Guidelines for Network Representation of Transit Access, State-of-the-Practice Summary

June 1998

TMIP

Travel Model Improvement Program

Department of Transportation
Federal Highway Administration
Bureau of Transportation Statistics
Federal Transit Administration
Assistant Secretary for Transportation Analysis

Environmental Protection Agency

U.S. Department of Transportation

U.S. Environmental Protection Agency

Travel Model Improvements Program

The Department of Transportation, in cooperation with the Environmental Protection Agency and the Department of Energy, has embarked on a research program to respond to the requirements of the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991. This program addresses the linkage of transportation to air quality, energy, economic growth, land use and the overall quality of life. The program addresses both analytic tools and the integration of these tools into the planning process to better support decision makers. The program has the following objectives:

1. To increase the ability of existing travel forecasting procedures to respond to emerging issues including; environmental concerns, growth management, and lifestyles along with traditional transportation issues,

2. To redesign the travel forecasting process to reflect changes in behavior, to respond to greater information needs placed on the forecasting process and to take advantage of changes in data collection technology, and

3. To integrate the forecasting techniques into the decision making process, providing better understanding of the effects of transportation improvements and allowing decision makers in state governments, local governments, transit operators, metropolitan planning organizations and environmental agencies the capability of making improved transportation decisions.

This program was funded through the Travel Model Improvement Program.

Further information about the Travel Model Improvement Program may be obtained by writing to:

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GUIDELINES FOR NETWORK REPRESENTATION OF TRANSIT ACCESS, STATE-OF-THE-PRACTICE SUMMARY

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF EXHIBITS

LIST OF TABLES

INTRODUCTION

The practice of travel demand forecasting as it has evolved since 1950 assumes that many of the choices made by tripmakers are influenced by the difficulty associated with making a trip. The measure of difficulty is often referred to as the impedance. The impedance is almost always a function of travel time and may include monetary cost and other factors. The choices related to travel impedance are postulated to be choice of destination (trip distribution), choice of travel mode (mode choice) and choice of route (path choice or assignment). It has also been suggested that travel impedance may affect the choice to make a trip (trip generation) and the time-of-day at which a trip is made.

Determining the impedance for any possible travel choice involves creating a network -- a schematic representation of the travel facilities available; associating an impedance with each segment (link or, in some cases, node) of the network; finding reasonable paths through the network from trip origin points to trip destination points; summing the impedance on each link in a given path to determine the origin to destination impedance over that path, and in some methods allocating travel over a set of feasible paths to assess origin to destination impedance.

The resulting impedances and, hence, the impedance values used to estimate and apply travel demand models, depend directly on the network structures -- the ways in which real world transportation systems are represented for computational analysis.

The methods used for network representation have evolved in response to the needs of travel forecasting models. The first models required estimates of the travel time over the highway system between analysis areas (traffic analysis zones or TAZs). The highway system was assumed to be composed of only major facilities -- freeways, expressways and arterial roads. Travel time, the only element of the impedance function treated, was estimated from field studies for each link of the highway system. Access to the roadway system from a TAZ was represented by a "centroid connector" between the center of activity of a zone and the arterial road system. In some cases, all "centroid connectors" were assumed to have the same travel time; in other cases, a uniform speed, often 15 m.p.h., was assumed for all centroid connections. All components of travel time were treated equally (i.e. as having the same effect on travel choices). Since the purpose of centroid connectors was merely to connect the traffic generation point within a zone to the roadway network and since all roads were "equal", there was no need for great care in establishing centroid connections.

The introduction of public transit issues into travel demand forecasting created a need for more complex network representation. Not only did mode choice modeling require consistency in impedance representation between highway and transit travel, but research also showed that, for transit, not all travel times were equal. The impedance of time spent walking to a transit stop or transferring between vehicles was different from the impedance of time spent traveling in a vehicle. To obtain better representation of walking times, the "centroids' of TAZs were more carefully located and walking distances from centroids to transit stops were carefully measured.

This approach seemed to work reasonably well when traffic analysis zones were small and homogeneous. It soon became clear, however, that many areas required more complex treatment. Unlike auto travel, in which all locations have immediate access to a roadway, access to public transit can be quite different for portions of a large traffic analysis zone. For portions of a zone close to a transit stop, most travelers would walk to transit. For portions of a zone at a greater distance from a transit stop, few people will walk to a bus. These travelers would either face a far greater impedance or might choose a path that involved driving to a park-ride lot. The situation became even more complex when access to different transit modes (e.g. bus or rail) or access at different locations (e.g. stations, park-ride lots) was considered. Network representation strategies evolved that included subdividing zones, ether explicitly through rezoning, or implicitly through definition of the proportion of a zone within walking distance of transit. Subsequent practice has also included the treatment of transit access as a choice within a nested mode choice model structure.

The key issues are:

- The probability of walking to transit is not constant across a zone, varying significantly with distance from a transit stop.

- Individuals who drive to transit do not always choose the nearest parking location.

- Transit access characteristics can be quite different for different transit modes.

The choice of transit access mode is influenced not only by travel time, but also by factors related to traveler characteristics, trip purpose and available transit modes. These factors cannot be treated fully by network representation and must be incorporated in the broader travel choice modeling framework.

As a result, no single, simple representation of a "walk link" to transit can reflect the impedance perceived by residents of a traffic zone. The resulting simple mean access impedance will not correctly reflect the paths available or choices made by most of the travelers from a zone. More complex and more detailed strategies for network representation are required to reflect the impedances faced by individuals in different travel markets for the available transit modes. The procedures for representing access and egress from transit services must be considered as part of the overall travel modeling process and be fully coordinated with the specification of the model components. Some of these methods, developed and applied by analysts involved in transit planning and travel demand forecasting, are documented in this report. This report is not intended to describe procedures applicable in all situations, but to identify and document methods that have been found useful in prior experience.

STATEMENT OF THE PROBLEM

Access and Egress Characteristics in Demand Forecasting

Representation of access to and egress from transit services is used for at least three functions in travel demand forecasting:

- impedance determination
- path building
- assignment

Impedance determination involves establishing the time, and cost if appropriate, associated with access to or egress from the transit system that will be applied to trips originating from or terminating in a specific traffic analysis zone. The impedance may be the same for all trips to or from the zone or may be different for geographic subareas of the zone. Different impedances may be developed for access to or egress from transit services at different locations or for access to and egress from different transit modes.

The impedance determination is often developed from the network representation. Walk access and egress times are often computed from the length of the access/egress network links and a walking speed of 3 mph (4.8 km/hr). Park-ride access times may be computed based on length of the connection links or may be derived using the highway network and associated path building procedures.

Access/egress impedances, however, need not be related to network representation and can be determined in other ways. The procedures used by the Chicago Area Transportation Study use the network links only to establish connectivity. Access and egress times are based on zonal characteristics including size and development density.

Path building involves determining feasible and reasonable connections between the TAZ of interest and other locations that make use of various transit services or modes. The connection patterns, established by the access/egress links coded in the network or by other methods, determine what modes or service may be considered for travel to or from a TAZ. The path building process also determines at what points trips will access or egress transit services (e.g. bus stops, transit stations). For a given market segment in a TAZ, the path choices may be limited (e.g. access/egress from a single mode representing a bus stop served by a single route) or may be numerous (e.g. access/egress at several bus stops on different routes, a walk connection at a rail station, and park-ride at one of several transit stations).

Assignment is the process of allocating trips to appropriate paths for the specific market group. The results of the assignment process yield values used in analysis and design such as ridership by mode and route, boarding and alighting volumes at bus stops and rail stations, demand for park-ride spaces and similar factors.

The number of trips assigned to a specific path is typically determined in a mode choice process. In the simplest situation, all trips to or from a given TAZ will access and egress the transit system at a single point (stop) on a single route. In more complex situations, trips to or from a given TAZ will both walk and drive to reach the transit system and will make use of multiple bus stops served by different routes and one or more rail stations. The allocation of trips among the various paths may be determined by the path building process, by an access mode choice model, by a multipath assignment algorithm or a combination of methods.

Technical challenges to be addressed in developing a transit access representation method include:

- how to reflect the impedances perceived by different traveler market segments *within a traffic analysis zone;*

- how to reflect the path choices likely to be made by travelers with each market segment.

It is useful to consider some of the situations that may arise.

Case 1. Walking access from a small zone to a single bus line (Exhibit 1)

This is the simplest situation. The TAZ is bordered by a bus line and has a depth of only one-quarter mile from the bus line. Within one-quarter mile, most travelers will be willing to walk to a bus stop. Assume bus stops regularly spaced along the bus line and homogeneous development within the zone.

Case 2. Walking access from a larger zone to a single bus line (Exhibit 2)

In this case, the depth of the zone from the bus line exceeds one-quarter mile. Few travelers from the area beyond one-quarter mile will be willing to walk to a bus stop. The two *portions of the zone must be treated separately.*

Case 3. Walking access from a zone bordered by multiple bus routes (Exhibit 3)

Where the bus routes serve different destination areas and walking distances from the market areas to the different bus services are quite different, as in Case 3a, zone splitting is the only way to get a correct representation for all destination possibilities. Where the bus routes serve a common destination area and the market areas are similar, as in Case 3b, a single walk link can yield approximately correct impedances but assignment volumes will need careful analysis.

Exhibit 1. Walking Access from a Small Zone to a Single Bus Line

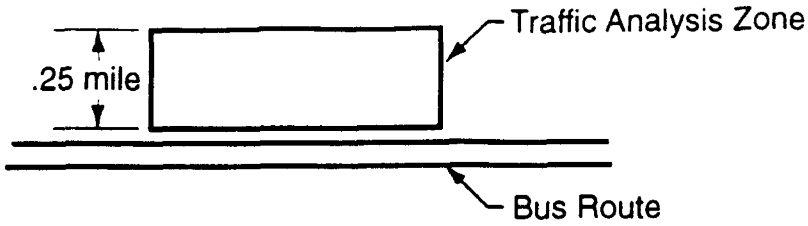


Exhibit 2. Walking Access from a Larger Zone to a Single Bus Line

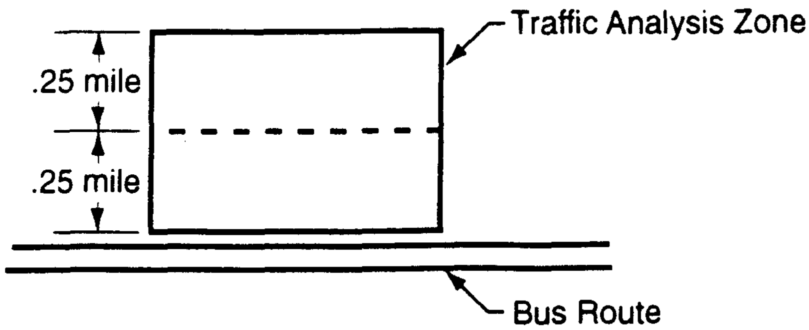


Exhibit 3. Walking Access from a Zone Bordered by Multiple Bus Lines

Exhibit 3a.

