUBGROUPS 1-4
C     SAMPOP = SAMPLE POPULATION (THE BASIS OF SELECTION PROBABILITY)
C     SUMBP = BP ACCUMULATOR FOR DATA CONSISTENCY CHECK
C     SUMHUB = HUB ACCUMULATOR FOR DATA CONSISTENCY CHECKS
C     TAP = TOTAL AREA POPULATION USED IN AREA SELECTION
C     THU = TOTAL HOUSING UNITS USED IN AREA SELECTION
C     TNO = CTN USED FOR READING IN TRACT DATA
C     TOTSP = TOTAL SAMPLE POPULATION
C     TP = TOTAL POPULATION OF TRACT
C     TSP = TOTAL SAMPLE POPULATION USED IN AREA SELECTION
C     W1,W2 = SAMPLE POPULATION WEIGHTING OPTION SWITCHES
C     X = RANDOMLY SELECTED NUMBER BETWEEN 0 AND 1
C     YEAR = YEAR IN WHICH CENSUS WAS TAKEN
C
C    ************************* INSTRUCTIONS ****************************
C
C    DIMENSION THE FOLLOWING INTEGERS WITH EITHER THE NUMBER OF CENSUS
C    TRACTS OR TOTAL NUMBER OF CENSUS BLOCKS, WHICH EVER IS LARGER.
C                   ABX,BBP,BHUD,CBN
      INTEGER ABX( 406),BBP( 406),BHUD( 406),CBN( 406)
```

```
C
C  DEFINE BPD, HUD, OUTPUT, W1, W2, AND YEAR AS INTEGERS.
      INTEGER BPD,HUD,OUTPUT,W1,W2,YEAR
C
C  DIMENSION THE FOLLOWING REAL VARIABLES WITH THE SAME VALUE AS THE
C  INTEGERS.
C                     TNO,CTN,TP,BP,HUT,HUB,PTG1-PTG4,
C                     PBG1-PBG4,SAMPOP,FRE,CF,SUMBP,SUMHUB
      REAL TNO( 406),CTN( 406),TP( 406),BP( 406),HUT( 406),HUB( 406)
      REAL PTG1( 406),PTG2( 406),PTG3( 406),PTG4( 406)
      REAL PBG1( 406),PBG2( 406),PBG3( 406),PBG4( 406)
      REAL SAMPOP( 406),FRE( 406),CF( 406),SUMBP( 406),SUMHUB( 406)
C
C  DEFINE MAXTSP, MAXTAP, MAXTHU, MAXCF1, AND MAXCF2 AS REAL VARIABLES.
      REAL MAXTSP,MAXTAP,MAXTHU,MAXCF1,MAXCF2
C
C  NOW THAT THE DIMENSION STATEMENTS ARE INSERTED, ENTER VALUES
C  FOR THE FOLLOWING VARIABLES AS SPECIFIED IN THE PROGRAM
C  DOCUMENTATION.
C                     YEAR,NPSGT,NPSGB,NT,NB,NSWR,NSWOR,
C                     MAXTSP,MAXTAP,MAXTHU,MAXCF1,MAXCF2,
C                     W1,W2,OUTPUT
      YEAR=1970
      NPSGT=1
      NPSGB=1
      NT=12
      NB=406
      NSWR=2
      NSWOR=3
      MAXTSP=1000000.
```

```
    MAXTAP=1000000.
    MAXTHU=10000.
    MAXCF1=1.0
    MAXCF2=.90
    W1=0
    W2=0
    OUTPUT=0
C
C NOW INSERT THE TRACT DATA CARD FORMAT (AS STATEMENT NO. 20).
  20 FORMAT (F6.2,F5.0,F4.2,F5.0)
C
C NOW INSERT THE BLOCK DATA CARD FORMAT (AS STATEMENT NO. 25),
C UNLESS THERE ARE NO BLOCK DATA, IN WHICH CASE A DUMMY FORMAT CARD
C IS INSERTED WHICH READS   25 FORMAT (1H )   .