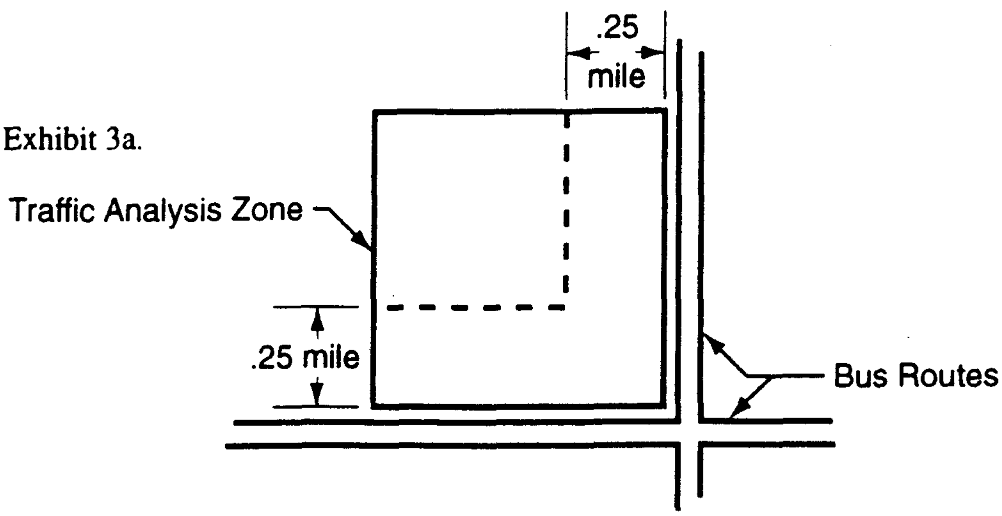
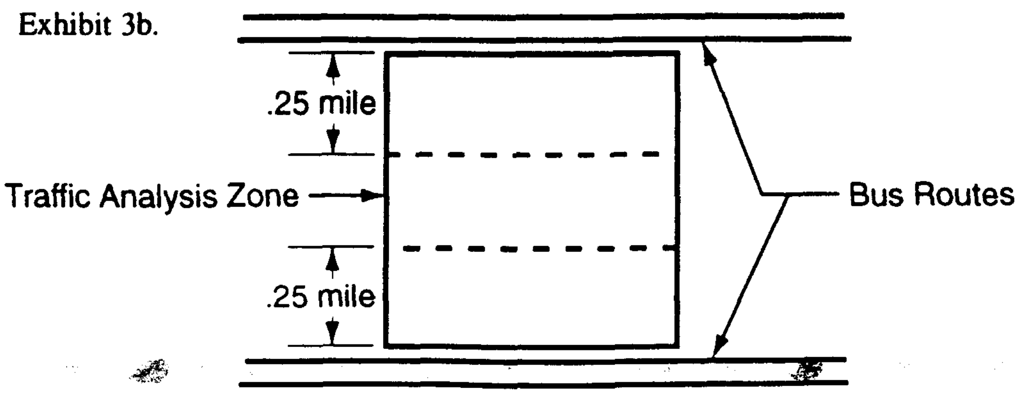


Exhibit 3b.



Case 4. Walking access from a zone to a bus route not adjacent (Exhibit 4)

This situation is quite common in Central Business Districts with TAZs as small as a single city block. The use of a "sidewalk" network representing available walking connections provides an effective method of access representation and helps to minimize overestimation of transit transfers.

Case 5. Access available to both bus and rail (Exhibit 5)

Case 5 illustrates three traffic analysis zones at varying distances from bus and rail service. The access options available to residents of these zones will vary depending on the distances of each zone from the bus and rail services. Residents of all three zones have park-ride as an access option to both rail and bus. Residents of zone 1 may walk to bus using the bus for an entire trip or for access to rail. Residents of zone 2 may walk to bus or rail. Residents of zone 3 would likely need to be driven to either bus or rail.

If the zones are properly sized (e.g. TAZ 2 about ½ mile on a side), these simple access choice stratifications may be appropriate. If the size of TAZ 2 is such that walking to bus and or rail is feasible, then an access choice model will be required.

Case 6. Walking access from a zone served by both bus and rail (Exhibit 6)

When a single zone served by both bus and rail is so large that it contains several distinct access market areas, explicit or implicit zone splitting combined with an access choice model can efficiently reflect the access choices in such areas.

Aggregation

The basic issue in network representation for travel demand forecasting is that most of the procedures in general practice use aggregated methods to estimate a disaggregate phenomenon. This is done for computational efficiency. A traffic analysis zone is an aggregate area. In fact, each individual making trips from a zone has different characteristics and faces a different travel impedance. A fully disaggregate method would consider each individual's characteristics and the impedances over the specific paths available to that individual.

When travel forecasting methods are applied at an aggregate (i.e. zonal) level, a single value is applied for all individuals included in the zone. A single income or auto ownership level may be assumed for everyone in the zone, although many models provide some disaggregation by assuming distributions of household characteristics. Similarly, a single access time may be considered for a zone. This single access time is chosen to be "representative" of the times appropriate for all individuals in the zone.

It can be shown that if the demand function applied is linear in time <u>and</u> if the demand density is uniform across the zone, then the arithmetic average time correctly represents the phenomenon being modeled. For example, in a distribution model of the form

Exhibit 4. Walking Access from a Zone to a Bus Route not Adjacent

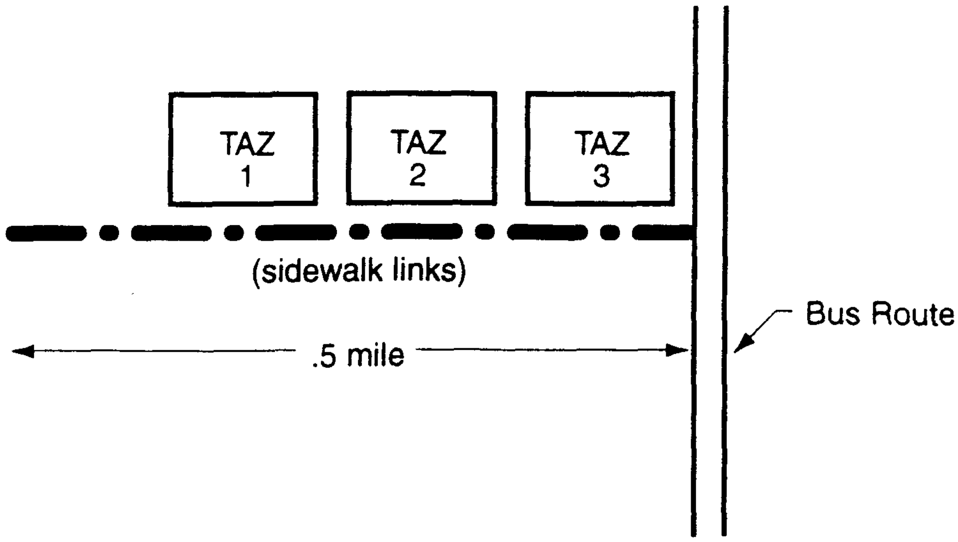


Exhibit 5. Access Available to Both Bus and Rail

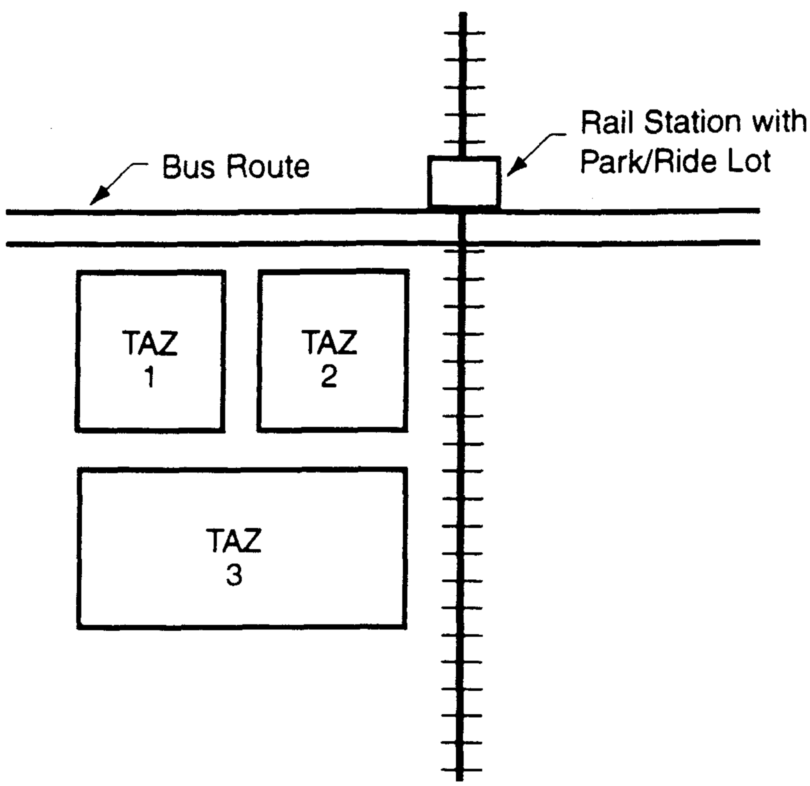
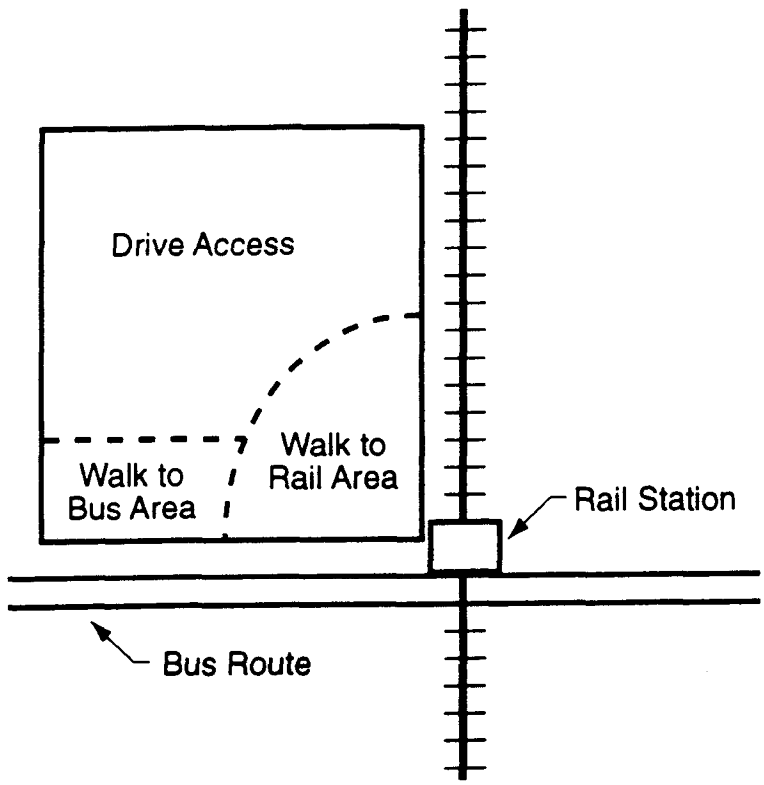


Exhibit 6. Walking Access from a Zone Served by Both Bus and Rail



$$\text{Trips(i-j)} = P_i * A_j * K(\text{access time} + \text{over-the-road time})$$

the use of the average zonal access time with aggregate zonal trip data would yield exactly the same demand estimate (i to j) as would a trip forecast derived by summing the estimated distribution of all individual trip makers in the zone if the stated conditions were met.