  25 FORMAT (5X,F6.2,I4,F7.0,6X,F3.2,F5.0)
C
C ****************** THE PROGRAM IS NOW READY **********************
C
    TOTSP=0.
    J=NB
    IF (NT.GT.NB) J=NT
    DO 40 I=1,J
    PTG1(I)=0.
    PTG2(I)=0.
    PTG3(I)=0.
    PTG4(I)=0.
    PBG1(I)=0.
    PBG2(I)=0.
    PBG3(I)=0.
    PBG4(I)=0.
```

```
      SAMPOP(I)=0.
      BBP(I)=0
      BHUD(I)=0
      SUMBP(I)=0.
      SUMHUB(I)=0.
   40 CONTINUE
C  WRITE HEADING FOR PRINT OUT OF DATA, RANGES, AND FREQUENCIES
      WRITE ( 3,50) YEAR
   50 FORMAT (1H1///46X,14HCENSUS DATA - ,I4///110HI  ID NO.  CENSUS TRA
     1CT  BLOCK  TOTAL BLOCK  POP IN  POP IN  POP IN  POP IN    SAMPLE
     2  FREQUENCY  CUMULATIVE/32X,10HPOPULATION,
     33X,32HGROUP 1 GROUP 2 GROUP 3 GROUP 4 ,
     410HPOPULATION,13X,9HFREQUENCY//)
C  TEST FOR IMPROPER INSTRUCTIONS FROM USER
      IF (NPSGT+NPSGB-4) 60,60,9910
   60 CONTINUE
      IF (W1.LT.0.OR.W1.GT.2) GO TU 9914
      IF (W2.EQ.1.AND.W1.NE.0) GO TO 9914I
C  READ IN DATA FOR POPULATION SUBGROUPS ENUMERATED BY TRACT
      DO 150 I=1,NT
      IF (NPSGT.LT.1) GO TO 130
      GO TO (110,115,120,125), NPSGT
  110 READ ( 2,20) TNO(I),TP(I),PTG1(I),HUT(I)
      GO TO 135
  115 READ ( 2,20) TNO(I),TP(I),PTG1(I),PTG2(I),HUT(I)
      GO TO 135
  120 READ ( 2,20) TNO(I),TP(I),PTG1(I),PTG2(I),PTG3(I),HUT(I)
      GO TO 135
  125 READ ( 2,20) TNO(I),TP(I),PTG1(I),PTG2(I),PTG3(I),PTG4(I),HUT(I)
      GO TO 135
```

```
  130 READ ( 2,20) TNO(I),TP(I),HUT(I)
  135 CONTINUE
C  TEST FOR ORDER AND REDUNDANCY IN TRACT DATA CARDS
      IF (I.EQ.1) GO TO 140
      J=I-1
      IF (TNO(J)-TNO(I)) 140,9920,9923
  140 CONTINUE
  150 CONTINUE
C  IF THERE IS NO BLOCK DATA, TRACT DATA IS CONVERTED TO BLOCK FORMAT
      IF (NPSGB.NE.0) GO TO 200
      IF (NPSGB.EQ.0.AND.W2.EQ.1) GO TO 200
      NB=NT
      DO 190 I=1,NB
      G01=0.
      G02=0.
      G03=0.
      G04=0.
      CTN(I)=TNO(I)
      CBN(I)=000
      BP(I)=TP(I)
      PBG1(I)=PTG1(I)
      PBG2(I)=PTG2(I)
      PBG3(I)=PTG3(I)
      PBG4(I)=PTG4(I)
      HUB(I)=HUT(I)
      G01=PTG1(I)
      IF (G01.LT.0.) G01=0.
      G02=PTG2(I)
      IF (G02.LT.0.) G02=0.
      G03=PTG3(I)
```

```
      IF (G03.LT.0.) G03=0.
      G04=PTG4(I)
      IF (G04.LT.0.) G04=0.
      IF (W1.EQ.0) SAMPOP(I)=(G01+G02+G03+G04)*TP(I)
      IF (W1.EQ.1) SAMPOP(I)=TP(I)
      IF (W1.EQ.2) SAMPOP(I)=((G01+G02+G03+G04)*TP(I))+TP(I)
      SAMPOP(I)=FLOAT(IFIX(SAMPOP(I)+.5))
      TOTSP=TOTSP+SAMPOP(I)
  190 CONTINUE
      GO TO 301
  200 CONTINUE
C  READ IN DATA ENUMERATED BY BLOCK
      DO 300 I=1,NB
      G01=0.
      G02=0.
      G03=0.
      G04=0.
      IF (NPSGB.GT.0) GO TO 205
      READ ( 2,25) CTN(I),CBN(I),BP(I), HUB(I)
      GO TO 230
  205 GO TO (210,215,220,225),NPSGB
  210 READ ( 2,25) CTN(I),CBN(I),BP(I),G01,HUB(I)
      GO TO 230
  215 READ ( 2,25) CTN(I),CBN(I),BP(I),G01,G02,HUB(I)
      GO TO 230
  220 READ ( 2,25) CTN(I),CBN(I),BP(I),G01,G02,G03, HUB(I)
      GO TO 230
  225 READ ( 2,25) CTN(I),CBN(I),BP(I),G01,G02,G03,G04,HUB(I)
  230 CONTINUE
      BPOP=BP(I)
```

```
      IF (BPOP.LT.0.) BPOP=0.
C     TEST DATA CARDS FOR ORDER AND REDUNDANCY
      IF (I.EQ.1) GO TO 240
      K=I-1
      IF (CTN(K).EQ.CTN(I).AND.CBN(K).EQ.CBN(I)) GO TO 9921
      IF (CTN(K).EQ.CTN(I).AND.CBN(K).GT.CBN(I)) GO TO 9924
      IF (CTN(K).GT.CTN(I)) GO TO 9924
  240 CONTINUE
      IF (I.EQ.1) J=1
      IF (CTN(I).GT.TNO(J)) J=J+1
      IF (CTN(I).GT.TNO(J)) GO TO 9930
  250 CONTINUE
C     INSERT DATA INTO THE BLOCK FILE
      IF (NPSGT.GT.0) GO TO 260
      PBG1(I)=G01
      PBG2(I)=G02
      PBG3(I)=G03
      PBG4(I)=G04
      GO TO 280
  260 CONTINUE
      GO TO (265,270,275),NPSGT
  265 CONTINUE
      PBG1(I)=PTG1(J)
      PBG2(I)=G01
      PBG3(I)=G02
      PBG4(I)=G03
      GO TO 280
  270 CONTINUE
      PBG1(I)=PTG1(J)
      PBG2(I)=PTG2(J)
```

```
      PBG3(I)=G01
      PBG4(I)=G02
      GO TO 280
  275 CONTINUE
      PBG1(I)=PTG1(J)
      PBG2(I)=PTG2(J)
      PBG3(I)=PTG3(J)
      PBG4(I)=G01
  280 CONTINUE
      G01=PBG1(I)
      IF (G01.LT.0.) G01=0.
      G02=PBG2(I)
      IF (G02.LT.0.) G02=0.
      G03=PBG3(I)
      IF (G03.LT.0.) G03=0.
      G04=PBG4(I)
      IF (G04.LT.0.) G04=0.