Neither the distribution models nor mode choice models in general use are based on functions that are linear in time. Use of a zonal average yields, at best, an approximation of the travel behavior that would be estimated using a truly disaggregate method. The discrepancy is minimized by keeping market areas geographically small, so that access time variations across the area are small, and by defining areas that have nearly uniform travel activity within the area.

The network coding procedures used represent attempts to define a value of a single zonal access time (T), such that

$$V * T = \text{SUM}\ [v_i * f(t_i)]$$

where:

V = aggregate zonal value of some parameter, say transit trips

v_i = individual values of the same parameter

t_i = individual values of access time

$f(t_i)$ = function of t_i used in the demand model

or:

$$T = \frac{\text{SUM}\ [v_i\ f(t_i)]}{V}$$

Since a single impedance value is a good approximation of the impedances perceived by all travelers in a zone in simple situations, improved representation of the access impedances in a complex situation can be achieved by subdividing the zone into several market areas. For each market area, a different simple representation is used, resulting in a better representation for the zone as a whole.

Analysts engaged in travel demand forecasting have developed a variety of approaches to more closely represent the time or impedance associated with the access choices available across a traffic analysis zone. These methods are used both to represent the access choice available to persons within different geographic portions of a zone, to associate proper access path/mode impedances with various market segments within a zone, and to allocate trips, in assignment, among multiple access points and transit modes.

ACCESS REPRESENTATION

Connection of Traffic Analysis Zones to Transit Stops

The connection between a traffic analysis zone and the network is made using links often referred to as "centroid connector links." These links connect the node representing the point of trip production or attraction to nodes representing bus stops, rail stations or other points of access to or egress from transit services. In most cases, an impedance is associated with centroid connectors that is interpreted as a measure of the time that would be spent by the average resident of the zone in walking to the transit stop. In procedures that compute access and egress impedance in other ways, the centroid connector serves only to establish network continuity.

Connections between a zone and the transit network should be provided to all "reasonable" access/egress options. The number of connector links, the transit stop nodes to which they are connected and the impedance associated with each connector link depend on several factors, including the size and shape of the zone, the distribution of development within the zone, the location of transit services and stops and the existence of topographic features that would affect access travel paths.

Centroid connection links may represent either walk access or auto access. The links may be manually coded or may be identified and coded using an automated procedure. Automated procedures not only reduce network coding effort, but also help to assure consistency in coding throughout any single network, between networks and between analysis years. Automatically generated connector links, however, should always be subject to manual review to assure logic and consistency.

Proper Definition of Access Times and Costs for Travelers at Different Distances from Transit Service

In theory, traffic analysis zones are intended to define areas that are generally homogeneous with respect to a variety of factors such as resident demographics, land uses, development patterns, travel behavior and access to the transportation system. In practice, true homogeneity is never achieved and there is variation in all measures — including the ease or difficulty of access to or egress from transit services.

Further, the access mode to transit also tends to vary across a zone, with persons close to a transit stop typically choosing to walk to and from the transit service while persons further from the stop will most likely choose to park-ride if that option is available. For zones that are geographically small, a single impedance value based on walking access can be a reasonable representation (e.g. no portion of the zone is more than one-third of a mile from a transit stop). Similarly, for zones that are at long distances from transit service (e.g. no portion of the zone closer than one mile from a bus stop), a single impedance based on auto access can be a reasonable representation.

It is generally agreed that travelers within close proximity to a transit route (i.e. within about 0.25 to 0.33 miles) will walk to the transit service and that travelers more than 1.0 miles from a transit service will drive to a park-ride location if they wish to use transit. Analysts differ on the treatment of travelers in the 0.3 to 1.0 mile distance from transit range. Many analysts believe that travelers will walk a greater distance to rail or other premium service (typically up to 0.5 miles). Other analysts provide a walking connection for travelers in the 0.3 to 1.0 mile from service area but assign greater impedance to the access connection or treat this market segment differently in mode choice analysis.

The consensus is that areas that are greater than 0.25 to 0.33 miles from transit service must be treated differently than areas close to a transit stop. This is achieved either by:

- Explicitly splitting zones to create two areas, one with walk access and one with drive or walk-to-local-bus access. This is often done when rail station locations are in or adjacent to a zone.

- Logically splitting the zone by determining the proportion of development in the zone that is within walking distance of transit and the proportion not within walking distance. The transit impedances for each market area are treated differently in mode choice.

Methods for Representing Times and Costs

- ***Simple Access Connection*** — One or more "centroid connector" links are used to connect each zone to nodes on the transit network (transit stops). Access impedance is taken to be the link travel time based on walking speed (typically 3 mph).

- ***Splitting of Zones*** — Available access or egress choices differ among geographic portions of a zone or a more precise representation of access choices and impedances can be achieved by splitting the zone into several parts, each of which is more homogeneous with respect to transit access and egress. A single zone might be split, for example, into a segment in which walk access predominates and a segment in which drive access predominates. If both rail and bus service are available, a zone might be split into a walk-to-bus area and a walk-to-rail area. The splitting of a zone can be accomplished in two ways — "physical" and "logical."

- ***Physical Splitting*** — This process involves restructuring of the planning traffic analysis zone structure, creating two or more new zones from one old zone. Since the new zone structure is used throughout all steps of the travel forecasting process, it is necessary to develop all data for each of the new zones (e.g. population, housing units, employment, parking costs, terminal times, etc.) and to restructure both the highway and the transit networks to include necessary nodes and connector links.

- ***Logical Splitting of Zones*** — Zones are treated in selected elements of the travel demand forecasting process as if they were made up of several components, but there is no actual splitting, i.e. no new zone numbers are created, no nodes or links are added to networks and neither demographic nor other data need be developed for the individual portions of the zones. In these procedures, the connection links from zone centroids to transit routes are used only to load the network for assignment purposes. The walk access "centroid connector "distance is not directly related to the transit access/egress time — those times are separately computed for logical subdivisions of each zone. The walk connector links serve only to define network connections for path building. For park-ride access, the access link distances may or may not be used in computing access times.

- **Binary split** — Each zone for which substantially different access/egress conditions exist for different geographic parts of the zone is logically treated as composed of two subzones. The split could be, and often is, based on areas within walking distance of a bus stop and areas beyond walking distance of a bus stop. Alternatively, the split might be based on areas within walking distance of a rail station and areas considered to be beyond walking distance to a rail station.

  In the former case (walk vs. non-walk), for each zone, the proportion of activity within walking distance of a transit line (typically 1/4 to 1/3 mile) is estimated. Two sets of transit paths may be built — one based on walk access paths and one based on park-ride paths — or it may be assumed that trips to or from locations outside the walk access area do not use transit. For simulation modeling activities in which transit access is used (e.g. mode choice) , each zone is treated, in analysis procedures, as if it had been split into two components. An estimate of trips produced in the zone for which walk access impedances apply is made by multiplying total trips by the proportion of activity within the transit walk buffer. Walk access path transit zone-to-zone impedances are used for computations related to this portion of the trips. The remainder of the trips are considered to be associated with locations beyond walking distance. Either park-ride impedances are applied or these trips are treated as "not served" by transit.

  In the case of access to rail vs. access to bus, the two sets of transit paths built would differ in that one set would permit direct walk access to rail stations and the other set would permit only walk access to bus stops. As illustrated in the next chapter, special coding techniques are often required to permit specialized, constrained path building.

  If this procedure is applied only to trip production zones, it results in two computations, rather than one, each time a computation is made involving each production zone. If the logical split of zones into walk and non-walk access areas is applied to both production and attraction zones, all computations must be applied four times for each zone-to-zone trip pair analyzed.

- **Multiple Split** (short-walk, long-walk, drive only) — In the procedures used by some analysts (c.f. Minneapolis-St. Paul in the next chapter), zones are logically divided into three areas — short walk, long walk and drive access only. The proportion of zonal activity must be estimated or quantified for each of the three areas and all zone-to-zone analysis must treat nine combinations per zone-to-zone pair.

Properly Reflecting Access Time and Cost to Different Modes

Travelers resident in a given zone will often have more than one transit mode available — usually local bus and rail or local bus and express bus. In studies of transit investment, the choices of travelers between two transit modes is frequently a major topic.

There are significant differences in the access conditions for local and "premium" modes. Typically, a local bus route traveling along or through a zone will have stops every 700 to 1,500 feet. In broad terms, the access impedance for all residents of the zone within the "walk-to-transit" market area will be the same and can be represented by a single access link or impedance.

Premium services (e.g. express bus on HOV lane or rail) typically serve a limited number of stations or stops, often with park-and-ride facilities. If the station is in or on the border of a zone, access by some residents will be by walking (often a longer walk than would be expected for local bus), or by driving.

The access conditions for premium services are different than for local bus and are far less uniform across the zone. At the very least, some type of geographic market stratification is essential to correctly reflect access impedance to premium services. This still leaves the question of representing the alternative access impedances available to travelers who have a choice of transit modes, determining the allocation of travelers between local and premium services and correctly representing transit impedance, including access, in the mode choice model.

Traditional path building procedures that find only a single "best" path for a given i-j movement cannot provide the needed information. Such path builders will select either the local access or premium access link or impedance depending on the minimum impedance for the overall i-j path. One approach that is used is to build, using standard procedures, several sets of transit paths for each i-j combination. This is done by artificially representing the travel time on one or the other of the modes as very high or very low, using the modal weighting factors available in all of the standard software packages. To find the best path using local bus, the analyst might weight all rail times by a factor of 5. This would tend to make the local bus path the "best" for all interchanges. Similarly, to find the best rail path, bus times could be increased by a factor of 5.0. The software packages permit summing and storing "real" times and impedances even if weighting factors are used.