      IF (W1.EQ.0) SAMPOP(I)=(G01+G02+G03+G04)*BP(I)
      IF (W1.EQ.1) SAMPOP(I)=BP(I)
      IF (W1.EQ.2) SAMPOP(I)=((G01+G02+G03+G04)*BP(I))+BP(I)
      SAMPOP(I)=FLOAT(IFIX(SAMPOP(I)+.5))
      TOTSP=TOTSP+SAMPOP(I)
  300 CONTINUE
  301 CONTINUE
C  DETERMINE FREQUENCIES, CALCULATE TESTS, AND PRINT DATA
      J=1
      DO 400 I=1,NB
      FRE(I)=SAMPOP(I)/TOTSP
      IF (I.EQ.1) GO TO 320
      L=I-1
```

```
      CF(I)=CF(L)+FRE(I)
      GO TO 330
  320 CONTINUE
      CF(I)=FRE(I)
  330 CONTINUE
      HUD=0
      BPD=0
      IF (HUB(I).LT.0.) HUD=1
      IF (BP(I).LT.0.) BPD=1
      BPOP=BP(I)
      BHU=HUB(I)
      IF (BPOP.LT.0.) BPOP=0.
      IF (BHU.LT.0.) BHU=0.
      IF (I.NE.1) GO TO 350
      IF (CTN(1).NE.TNO(J)) GO TO 9930
  350 CONTINUE
      IF (CTN(I).NE.TNO(J)) J=J+1
      IF (CTN(I).NE.TNO(J)) GO TO 9930
      SUMBP(J)=SUMBP(J)+BPOP
      BBP(J)=BBP(J)+BPD
      SUMHUB(J)=SUMHUB(J)+BHU
      BHUD(J)=BHUD(J)+HUD
      WRITE ( 3,380) I,CTN(I),CBN(I),BP(I),PBG1(I),PBG2(I),PBG3(I),PBG4
     1(I),SAMPOP(I),FRE(I),CF(I)
  380 FORMAT (4X,I4,6X,F7.2,5X,I3,5X,F6.0,2X,4(5X,F3.2),F10.0,7X,F5.4,
     16X,F5.4)
  400 CONTINUE
C   DOCUMENT BLOCK DATA CONSISTENCY WITH TRACT DATA
      WRITE ( 3,420)
  420 FORMAT (1H1,50X,22HDATA CONSISTENCY CHECK//5X,
```

```
     157HCENSUS TRACT   POPULATION  POPULATION       HOUSING UNITS,3X,
     213HHOUSING UNITS,3X,
     318HNO. OF BLOCKS WITH,4X,18HNO. OF BLOCKS WITH/20X,
     456HFROM INPUT  CALCULATED          FROM INPUT      CALCULATED,4X,
     521HHOUSING UNITS DELETED,2X,18HPOPULATION DELETED//)
      DO 450 I=1,NT
      WRITE ( 3,440) TNO(I),TP(I),SUMBP(I),HUT(I),SUMHUB(I),BHUD(I),
     1BPP(I)
  440 FORMAT (8X,F7.2,5X,F8.0,4X,F8.0.10X,F8.0,8X,F8.0,6X,I10,3X,I20)
  450 CONTINUE
C  ELIMINATE DELETION ENTRIES FOR SAMPLE SELECTION,
      DO 500 I=1,NB
      IF (BP(I).LT.0.) BP(I)=0.
      IF (HUB(I).LT.0.) HUB(I)=0.
  500 CONTINUE
C  SELECT THE SAMPLES, TAKING THOSE WITH REPLACEMENT FIRST
      NS=NSWR+NSWOR
      IF (NS.LT.1) GO TO 9900
      DO 800 I=1,NS
      WRITE ( 3,503) I
  503 FORMAT (1H1,45X,10HSAMPLE NO.,I3//37X,
     131HRANDOMLY SELECTED CENSUS BLOCKS//)
      IF (I.GT.NSWR) GO TO 505
      WRITE ( 3,504)
  504 FORMAT (40X,26H(SAMPLES WITH REPLACEMENT)///)
      GO TO 507
  505 WRITE ( 3,506)
```

```
506 FORMAT (45X,16H(UNIQUE SAMPLES)///)
507 IF (OUTPUT.EQ.2) GO TO 510
    WRITE ( 3,508)
508 FORMAT (7X,96HCENSUS TRACT  BLOCK   CUMULATIVE POPULATION  CUMULAT
   1IVE POPULATION  CUMULATIVE NO.    CUMULATIVE/31X,
   271HOF TARGET SAMPLE          OF SELECTED AREAS  OF HOUSING UNITS   F
   3REQUENCY //)
510 CONTINUE
    IF (I-NSWR-1) 512,512,520
512 CONTINUE
    DO 515 K=1,NB
    ABX(K)=0
515 CONTINUE
    CUMFRE=0.