The rail path will include the appropriate rail access impedances while the bus path will have the bus access impedances. These impedances can then be used in a sub-mode choice procedure to allocate transit trips among the transit modes.

A variant of this process used by the Chicago Area Transportation Study (CATS) determines rail and bus access impedances exogenously and adds them to the appropriate transit path times.

At least one software package permits developing multiple "reasonable" transit paths and impedances for each I-j pair.

Estimating the Proportion of Transit Riders Who Will Access Transit in Different Ways

If geographically-defined market areas were segregated and independent, the access choices could be assessed simply by identifying trips from each market segment with each area. For example, all trips originating from locations in a rail station walk-shed would be allocated to walk-to-rail; trips originating in the bus-stop shed would be allocated to walk-to-bus with the determination of whether a particular trip also went to a rail station considered in the path builder; all other trips would be assumed to use auto-access (i.e. park-and-ride). In fact, many studies have been done using such simplifying assumptions.

In practice, however, market areas do exhibit overlap. Travelers who can walk-to-local bus can also drive-to-rail. For these market groups, some type of choice model is required to correctly reflect access options.

The choices presented to a traveler (except in the most simple situations) include not simply whether or not to use transit, but if transit is used, the transit route or mode to use, the transit stop to use and the mode (walk or auto) to use to access the transit system. Each of these choices would yield a different travel impedance. The choice is influenced by many factors including the difficulty in traveling to a given transit stop, the ultimate trip destination, the quality of transit service available at each access point and, for park-ride trips, the availability and cost of parking at the access location.

The zone-to-zone transit impedance perceived by travelers in a given market segment reflects all of these factors and is some function of the impedance of each of the choices considered by a traveler. The methods used to account for or represent these several choices include:

- ***Single access for entire zone*** — All travelers within a zone are assumed to use a single access mode — typically as represented by one-or-more centroid connector links that represent either walk access to a transit line operating through or near the zone or drive access to, typically, a single park-ride lot. This representation can be reasonable where zones are small (e.g. not more than about ½ mile on a side) and transit is either clearly available or clearly not available.

- ***All-or-nothing by market segment*** — Transit access is considered to be identical for all travelers in a market segment and to connect to the transit system at a single point for all trip paths for a given i-j combination for members of that segment. For example, all travelers in the walk access area are assumed to walk to transit so that all choice decisions for this segment are based on walk access impedances. All travelers not in the walk access area are assumed to park-ride with park-ride path impedances applied to all choices.

- ***Multiple paths*** — Separate transit paths are built representing multiple choices of access mode and/or travel mode available to each market segment. This is achieved in path building by applying weighting factors to the transit travel times of specific link types (i.e. modes) so that the resulting paths are the "best" available for the access or travel mode being considered. For example, two sets of paths might be constructed for a given zone — one representing the "best" transit path involving walk access and another representing the "best" transit path involving park-ride access. Alternatively, paths could be built reflecting the "best" path in which rail is used for a trip and the "best" in which rail is not used.

More complex combinations can also be developed (e.g. best walk-access-to-bus path, best drive-access-to-bus path, best walk-access-to-rail path).

The allocation of trips among the competing transit paths can then be addressed either through a separate sub-mode choice model or, more commonly, as choices within a nest level in a nested logit mode choice mode.

Creating multiple transit impedance matrices takes added time and requires careful record keeping to keep track of multiple files and the factors used when the files were created. Multiple path combinations should be developed only if supported by or required by the travel forecasting model.

Structuring Networks to Permit Determination of Access Mode Volumes

The number of persons accessing a transit station by various modes can be a key factor in station design. Access mode volumes affect layout of walkways, specifications for bus bays and parking lot design.

For determining path impedances, it is possible to represent a transit station with a single node that also serves as the bus line node for the station, the walk connector termination and the park-ride connector termination. This coding scheme could properly reflect all the possible mode change connections but would not permit the analyst to identify modal approach volumes or to prohibit illogical connections.

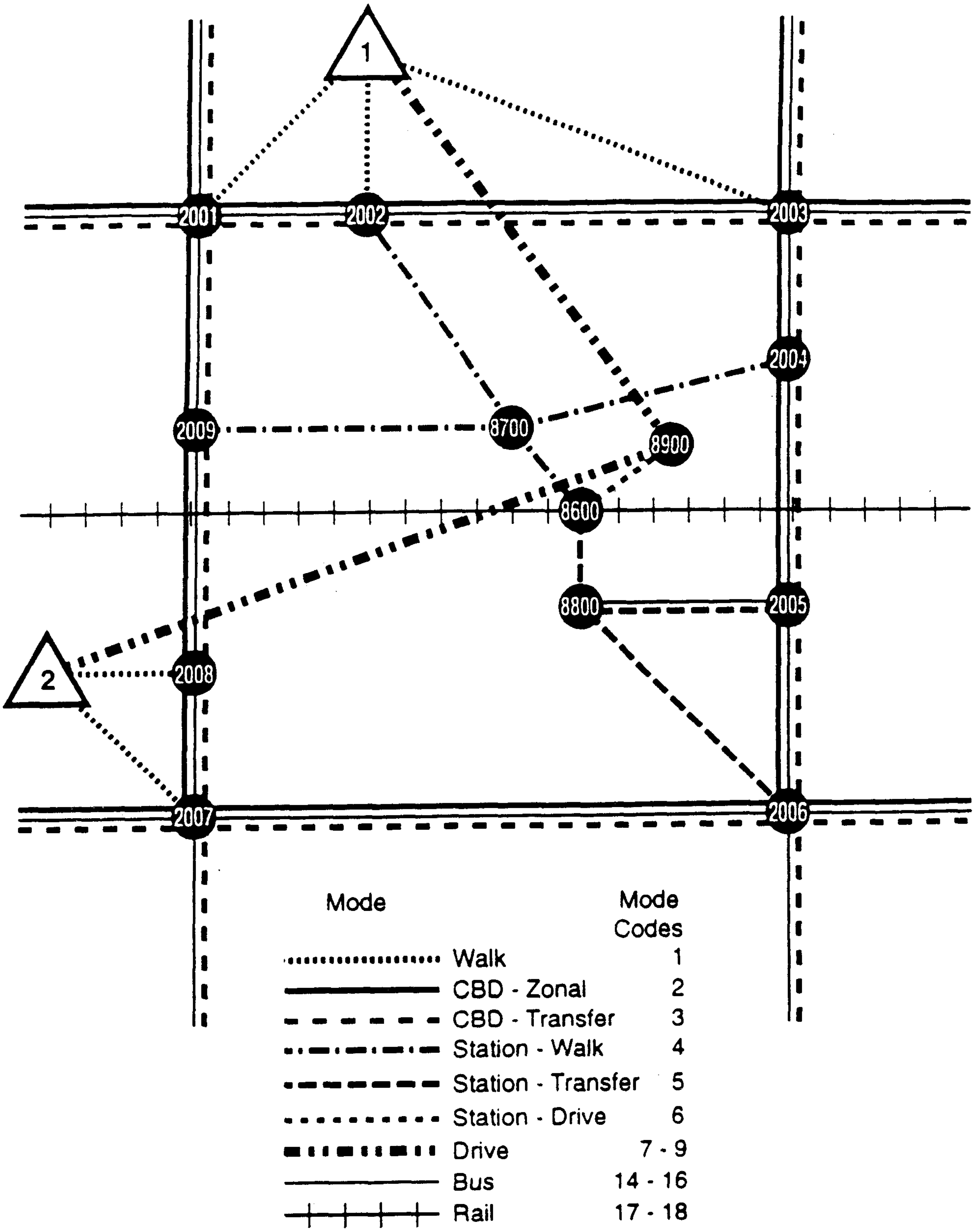
To avoid this problem, more complex coding schemes for complex areas such as transit stations have been developed. Exhibit 7, taken from *Service and Patronage Forecasting Methodology, Second Draft, June 1994* prepared for the Greater Cleveland Regional Transit Authority, illustrates such a coding scheme.

This coding scheme is designed not only to permit proper representation of access/ egress times for several modes, but also to permit assessing penalty times to specific transfer activities and to facilitate analysis of transfer movements following assignment of trips to the transit network.

Two traffic analysis zones, 1 and 2 (with centroids illustrated by the triangular symbol), are shown, along with a rail station (node 8600), bus routes on each major street, and various connecting links. Zones 1 and 2 each have direct walk access to bus routes operating along major streets (e.g. links 2-2008 and 1-2001).

The rail station at node 8600 is provided with three access/egress connections — 8600-8700 for direct walk on/off, 8600-8900 for drive access and 8600-8800 for transfers to and from bus routes. Drive access links from zones 1 and 2 connect to node 8900. Penalties

Exhibit 7 Coding Conventions for Rail Stations used in Cleveland Dual Hub Corridor Study



Source: Greater Cleveland Regional Transit Authority associated with drive access can then be represented as a "time" on 8900-8600. Walk access from zone 1 is represented by a series of links: 1-2002, 2002-8700, 8700-8600. Zone 2 is too far from the station to permit direct walk access, but indirect access is permitted via a local "sidewalk" network with the path 2-2008 walk from zone, 2008-2009 on the sidewalk network, 2009-8700 walk access to station and 8700-8600 walk-to-rail link. Finally, transfers to and from bus lines are accommodated via 2005-8800 and 2006-8800 to 8800-8600, the link that permits "counting" of bus rail transfers.

By restricting mode-to-mode movements (e.g. a "transfer" from a mode 4-station walk link to a mode 5-station transfer link is prohibited), illogical movements are prevented, but all possible access options can be represented, all path options can be analyzed and all movements can be isolated for tabulation.

Neighborhood Structure Issues

It has been suggested that the detailed arrangement of land uses in a zone and the provision of facilities to accommodate access to transit affect both the real and perceived transit access impedance. To account for these effects, some travel forecasting procedures have attempted to reflect detailed land use features in market definition and/or mode share analysis.

Use of GIS to Define Market Areas

Typically, it has been assumed that trips by persons within relatively short access distances to transit will walk to a transit stop. The distances used to define these market areas are generally 0.25 to 0.33 miles for bus lines and 0.5 miles or more for rail stations. General practice has been to define all areas with the set distance (say 0.25 miles) of a bus line or a radius distance (say 0.5 miles) of a rail station as being in the walkshed.

Use of a simple buffer distance or radius is, however, not a correct representation of actual walking distances. In many suburban areas, the auto oriented street patterns, often combined with walls along arterial or collector streets, greatly increase walking distances to bus stops. A traveler whose home is 0.15 miles from a bus stop may have to walk 0.5 miles over the existing roadway or sidewalk network to reach the bus stop.