520 CONTINUE
    J=0
    TSP=0.
    TAP=0.
    THU=0.
600 CONTINUE
    X=RAN(1.0)
    DO 620 L=1,NB
    IF (X.GT.CF(L)) GO TO 620
    K=L
    GO TO 630
620 CONTINUE
630 CONTINUE
    IF (ABX(K).NE.0) GO TO 600
    ABX(K)=1
    IF (I.GT.NSWR) ABX(K)=I-NSWR
    J=J+1
    TSP=TSP+SAMPOP(K)
    TAP=TAP+BP(K)
```

```
      THU=THU+HUB(K)
      CUMFRE=CUMFRE+FRE(K)
      IF (OUTPUT.EQ.2) GO TO 660
      WRITE ( 3,650) J,CTN(K),CBN(K),TSP,TAP,THU,CUMFRE
  650 FORMAT (2X,I4,4X,F7.2,5X,I3,10X,F8.0,15X,F8.0,13X,F8.0,8X,F5.4)
  660 CONTINUE
      IF (TSP.GT.MAXTSP) GO TO 700
      IF (TAP.GT.MAXTAP) GO TO 700
      IF (THU.GT.MAXTHU) GO TO 700
      IF (NSWR-I) 680,690,690
  680 CONTINUE
      IF (CUMFRE.GT.MAXCF2) GO TO 700
      GO TO 600
  690 CONTINUE
      IF (CUMFRE.LT.MAXCF1) GO TO 600
  700 CONTINUE
C  WRITE ORDERED LISTING
      IF (OUTPUT.EQ.1) GO TO 790
      WRITE ( 3,720) I
  720 FORMAT (1H0//5X,7HSAMPLE ,I4/5X,
     125HORDERED LISTING OF SAMPLE/6X,
     224HCENSUS TRACTS AND BLOCKS,10X,20HNO. OF HOUSING UNITS//)
      DO 750 K=1,NB
      IF (ABX(K).EQ.0) GO TO 750
      L=1
      IF (I.GT.NSWR) L=I-NSWR
      IF (ABX(K).NE.L) GO TO 750
      WRITE ( 3,730) CTN(K),CBN(K),HUB(K)
  730 FORMAT (10X,F7.2,9X,I3,13X,F10.0)
  750 CONTINUE
```

```
      WRITE ( 3,760) TSP,TAP,THU,CUMFRE,J
  760 FORMAT (1H0/20X,20HSAMPLE POPULATION,= ,F8.0/20X,
     124HTOTAL AREA POPULATION = ,F8.0/20X,22HTOTAL HOUSING UNITS,=,,
     2F8.0/20X,23HCUMULATIVE FREQUENCY,= ,F5.4/20X,
     424HNUMBER OF AREAL UNITS = ,I4,1H.)
  790 IF(I.GT.NSWR.AND.CUMFRE.GT.MAXCF2) GO TO 9902
  800 CONTINUE
C  DIAGNOSTICS
 9900 WRITE ( 3,9901) NS
 9901 FORMAT (1H1/////25X,18HCONGRATULATIONS...///25X,
     111HA TOTAL OF ,I4,23H SAMPLES WERE SELECTED.)
      GO TO 9999
 9902 WRITE ( 3,9903)
 9903 FORMAT (1H0,25X,72HAGGREGATE CUMULATIVE FREQUENCY FOR SAMPLES WITH
     1OUT REPLACEMENT EXCEEDED.)
      GO TO 9900
 9910 WRITE ( 3,9911)
 9911 FORMAT (1H /////25X,10HS.N.A.F.U.///25X,
     150HTOO MANY POPULATION SUBGROUPS HAVE BEEN SPECIFIED.)
      GO TO 9999
 9914 WRITE ( 3,9915) W1
 9915 FORMAT (1H /////25X,10HS.N.A.F.U.///25X,
     146HWEIGHTING SCHEME IS IMPROPERLY SPECIFIED.//25X,
     212HTHE INTEGER ,I2,28H DOES NOT EQUAL 0, 1, OR 2,//25X,
     328HOR W2=1 WHEN W1 IS NOT ZERO.)
      GO TO 9999
 9920 WRITE ( 3,9922) TNO(I)
      GO TO 9999
 9921 WRITE ( 3,9922) CTN(I)
 9922 FORMAT (1H /////25X,10HS.N.A.F.U.///25X,
```

```
     148HTHERE ARE REDUNDANT DATA CARDS FOR CENSUS TRACT ,F7.2,1H.)
      GO TO 9999
9923  WRITE ( 3,9925) TNO(I)
      GO TO 9999
9924  WRITE ( 3,9925) CTN(I)
9925  FORMAT (1H /////25X,10HS.N.A.F.U.///25X,
     150HEITHER TRACT OR BLOCK DATA CARDS ARE OUT OF ORDER.//25X,
     222HCHECK CARDS FOR TRACT ,F7.2,1H.)
      GO TO 9999
9930  WRITE (3,9932) CTN(I)
9932  FORMAT (1H /////25X,10HS.N.A.F.U.///25X,
     113HCENSUS TRACT ,F7.2,31H IS MISSING IN TRACT DATA DECK.)
      GO TO 9999
9999  CONTINUE
      STOP
      END
```

APPENDIX C

THE NECO PRETESTS DATA BASE: CONTENT AND TABULATION

Information can be biased, even in a perfectly implemented data collection procedure, by the method of tabulation. In the NECO Minibus experiment, tabulation problems were compounded by the open nature of the questionnaire, which allowed substantial latitude in the number and detail of trips recorded. This diversity had to be captured by the eight variables listed in Table C-1. Three aspects of the tabulation problem — interpretation, quality control, and ease of manipulation — are now considered in turn.

Successful interpretation requires a valid transformation of information on the questionnaire into variables. By asking the somewhat redundant questions of where the respondent went, why, and where was the destination located, the purposes and destinations of most recorded trips could be determined. This required classification of trip purposes and destinations beforehand. These classifications are listed in Tables C-2 and C-3 respectively.[1] Major trip purpose categories used in Chapter 6 are easily aggregated from

---

[1] Multi-purpose trips are captured by the undifferentiated categories in Table C-2.

Table C-2.[2] During tabulation, the destinations had to be reclassified, adding a substantial amount of time in recoding questionnaires.[3] Interpretation of the first question (how many members of the household are elderly, handicapped, or both) was far less successful. In many instances, the same number was repeated for all three categories, suggesting either of two interpretations:

1. "X" number of elderly, "X" number of handicapped, and "X" number of persons both elderly and handicapped live in the household for a total of "3X" persons; or
2. "X" number of persons are both elderly and handicapped and zero persons fall into the other categories.

In other instances, check marks rather than numbers were entered in the appropriate spaces. For this reason, variables three through five in Table C-1 cannot be used with complete confidence. All remaining variables can be used with confidence, particularly since only one person coded the questionnaires. This reduced the possibility of conflicting interpretations.

---

[2] The major categories include all retail trips (categories 1+2+2a +2b in Table C-2), trips for medical services (categories 3+3a+ 3b+3c), trips for services other than medical (the sum of categories 4 through 4f), and social-recreational trips (the sum of categories 5 through 5g).