In one reported study (Bakersfield, CA), a Geographic Information System (GIS) with the ability to define "over-the-network" distances was used to estimate transit walksheds. The analysts report that this yields substantially smaller walk-to-transit market proportion estimates than conventional buffering techniques.

Use of GIS methods should support better definition of walk market areas and will permit analysts to directly address the effects on transit ridership of urban design actions that improve walking access.

Inclusion of Zonal Access Condition Factors in a Mode Choice Model

The Maryland National Capital Park and Planning Commission in 1987 developed a mode choice model that attempted to capture the "pedestrian friendliness" of traffic zones.

Measures considered ratio of sidewalk miles to street centerline miles, a direct measure of the availability of pedestrian ways and a "pedestrian friendliness index (PFI)."

The PFI for each traffic zone reflected the availability of sidewalks, bicycle paths and bus stop shelters, the extent of building setbacks and the mix of street level land uses. Analyst Michael Replogle reported that this index was found to be "highly statistically significant" in explaining variation in mode choice.

In work done for the Chicago Area Transportation Study, the measure "census blocks per square mile" was tested as a surrogate measure of street density and connectedness for use in a mode share model.

It has been hypothesized that the small area organization and structure of a neighborhood can affect many aspects of travel behavior. Proponents of alternative development styles (e.g. Pedestrian Pockets, Traditional Neighborhood Development, The New Urbanism) argue that a greater mixing of land uses that increases the proximity of employment opportunities and retail services to residential properties can affect both trip distribution (destination choice), and mode choice (transit, bike or walking vs. auto use). It is also argued that street systems offering greater connectivity than is found in conventional suburban developments, combined with the provision of pedestrian amenities, can affect mode choice and path choice. A few, limited empirical studies support some of these claims, while other studies suggest little or no effect. Several agencies have constructed travel demand models that incorporate neighborhood structure variables in mode choice models.

The Maryland National Capital Park and Planning Commission developed a logit structure mode choice model in 1982 that included a Pedestrian and Bicycle Friendliness Index (PFI) as a variable in the utility function. The index — one value for each traffic zone — related to such factors as the availability of sidewalks, bus stop shelters and the extent of building setbacks. Although the index values were not developed using vigorous quantitative measurements — each area was rated by an "eyeball" survey — the index was found to be statistically significant, explaining variations in transit mode share not accounted for in model structures that used only time and cost variables.

The METRO planning agency in Portland, Oregon developed for each analysis area a pedestrian environment factor (PEF) that reflected factors such as sidewalk continuity, ease of street crossings, topography and grid vs. cul-de-sac streets. It is reported that the pedestrian environment factor proved to be strongly related to auto ownership and, therefore, an important factor in modeling transit choice.

The Sacramento Area Council of Governments (SACOG) has also developed travel demand models, based on the work done in Portland, that include a pedestrian environment factor.

To date, rigorous quantitative measures have not been developed to reflect pedestrian access conditions in system representation. Factors reflecting "pedestrian friendliness" have, in most cases, been subjectively assessed using general guidelines reflecting path conditions (e.g. sidewalk availability) and neighborhood layout (e.g. building proximity to the street). With the growing availability of GIS systems, quantitative measures (e.g. ratio of sidewalk miles to street centerline miles) have been considered. Further work on developing neighborhood attribute measures and quantifying these measures for use in transit choice models may be expected over the next few years.

Access Representation Consistency

The manner in which access to and egress from transit services are represented in the networks affects directly both choices considered in the travel simulation process and the impedances used in evaluating mode and path choices. As with all parts of the travel forecasting process, consistency between years and between alternatives is essential if the results of the process are to reflect true differences in travel behavior and not just artifacts of the network coding process.

The market segment definitions and impedance calculations applied in a base year are reflected in the values estimated for components of mode choice and other models. Changing the coding procedures or market definitions for future years means that the estimated coefficients and constants used in the models do not apply. Similarly, if coding conventions are not applied consistently among alternatives, differences in travel behavior resulting from true quality-of-service differences can be masked by changes arising in network coding. For these reasons, it is useful to fully document the coding conventions used in model development and to develop standardized, or even automated, network coding procedures.

RECOMMENDED PRACTICE

As illustrated above, the issues involved in representing access to and egress from transit services can become quite complex. The analyst must consider questions related to connectivity, impedances perceived by potential transit riders and the ways projected passengers loadings are allocated to stops and services. Existing network analysis and mode choice procedures coupled with the ingenuity of analysts offer the possibility for quite precise representation of transit access. Achieving precision, however, comes at a price in both the labor required to develop networks, zone systems and demographic data and in the computer time required to process data.

The methods and techniques that are appropriate depend on the nature of the analyses being conducted and on the use of resulting forecasts. In a small metropolitan area, transit demand forecasts may be developed primarily to assess reductions in highway traffic and the general level of bus service required. In a large metropolitan area, the transit demand forecasts may be used in evaluation of transit capital projects and in design of facilities. The latter studies merit both greater time and effort while the sophisticated procedures that would be used in a Major Investment Study would be excessive for analysis of small city transit service.

Based on the review of current practices prevailing in 1996, the following procedures are suggested.

Single Mode Transit System in a Small City; Little or No Park-ride Activity

In most cases, use of centroid-to-bus-route access links (one or more depending on transit service availability) will give a representation of transit access paths and impedances suitable for most purposes. Analyses conducted using this method could include analysis of transit paths, analysis of the effects of changes in route frequency and estimation of the effects of transit service on projected highway volumes.

If zones are large, say over one mile on a side, or if the analyst wishes to consider alternative routing structures, some type of logical stratification of zones into separate geographic market areas may be needed.

Single Mode Transit System with Park-Ride Opportunities

Consideration of both walk access and drive access paths will be required. Geographic market stratification of zones, either logically or by physical splitting of zones, is suggested. Building of multiple paths and use of a transit access mode allocation procedure may be required.

Larger Cities, Multi-modal Systems, MIS Studies

Detailed methods for representing transit mode-of-access and for allocating transit trips among the transit modes and access choices is called for. The current practice suggests careful geographic market segmentation and separation of analysis of access mode from over-the-transit system paths as is done in San Diego, Chicago and the Dulles Corridor. The choice of access mode (and access location, if appropriate) should be treated as a choice decision in the mode choice model. This is typically done in a lower nest level in a nested-logit structure model.

In the Statement of the Problem, several cases were presented illustrating access representation issues that may arise. Table 1 summarizes a suggested approach, consistent with current practice, for dealing with each case under different conditions.

(Table 1, 3 pages, follows.)

TABLE 1

Summary of Recommended Practice

Small City ***Little Park-Ride*** ***No Rail or Express Bus***		**Impedance Determination**	**Path Building**	**Assignment**
Case 1 -	Small Zone, Single Bus Line	Single access link. Based on walk link distance	Single path for each i-j	All-or-nothing
Case 2 -	Large Zone, Single Bus Line	Multiple access links. Logically split zone into walk access and no access areas. Base impedance on average walk distance for each walk area. Treat "no access" area as disconnected.	As above	As Above
Case 3 -	Walk access to multiple bus routes	Multiple access links. Logically split zone into walk access and no access areas. Access link from walk areas to each bus route with impedance based on average walk time for the area within one-fourth mile of any bus route (about 2.5 minutes). Treat "no access" area as disconnected.	As above	As above
Case 4 -	Walk to bus routes not adjacent	Walk links connect to "sidewalk" links for zones within a reasonable distance of the bus line (about one-half mile).	As above	As above
Case 5 -	Access available to both bus and rail	*Not applicable*		
Case 6 -	Walking access to both bus and rail	*Not applicable*		

TABLE 1 (Continued)

Mid-Size City Some Park-Ride No Rail or Express Bus		**Impedance Determination**	**Path Building**	**Assignment**
Case 1 -	Small Zone, Single Bus Line	Base impedance on average walk distance.	Single path for each i-j	All-or-nothing
Case 2 -	Large Zone, Single Bus Line	Logically split zone into walk access and park-ride access areas. Base impedance for walk area on average walk distance. Base impedance for park-ride area on park-ride link time or over-the-road time from highway network	Build separate walk and park-ride paths	Allocate trips based on proportion of activity in walk and park-ride access area or use access choice model.
Case 3 -	Walk access to multiple bus routes	Access links from walk areas to each bus route. Logically split zone into walk access and park-ride access areas. Base impedance for walk area on average walk distance. Base impedance for park-ride area on park-ride link time or over-the-road time from highway network	As above	As above
Case 4 -	Walk to bus routes not adjacent	Walk links connect to "sidewalk" links for zones within a reasonable distance of a bus route.	As above	As above
Case 5 -	Access available to both bus and rail	*Not applicable*		
Case 6 -	Walking access to both bus and rail	*Not applicable*		

TABLE 1 (Concluded)

Larger City Park-Ride Rail or Express Bus	Impedance Determination	Path Building	Assignment
Case 1 - Small Zone, Single Bus Line	Base impedance on average walk distance or neighborhood characteristics. If zone is in rail or express bus park-ride influence area also provide park-ride connections.	Build both walk access and park-ride access paths.	Use mode-of-access choice model and station/park-ride location choice model if appropriate
Case 2 - Large Zone, Single Bus Line	Logically split zone into walk access and park-ride access areas. Base impedance for walk area on average walk distance or neighborhood characteristics. Base impedance for park-ride area on park-ride link time or over-the-road time from highway network	Build separate walk and park-ride paths	Allocate trips based on proportion of activity in walk and park-ride access area or use access choice model.
Case 3 - Walk access to multiple bus routes	Access links from walk areas to each bus route. Logically split zone into walk access and park-ride access areas. Base impedance for walk area on average walk distance. Base impedance for park-ride area on park-ride link time or over-the-road time from highway network	As above	As above
Case 4 - Walk to bus routes not adjacent	Walk links connect to "sidewalk" network for zones within a reasonable distance of a bus route.	As above	As above
Case 5 - Access available to both bus and rail	Code walk links to bus or rail as appropriate. If zones are small "sidewalk" links connecting to rail station may be appropriate	Build separate paths for access to bus and access to rail. These will probably include walk-to-bus, walk-to-rail and park-ride.	Use transit sub-mode choice model, mode-of-access choice model and station/ park-ride location choice model if appropriate
Case 6 - Walking access to both bus and rail	Logically or physically split zone into walk-to-bus, walk-to-rail access and park-ride access areas. Base impedance for walk areas on average walk distance to rail and bus, respectively, or on neighborhood characteristics. Base impedance to park-ride on over-the-road time from highway network	As above	As above

APPENDIX A

METHODS USED TO REPRESENT ACCESS TO TRANSIT

Analysts faced with developing procedures for forecasting transit demand in situations where multiple choices are possible have developed creative methods both to assess the impedances of various transit choices and to efficiently process relevant data. The materials contained in this Appendix describe several of these methods. These are drawn from larger metropolitan areas, since it is in these larger areas that situations involving choices of transit mode or path typically arise.

The procedures developed for Minneapolis-St. Paul illustrate the logical subdivision of traffic analysis zones into areas having different transit access choices. The North Central Texas COG methods illustrate the use of automated procedures to define transit access links and impedances by market segment. The San Diego methods illustrate an innovative use of Geographic Information Systems (GIS) to store and manipulate data and to determine appropriate access impedances. The Pittsburgh model set illustrates the use of a nested mode choice model to allocate trips among several access modes. The Sacramento discussion relates to treatment of markets where access to either bus or rail would be a logical choice. The Chicago Area Transportation Study method for determining access impedance not only uses area characteristics rather than link distances to determine impedance, but also uses simulation techniques to assess disaggregate impedance values in model applications. The procedures of the Puget Sound Regional Council illustrate the use of matrix convolution to efficiently obtain impedance values where many path choices must be considered. The Dulles Airport Corridor Model illustrates the separation of access impedance analysis from i-j path determination in conjunction with the use of matrix convolution methods to obtain zone to zone impedances for multiple path possibilities.

MINNEAPOLIS-ST. PAUL (MPO)

In 1993, the Minnesota Department of Transportation, in conjunction with the Hennepin County Regional Railroad Authority and the Ramsey County Regional Railroad Authority, were conducting an Alternatives Analysis for the Central Corridor connecting Minneapolis and St. Paul. The procedures developed for these studies were intended for use in assessing differences between transit technologies and route alignments. In these procedures, choice of access mode was treated in a nested-logit model, with aggregation of access impedance by mode achieved using a logsum term.

Access coding in the procedures used for transit supply analysis in the Minneapolis-St. Paul region relied on access-market segmentation to reflect the differences in transit access and egress impedance. Traffic analysis zones were divided into three market areas based on the proximity of portions of each zone to a transit route. The three segments were:

- Short walk to transit -- the portion of a TAZ within one-third mile of a transit route.

- Long walk to transit -- the portion of a TAZ between one-third mile and one mile of a transit route.

- Drive access only -- the portion of a TAZ more than one mile from a transit route.

The proportion of each zone in each market area was determined by measurement and stored in a file. These data are used in the mode choice model.

Each market segment was treated separately in the mode choice model. Where walk access was a possibility (i.e. for portions of zones within one mile of a transit route), walking was considered to be an available option for both trips produced in the zone and trips attracted to the zone. Trips produced in portions of a zone more than one mile from a transit route are presumed to have a "drive-to-transit" option available. Trips attracted to portions of a zone more than one mile from a transit route are considered not to have a transit option.

Walk to Transit Links

Every zone that has at least some portion of its area within one mile of a transit route is given at least one walk access link. More walk access links may be provided if dictated by the structure of the transit network. The structure of the mode choice model requires that all access/egress links from a given zone be coded with the same estimated walk time.

Walk times are assumed to be 20 minutes per mile (3 mph). The access time assigned to a walk link is determined by applying the assumed speed to an estimate of the average access distance.

Drive to Transit Links

All zones, except CBD zones and zones more than fifteen miles from a transit route, are provided with a drive access link. These links are connected to formal or informal park-ride lots, if possible, or, if not possible, to a CBD oriented transit route. Travel time is based on the straight line distance of the drive access link and a speed of 15 mph.

Access Mode

The access mode used (e.g. walk or drive) for trips produced in portions of a zone in which both options are possible, is treated as choice within a nested logit based mode choice model. The combined impedance to the walk and drive access choices to the primary auto-transit level of the mode choice model is represented using the logsum term with a nesting coefficient of 0.30.

$$\text{Transit Utility} = 0.30 * \{-\ln[\exp(\text{walk utility}) + \exp(\text{drive utility})]\}$$

Source: Parsons, Brinckerhoff, Quade & Douglas, Inc. *Methods and Assumptions for Travel Forecasting, Central Corridor Alternatives Analysis*, January 5, 1993.

NORTH CENTRAL TEXAS COG

The mode choice model applied by the North Central Texas Council of Governments (NCTCOG) for the South Oak Cliff Corridor Alternatives Analysis studies had a multinomial logit structure. For home based work and home based other trips, walk-to-transit and drive-to-transit were considered as competing modes. Separate impedances were computed for walk-to-transit and drive-to-transit paths. In addition, each zone is subdivided into up to three market areas reflecting different walk-access distances.

Because the mode choice model being used permits walk access to transit distances up to 2.5 miles, the number of transit access walk links from a given zone is, potentially, quite large; so large that manual coding was seen as infeasible and likely to lead to inconsistency. To address this problem, an automated procedure was developed.

The process relies, in part, on the tiered traffic analysis zone system used by NCTCOG. Data are collected and stored at a highly disaggregate level using 6,400 Transportation Survey Zones (TSZs). Forecasts of households, population and employment are developed at the TSZ level. For any specific planning or analysis effort, NCTCOG can specify a system of about 800 Transportation Analysis Process (TAP) zones. Each TAP zone is an aggregation of TSZs.

The NCTCOG procedure also includes stratification of the transit access market in each TAP zone into three partitions such that the walk access variance within each partition is minimized. This is possible because the TAP zones are aggregations of the TAS zones that represent a finer geographic detail. The process not only reduces aggregation bias, but also permits more accurate representation of access from zones in which walk-to-rail and walk-to-bus are options. Portions of the TAP zones truly within walking distance of a rail (or express bus) station are given appropriate walk access impedances, while portions of the zones beyond walking distance to a station are given walk-to-bus-to-rail or drive-to-park-and-ride times and costs. Since the process is automated, potential bias arising from judgments made during the network coding process are removed and consistency in access coding between years and alternatives is assured.

The following materials, taken from *South Oak Cliff Corridor Alternatives Analysis/Draft Environmental Impact Statement, Methods Report, Service and Patronage Forecasting, Report 10, Dallas Area Rapid Transit, March 8, 1990* describe the procedure in detail.

Access Coding

NCTCOG has developed a computer program that automatically generates walk- and drive-access centroid connectors for transit networks. The automation of this process is important because the mode choice models consider transit to be an option up to very large maximum distances for transit access. These large maximum distances lead to a very large number of access links that would require an unacceptably large effort to code manually. Development of the program involved several iterations in which preliminary versions were used with test networks, systematic deficiencies in the generated links were identified by NCTCOG coding staff, and the program was updated to include additional rules and/or user-supplied parameters to better replicate manual judgment.

This process has resulted in a program that considers a wide variety of influences on the selection of access links, and that replicates manual coding results to a very large degree. Application of the program reduces the necessary manual coding effort substantially. Nevertheless, NCTCOG performs a detailed review of the results of the automated process; this review leads to generally minor adjustments to the access links, including the removal of walk-access links that cross physical barriers (watercourses, for example).

General Considerations

The overall goal for the criteria built into the automatic access coder was to replicate to the extent possible the rules used by NCTCOG staff in manual coding of access links. Some of these rules were well established and were included in the earliest versions of the program. Others were more subtly embedded in the judgment of the coding staff and emerged through the reviews by the staff of the links generated by early software versions.

The final criteria embedded in the program include five considerations.

1. Variety of transit modes. To ensure adequate connection of each zone to all transit modes, the program does entirely separate analyses of walk-access to local and express services. The program generates for each zone one set of walk-access links to nodes served by local bus routes, and a separate set to nodes served by express buses and rail lines. Thus, the program can reach beyond nearby "local" nodes to connect the zone to more distant "express" nodes or rail stations that are within the maximum walk-access distance. The program does not distinguish among modes serving drive-access nodes because these nodes are almost invariably located on express bus lines or (in future networks) at rail stations.

2. Variety of directions. The program attempts to provide a wide dispersion of access links in terms of direction from the zone centroid. It avoids the generation of links connected to nodes that are near to each other, unless one of the nodes is "local" and the other is "express."

3. Limited numbers. To avoid software revisions to other programs used by NCTCOG for transit network processing, and to avoid unnecessary time and cost in processing superfluous access links, the program generates for each zone a maximum four walk-to-local links, four walk-to-express links, and four drive-access links.

4. Priority to "intersection" nodes. A high priority for connection with a walk-access link is any stop node at which transit lines intersect. This priority arises because a single connection to an intersection node makes walk access possible to more than one transit line, reducing the need for transfers and generally increasing transit access.

5. Priority to rail stations. Similarly, the program gives priority to rail stations for connection with walk access links. This priority reduces the chances that travelers from a zone have to use an unrealistically short bus-trip to reach the rail station, when a slightly longer walk would bring them directly to the station.

Together with the user-specified parameters, these considerations make possible the automatic generation of access links that closely reflect the judgment of the user. All validation tests on the mode choice models used transit networks with access links generated and coded by the automatic access coder.

Program Logic

For each zone in the region, the program uses two separate phases to generate (or pass) access links for a transit network. The first phase identifies a set of candidate nodes that qualify for connection with access links. The second phase then selects the optimum set of these nodes and generates the links.

Phase I: Identification of Candidate Nodes. For each zone in the region, the program first identifies three sets of candidate nodes: walk-to-local, walk-to-express, and drive-access. Each set contains up to eight nodes, one in each of the octants of a coordinate system constructed with origin at the zone centroid.

For walk-access, the program scans the entire list of transit nodes in the network and evaluates each stop node as a possible candidate for generation of a walk-access link. The program computes the airline distance between the zone centroid and the node, and determines the octant in which the node lies. If the distance is less than the maximum walk distance, the program determines whether the node is the best candidate found thus far in the octant using three classes of priorities:

1. Rail stations have the highest priority. The program selects the nearest rail station node in an octant, even if other stop nodes are nearer the centroid, so long as the station is within the maximum threshold distance for rail station priority (1.25 miles). The program always treats rail stations as express nodes.

2. Intersection nodes have the next highest priority. The program selects the nearest intersection node, even if other stop nodes are nearer the centroid, so long as the intersection node is within the maximum threshold distance for intersections (0.75 miles) and there is no rail station available in the octant. The program may treat intersection nodes as either local or express, depending on the services available at the node.

3. All other nodes have the third priority. The program selects the nearest stop node, in the absence of rail and intersection nodes. These nodes may also be either local or express, depending on the service available at the node.

The program finds the most desirable candidate node in each octant by evaluating all stop nodes in the network. For drive access, the program similarly evaluates all valid drive-access nodes in the region, first checking that the area-type of the zone permits drive access.

Phase II: Selection of an Optimal Set of Access Nodes. In the second and final phase, the program evaluates the set of candidate nodes and selects the subset of nodes that provides best access from the zone. It is important to recognize that this evaluation considers all of the nodes in the set together, not just each node by itself. Therefore, a network revision that provides service to a node may revise the entire set of access links for the zone, rather than simply generating a single additional access link.