[3] It should be noted that a thorough, personal knowledge of the region was necessary to classify and identify destinations. While any literate person could tabulate the other variables, this requisite geographic knowledge limited the availability of coders and increased the time needed for tabulation.

Even if the questionnaires are interpreted consistently and accurately, quality controls are necessary to catch improper transformations of the data. This was accomplished by two means. First, two persons compared the data coding-sheets with a printout of the data once it was put in machine-readable form. Second, several consistency checks were made between different computer programs utilizing the same data base for similar purposes. Consistency checks are specifically built into CENSAM, the program listed in Appendix B to select the sample blocks from the study area.

The third consideration in tabulating data is the ease of manipulating the resulting data files. The fullest detail which can be tabulated increases more than coding time; it requires more complicated and expensive computer programs to extract and manipulate the data. This problem is greatly magnified by the variable lengths of the questionnaire responses. Only after the original file was reorganized by trip rather than by household could trip generation rates and L-factors be calculated for Chapter 6 with relative ease.

TABLE C-1

VARIABLES TABULATED FROM NECO QUESTIONNAIRE

FOR EACH RESPONDING HOUSEHOLD

1. Unique questionnaire identification number
2. Date of the questionnaire's return
3. Number of elderly (over age 60) persons in household
4. Number of handicapped persons in household
5. Number of persons both elderly and handicapped in household
6. Type of residence (single-family house, apartment in house, apartment in apartment building)
7. Cartesian coordinate of residence

FOR EACH RECORDED TRIP

8. Trip purpose
9. Trip frequency
10. Cartesian coordinate of destination
11. Trip length in opportunity distance, rectilinear distance, and Euclidean distance
12. Mode used to reach destination
13. Mode used to return from destination
14. Duration of stay at destination
15. Problems hindering travel

TABLE C-2

CLASSIFICATION OF TRIPS RECORDED ON NECO QUESTIONNAIRES

The following purposes are divided between trips actually taken and trips which are desired but not taken:

1. Undifferentiated social and retail trips
2. Undifferentiated retail trips
    a. Low-order retail trips
    b. High-order retail trips
3. Undifferentiated trips for medical services
    a. Trips to the doctor
    b. Trips to the dentist
    c. Trips for rehabilitation therapy
4. Undifferentiated trips for nonmedical services
    a. Personal business trips (bank, etc.)
    b. Trips for public assistance
    c. Trips to the library
    d. Trips to the Eating Together program
    e. Trips to the hairdresser or barber
    f. Trips to a restuarant
5. Undifferentiated social-recreational trips
    a. Trips to church
    b. Trips to club meetings
    c. Trips to athletic events
    d. Trips to movies
    e. Trips to visit friends and relatives
    f. Tours and sightseeing trips
    g. Trips to museums
6. School trips
7. Work trips

TABLE C-3

CLASSIFICATION OF DESTINATIONS FOR CODING

NECO QUESTIONNAIRE RESPONSES

1. Loch Raven at Northern Parkway
2. Belvedere Gardens on Hillen Road
3. Alameda Shopping Center
4. Coldspring at Loch Raven
5. Northwood Shopping Center
6. Crestlyn West of Vets Hospital
7. Old York Road above 39th Street
8. Waverly Greenmount and 33rd Street
9. Rex York Road at Coldspring Lane
10. Homeland York and Woodbourne
11. Govans York Road at Bellona Avenue
12. York Road and Belvedere
13. York Road from Northern Parkway to City Line
14. Southern Towson York below T S C
15. Central Towson York and Joppa
16. Eudowood Shopping Center
17. Baynesville Loch Raven and Joppa
18. Loch Raven and Taylor
19. Idlewyld Alameda and County Line
20. Perring Parkway Shopping Center
21. Northern Parkway and McClean Boulevard
22. Hamilton at Harford Road
23. Homewood St. Paul at 31st Street
24. Hampden Roland and 36th Street
25. Cross Keys Village
28. Greater Baltimore Medical Center
29. Loch Raven Btwn Belvedere Woodbourne
30. Downtown Baltimore General
31. Downtown Baltimore Retail District
32. Lexington Market
33. Waxter Center
40. Census Tract 901 in NECO
41. Census Tract 902 in NECO
42. Census Tract 903 in NECO
43. Census Tract 2708 01 in NECO
44. Census Tract 2708 02 in NECO
45. Census Tract 2708 03 in NECO
46. Census Tract 2708 04 in NECO

TABLE C-3

CLASSIFICATION OF DESTINATIONS FOR CODING NECO QUESTIONNAIRE RESPONSES (Continued)

47. Census Tract 2708 05 in NECO
48. Census Tract 2709 01 in.NECO
49. Census Tract 2709 02 in NECO
50. Census Tract 2709 03 in NECO
51. Census Tract 2710 in NECO
52. Census Tract 905 Not in NECO
53. Census Tract 906 Not in NECO
54. Census Tract 1201 Not in NECO
55. Census Tract 1202 Not in NECO
56. Census Tract 2702 Not in NECO
57. Census Tract 2703 01 Not in NECO
58. Census Tract 2706 Not in NECO
59. Census Tract 2707 01 Not in NECO
60. Census Tract 2707 02 Not in NECO
61. Census Tract 2711 Not in NECO
62. Census Tract 2712 Not in NECO
63. Census Tract 4906 01 Not in NECO
64. Census Tract 4906 02 Not in NECO
65. Census Tract 4910 Not in NECO
66. Census Tract 4911 Not in NECO
67. Census Tract 4913 Not in NECO
68. Census Tract 4914 Not in NECO
70. Roland Park RPD 103
71. Clifton RPD 112
72. Midtown Tracts Between Homewood and CBD
74. Northwest Baltimore from I83 to I170
75. Northern Baltimore Beyond I695 E of I83
76. Eastern Baltimore North of Herring Run
77. Eastern Baltimore South of Herring Run
78. Southern Baltimore South of I170 CBD I83
90. Within 100 meters of origin
91. Within 500 meters of origin
98. Variable within Baltimore region
99. Destination Unknown

APPENDIX D

EXPECTED FREQUENCIES PROGRAM

The following program calculates expected frequencies over intervals of the cumulative density function of an exponential probability distribution. The program is designed for any calculator which uses Reverse Polish Notation and has a four-stack register plus at least one addressable memory. (The particular calculator used in the present study was a Hewlett-Packard 21.) Notation is as follows:

EF_i = expected frequency of interval i
UB_i = upper bound of interval i
LB_i = lower bound of interval i
β = single parameter of the exponential distribution
STO = memory store key
RCL = memory recall key
CHS = change sign (+/-) key
CLR = clear register key
↑ = enter data key
R↓ = roll down data registers key
* = multiplication key
\- = subtraction key
e^X = exponentiation key
X※Y = switch botton register key

The computational formula is:

$$EF_i = e^{-\beta(LB_i)} - e^{-\beta(UB_i)} \qquad (\max i = n)$$

The program is as follows:

Line Number	Data to be Entered	Operations	Display	Remarks
1.	β	CHS STO CLR		If the first $LB_i \neq 0$, go to line 8.
2.	1	↑		
3.	UB_i	↑ ↑ RCL X⇄Y R↓		
4.		* e^x	$e^{-\beta(UB_i)}$	
5.		↑ ↑ R↓ R↓ −	EF_i	
6.		R↓		If $i<n$, go to line 3 If $i=n$ and $UB_n < \infty$, stop. Otherwise, go to line 7.
7.			EF_n	Stop.
8.	LB_i	↑ RCL * e^x	$e^{-(LB_1)}$	Go to line 3.

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