For all three sets of candidate nodes, the program uses three steps to select the final nodes for connection.

Step 1. The program assigns a score to the node in each octant depending on its relative proximity to the zone centroid compared to the nodes in adjacent octants. If the node is nearer the centroid than the nodes in either adjacent octant, the program assigns the node a score of 2. If the node is closer than the node in one adjacent octant, the program assigns a core of 1. If the node is not closer than the node in either adjacent octant, the program assigns a zero. The program then tentatively marks all nodes with scores of zero for deletion from the candidate nodes.

Step 2. The program then scans the remaining nodes, selecting the most attractive and (for walk-access only) tentatively marking for deletion the nodes in its two adjacent octants. This selection again uses the three priority groups, choosing rail station first in order of increasing distance, then intersection nodes in order of increasing distance, and then all other nodes, again in order of increasing distance. It continues this scan until all nodes have either been selected or deleted. For drive access, the program does not delete node in octants adjacent to selected nodes, provided that the selected node lies beyond a specified threshold distance (8.0 miles) from the zone. This feature permits the generation of drive-access links in adjacent octant from zones outside of the immediate transit service area. Access in these peripheral areas generally lies in one direction (towards the CBD), and the no-adjacent-connector rule tends to limit the generation of otherwise reasonable links.

Step 3. Finally, the program then makes a final scan of the tentatively deleted nodes to identify any "gaps" in the selected nodes that can be in-filled. A gap occurs where there are three (or more) adjacent octants without selected nodes. If a node exists in the center octant in this gap, the program adds this node to the set of selected nodes.

The program then writes to the output file one record for each of the selected nodes, providing a full set of entries for all fields on the record. For drive-access links, the program also generates special walk links at user-specified locations. The user designates these locations by identifying station nodes on the valid drive-access file. Where the drive-access file includes a station node associated with a drive-access node, the program creates a link between the two nodes to represent walk times between the park/ride lot and the station platform.

Partitioning of TAP Zones into Walk Markets

The mode choice models consider a walk-access market that ranges up to 2.5 miles from transit. The survey data used in calibration of the models included the specific TSZs [Transportation Survey Zones] of both the origin and destination of each trip. Because the trip ends were associated with specific TSZs rather than the larger TAP [Transportation Analysis Process] zones, it was possible in calibration to portray walk-access and walk-egress distance with more precision than is usually possible with analyses at the traffic-zone level.

The 2.5-mile maximum walk distance presents some difficulties in application, however. Chief among these is the concern that the use of TAP-zone walk distances will create aggregation errors in the forecasts. Aggregation errors occur when non-linear models are calibrated with disaggregate data but then are applied in forecasting with aggregate data. Since the mode choice models use the non-linear multinomial logit formulation, a significant risk of aggregation error would exist in application of the models with aggregate walk-access and walk-egress markets of up to 2.5 miles across.

To avoid these risks, NCTCOG uses a preprocessor program with the mode choice models to partition the walk-access market within each TAP zone in a way that minimizes the effects of aggregation error. The strategy used by the program is to group the TSZs within each zone into a maximum of three walk-access partitions so that the TSZs within each partition have walk distances that are as similar as possible. The mode choice models then evaluate separately the mode shares of trips produced by and attracted to each of the walk-access partitions, using the walk times specific to each of the partitions. This strategy ensures that the mode choice models are applied to walk-access and walk-egress markets that are as homogeneous as possible. The increased homogeneity of the markets, in turn, minimizes the degree to which the average walk-access time for each market might badly overstate or understate the actual walk times for any trip within the markets.

Criteria for Aggregation of TSZs in the Walk Market

The best measure of the homogeneity of TSZ groupings for this application is the sum, across all groups, of the variance around the mean walk-access distance within each group. The variance within a group is, by definition:

$$\text{(1)} \qquad \text{Variance}_g = \frac{\text{SUM}_{t=1,N}(D_t - D_{avg})^2}{N-1}$$

where: D_t is the walk distance from the TSZ centroid to the stop node; and

N is the number of TSZs in the zone.

If all of the TSZs within the group have nearly the same walk distance to the transit stop, then the variance for the group will be very small. If a similar degree of homogeneity exists for all of the groups within the TAP-zone, then the sum of the variances across the TAP-zone will also be small.

For example, one possible grouping scheme in a TAP-zone with 10 TSZs would be to place the four TSZs nearest the transit stop node into the first partition, the three next closest TSZs into the second partition, and the last three (most distant) TSZs into the third. The variance for the first partition would be computed with Equation (1), using the distance from each of the four TSZ centroids to the transit stop node and the average of these four distances. The variance for each of the other two partitions would be computed similarly. The sum of the variances computed for each of the three partitions would then represent the degree of homogeneity of this particular grouping scheme for the TAP-zone. To identify the best grouping possible, it is necessary only to evaluate the total variance for all possible groupings of the 10 TSZs. The best grouping is the one that has the lowest total variance.

Program Logic

Because the program describes the walk-accessibility of trip ends to the transit network, each alternative transit network requires three separate applications of the program -- one for the trip ends associated with each trip purpose. Within each application, the program uses four steps to create a file that describes the walk accessibility of each TAP-zone to transit.

Step 1. For each TAP-zone, the program first determines whether the zone has more trip productions or more trip attractions. This permits the determination of groupings within each TAP-zone in a way that recognizes the primary character of the TAP-zone. The program determines groupings for TAP-zones that are primarily residential on the basis of the trip productions in each TSZ, while it determines groupings in employment and commercial areas on the basis of trip attractions.

Step 2. The program then selects the first stop node to which the TAP-zone is connected with a walk access link in the transit network. For each TSZ in the TAP-zone, it computes the distance between the TSZ centroid and the stop node. Depending on this distance, the program then classifies the TSZ into one of 11 distance intervals. The first 10 of these intervals represent 0.25-mile increments in walk distance, ranging between zero and the maximum 2.5-mile walk distance. The eleventh interval represents areas of the TAP-zone that are beyond walking distance to the transit stop node. When this step is completed, the program has allocated each TSZ in the TAP-zone to one of the 11 intervals.

Step 3. In the third step, the program compresses the 11 walk intervals into the four partitions -- three representing walk-access of increasing distances and the fourth representing portions of the TAP-zone beyond the maximum 2.5-mile walk-access distance. To compress the 10 intervals within walking distance, the program constructs all possible groupings of the 10 intervals and computes the variance for each. In many TAP-zones, this problem is quite simple. If all TSZs in the TAP-zone fall into three or fewer intervals, then each interval becomes a walk-access partition. As the number of intervals with TSZs grows, however, the problem requires more computing time to solve. The maximum size of this problem occurs when each walk-access interval has at least one TSZ. In this case, there are 36 alternative groupings of the 10 intervals into three partitions. It is useful to represent each grouping as a 3-digit number, where the first digit indicates the number of intervals grouped into the first partition, and the second and third digits represent the second and third partitions:

<u>Possible groupings when TSZs are found in all 10 intervals:</u>

811			
721	712		
631	622	613	
541	532	523	514

451	442	433	424	415			
361	352	343	334	325	316		
271	262	253	244	235	226	217	
181	172	163	154	145	136	127	118

The problem requires fewer computations as the number of intervals with TSZs becomes smaller. For example, when six intervals have TSZs, there are only 10 possible groupings:

Possible groupings when TSZs are found in 6 intervals:

411			
321	312		
231	222	213	
141	132	123	114

The program repeats Steps 2 and 3 for each transit stop node to which the TAP-zone is connected with a walk-access link.

Step 4. Finally, the program computes the aggregate characteristics of the households, employment and trip ends across the TSZs in each walk-access partition. It writes an output file that includes one record for each TAP-zone. On each record, the program writes:

- TAP-zone number
- terminal times
- parking cost
- area type
- transit stop nodes to which the TAP-zone is connected; for each stop node:
- average walk distance to each partition
- average autos per household, for each partition
- average autos per person, for each partition
- flag indicating high incidence of 0-car households
- trip productions by income group, for each partition
- number of attractions, for each partition

For TAP-zones that are not walk-connected to the transit network, the program writes zonal totals into the fields normally used to represent access to the first stop node, and flags the TAP-zone as not-walk-connected.

Beyond the general appeal in this procedure's ability to reduce problems caused by aggregation bias, the procedure largely overcomes a long-standing problem with representation of walk access in zones with rail stations. The conventional approach to coding walk access involves manually-developed estimates of the share of each zone's trip ends that are within walking distance of transit. This convention has difficulties in zones with rail stations, however. Most rail stations are served by significant numbers of feeder bus lines -- particularly those stations in the larger zones found in suburban areas. Consequently, most or all of the trip ends within the surrounding zone have walk access to some transit service. For many trip ends, however, this walk access is to a feeder bus, not the rail station itself. The difficulty arises because the minimum-impedance path often, perhaps usually, uses the direct walk connection to the station. The resulting path represents the service available only to those trip ends within walking distance of the station itself, and omits the additional time and fare associated with the feeder bus access that must be used by most of the trip ends in the zone. The access coding and pathbuilding therefore overstate the overall quality of transit service available to trips to and from the zone.

The NCTCOG procedure largely solves this problem. When the best path involves direct walk access to the station, the three walk-access partitions around the station accurately portray the distribution of walk-access distances to the station. The mode choice model can therefore evaluate accurately the higher transit shares likely in areas immediately adjacent to the station, and the decline in transit share that occurs as the walk distance becomes larger.

SAN DIEGO

The San Diego Association of Governments (SANDAG) uses a unique approach, integrated with a GIS system that stores data, to define transit access and to build transit paths. SANDAG's smallest unit of geography is the Master Geographic Reference Area (MGRA). There are 25,929 MGRAs in SANDAG's system.

MGRA's are based on blocks as defined by the Census Bureau for use in the 1990 Census. Blocks are polygons bounded by streets that existed in 1989 and other Census Bureau features such as Census Tract boundaries. There are 20,317 blocks averaging 600 feet on a side in size, but ranging from 100 feet to over 10 miles on a side. The main problem with using blocks directly for planning purposes is the size of blocks in rural areas slated for development. Since blocks only reflect on-the-ground features, they are not well suited for analyzing proposed development sites. Another problem with blocks is that they meander along ridge lines and other areas that lack regular street patterns.

In order to overcome these problems, blocks were split by the following features to create MGRAs:

- Community plan boundaries
- Zip code boundaries
- City sphere of influence boundaries
- Planned roadways
- 1/2 mile buffer around transit routes
- Transportation zone boundaries

Information is most often requested by zip code, community plan area, city, and city spheres of influence. These boundaries were added where they differed from census block boundaries.

Planned freeways and local circulation element roads were added to further subdivide blocks. These facilities provide convenient breakpoints and were brought into the MGRA boundary file from transportation network files.

Specifying the amount of activity within walking distance of transit is important when estimating transit patronage. SANDAG assumes 1/2 mile is the maximum distance people will walk to transit. Blocks were manually split as necessary to delineate walk areas around existing and proposed transit routes and rail stations. Ridge lines and other topographic features that prevent walk access to transit were also added.

MGRAs were further subdivided for highway modeling purposes. This part of the process was done in conjunction with developing a transportation zone system, which is the next highest level of geography. One of the objectives of upgrading transportation models was to allow analysis of traffic volumes for smaller streets and local transit routes. This dictated having a large number of zones. Much of the region had previously been modeled at a detailed level in various sub-area traffic studies. Zone boundaries from these studies were added to the MGRA file where there were no nearby features already in the file. MGRAs in the rest of the region not covered by past studies were split as necessary to separate dissimilar land uses and specify access opportunities.

Once all additional features had been added to the block file, creating transportation zones was a matter of aggregating MGRAs to zones. A total of 4,545 transportation zones were created. Of these, 4,536 zones are internal to the Region and nine are external zones located where major roads cross the County line.

All geographic files are maintained as Arc/Info coverages. This enables other aggregations of forecasted data to be easily produced as requested. Cross-reference files between different levels of geography can be readily produced. Arc/Info also has sophisticated mapping capabilities which are useful for checking and display purposes.

In most areas, transit paths are built from zone centroid to zone centroid. Since SANDAG uses a system of 4,545 traffic analysis zones in order to maintain detail, normal pathbuilding would be excessively time consuming. To reduce processing time, SANDAG defines a set of Transit Access Points (TAPs) that are similar to bus stops or rail stations. Paths through the transit network are built from TAP to TAP rather than from zone to zone. Access from and egress to each zone to the appropriate TAP is determined in a separate process. These access and egress data are then combined with the data from the pathbuilding exercise.

Since demographic and trip data are developed and stored at a fine level of geographic detail, transit markets reflecting actual access conditions can be developed using automated procedures. Further, the appropriate access impedances can then be associated with each market segment.

The following materials, taken from *Draft Regional Transportation Models, San Diego Association of Governments, November 1994* describe the process of network development and access coding in greater detail.

Input Files

Arc/Info is used to maintain most transit network information in the master transportation coverage. The use of Arc/Info enables transit network data to be related to other SANDAG geographic data and produce high quality plots for editing and display purposes.

Arc/Info Coverages

An Arc/Info "route attribute table" is associated with the transportation coverage and contains a sequential listing of arcs that are used by each transit route. Coders update the route attribute table to add new routes or alter existing routes. Arc/Info updates the route attribute table when underlying network changes are made such as splitting arcs. Coders also locate nodes at transit stops in the transportation coverage. Node attributes include:

- Stop Type
- Park and Ride Conditions
- Dwell Times
- Timed Transfer Points

Route Description File

An ASCII route description file contains transit network information that is not spatially oriented. The file has an entry for every route configuration to be included in a transit network alternative. Routes as defined by transit operators need to be partitioned into route "configurations" or Tranplan "lines" for modeling purposes. Almost every route has two configurations that differ by direction. In addition, many routes have some configurations that take alternate roads or travel only part of the main route. Finally, service modifications for a route may be proposed for the future that add more configurations.

Transit modes group together routes with similar characteristics in order to assign service characteristics and summarize model results. Modes used in SANDAG transit modeling are Commuter Rail, Light Rail, Express Bus, South County Local Bus, and North County Local Bus.

Headways indicate the time between bus arrivals and hence the frequency of service for route configurations. The model uses headways to compute the time transit riders would encounter when initially waiting for a bus arrival or when transferring between buses.

Transit operators may adjust the frequency of service throughout the day to match transit capacity with ridership demand. In order to reflect these different service levels, headways are coded for morning peak (6:00 to 9:00 AM), mid-day (9:00 AM to 3:00 PM), afternoon peak (3:00 PM to 6:00 PM), and night (6:00 PM to 6:00 AM). The hours of evening service are coded to reflect the variation in night service by route. Morning peak period and mid-day headways are input to the mode choice model and affect transit patronage estimates. Afternoon peak period and night headways only go into the calculation of total daily transit miles, affecting transit cost and emission estimates.

Base year headways are obtained from published time schedules. Buses arrive at regular intervals on most routes and the time between bus arrivals is obvious. The following equation is used to calculate average headway on other routes with service variations:

$$H(P) = 60*HR(P) / N(P)$$

where:

H = Headway for time period (Minutes)

HR = Hours of service in time period

P = Time period (AM, Mid, PM, Night)

N = Number of buses or trains in time period

A few routes have very limited service during a time period. A typical example would be commuter express bus service, which may have two runs in the morning peak period, timed to match peak arrival times. The equation above would yield a headway of 90 minutes for these routes. Some practitioners would code a shorter headway since the longer headway overstates the time a transit rider would actually wait at a transit stop. SANDAG codes the full computed headway for these routes to reflect the inconvenience of infrequent service. Later in the mode choice model, long wait times are factored down to prevent over-emphasis.

Headways for future year alternatives may be carried over from the base year, adjusted to meet policy service levels, or adjusted to meet forecasted ridership levels.

Network Processing

Once the master transportation coverage and route description file have been edited, a combination of Arc/Info routines and SANDAG Fortran programs generate transit network inputs for Tranplan's Build Transit Network function. Network inputs consist of "link" and "line" records. Line records describe line characteristics and the path of each transit line. Link records describe network characteristics over which lines operate.

Arc/Info Procedures

A SANDAG Fortran program generates transfer links between routes that come close to each other but do not intersect. The program reads route description records, node coordinates, stop types at nodes, and nodes used by route configurations. Straight-line distances are computed between stops on a route and stops on other routes after dropping stops within 1/2 mile of any common stops between route pairs. When distances of 1/2 mile or less are found, Arc/Info node numbers and the distance between nodes are written out to a temporary file.

Transfer Links

A SANDAG Fortran program generates transfer links between routes that come close to each other but do not intersect. The program reads route description records, node coordinates, stop types at nodes, and nodes used by route configurations. Straight-line distances are computed between stops on a route and stops on other routes after dropping stops within ½ mile of any common stops between route pairs. When distances of ½ mile or less are found, Arc/Info node numbers and the distance between nodes are written out to a temporary file. [Note: This step can be important. In areas with a high density of routes such as a CBD, failure to represent walking connections to/from zones and between transit stops can lead to significant overstatement of transfers or, as in the case described above, failure to properly reflect a transfer opportunity.]

Tranplan Input File

Another SANDAG Fortran program creates Tranplan transit network input files. The program reads arcs and nodes associated with each route configuration in the route description file. Arc/Info transit coverages contain nodes at transit stops, traffic signals, and street intersections. This is more detail than is necessary to carry into Tranplan. The first step in the program is to assign Tranplan nodes at selected transit stops. The program puts these nodes called transit access points (TAPs) at route intersections, rail stations, timed transfer points, transfer link nodes, and other stops every 1/2 mile along a route. TAPs are assigned sequential numbers that are used in Tranplan modeling. Tranplan does not allow a node to be used more than once on a line. Duplication nodes are assigned a "dummy" number. Transfer links with zero time connect dummy nodes to underlying nodes.

Once TAPs have been located along a route, the program writes out a Tranplan link record. Distance is computed by summing up Arc/Info distances for individual arcs making up a transit link. Morning peak and off-peak bus times are computed using the following formula:

$$BT(P) = HT(P) + D*N$$

where:

BT = Bus link time (minutes)

P = Time Period (AM peak or off-peak)

HT = Highway link time (minutes)

D = Stop Delay (18 seconds or 0.30 minutes per stop)

N = Number of transit stops on link

Highway times include the effects of modeled congestion on speeds and are drawn from the highway assignment model. Buses incur additional delay when stopping for passenger boarding and alighting. Differences in bus stop activity, the type of routes serving a stop, and the physical characteristics of a stop make simulating bus stop delays very complicated. SANDAG uses an average stop delay for all bus stops that is based on actual system-wide transit speeds.

Rail station-to-station times for existing light rail lines are drawn from published time tables. Some proposed light rail lines have been through studies where station-to-station times were estimated through train simulation. Station-to-station time estimates are coded directly where they exist. Preliminary studies of rail extensions lacking detailed time estimates use station-to-station times from the following equation:

RT = DI*60/MS + MS/60*(AC(MS)*DE) + DW

where:

RT = Rail link time (minutes)

DI = Link distance (miles)

MS = Maximum link speed (MPH)

AC = Acceleration rate (2.48 MPHPS at 25 MPH to 0.83 MPHPS at 50 MPH)

DE = Deceleration rate (3.31 MPHPS)

DW = Station dwell time (0.33 Minutes)

Maximum speeds of 35 MPH to 50 MPH are coded on rail arcs in the master transportation coverage. These maximum speeds, along with acceleration rate, deceleration rate, and station dwell time assumptions, allow station-to-station rail times to be computed. The program estimates a maximum speed based on acceleration and deceleration rates for stations spaced too closely together to reach the maximum coded speed.

Parallel walk transfer links are created to Centre City street links. These walk links allow transit riders to walk between transit lines in Centre City that do not intersect. Transfer links created in previous steps only allow transfers between routes that are within 1/2 mile of each other.

The program generates all the link records making up a line and then outputs a Tranplan line record. A sequential line number and node listing for each route are generated by the program. Other line record data items come directly from the route description file.

In addition to Tranplan link and line cards, the program produces reports summarizing route information. Computer-generated plots showing route alignments, walk access assumptions, and transit network inputs are also available.

Tranplan Transit Network

ASCII link and line files produced by SANDAG's program are merged, and Tranplan's Build Transit Network function is run to produce an unformatted, binary Tranplan file that is used by Tranplan transit functions. The Build Transit Network function also performs some edit checks.

Tranplan Zone-to-Zone Travel Time and Fare Files

Tranplan's Build Transit Paths function is run to determine minimum time paths between transit access points. A number of parameters are available in the program to control the types of paths that are built. SANDAG uses the following parameters:

- Minimum bus wait penalties of 5 minutes
- In-vehicle time factors of 0.5
- Wait time factors of 1.25
- Transfer walk time factor of 1.0
- Added transfer penalties of 6.0 minutes

The minimum wait penalty of 5 minutes reflects the fact that buses tend to bunch up on streets with very frequent service. The parameter prevents over-estimating short Centre City transit trips where frequent transit service is prevalent.

Wait time factors penalize initial wait and transfer time more heavily than transit in-vehicle time. This reflects surveys that show transit riders find wait time to be more onerous than in-vehicle time. The factors coincide with weights attached to transit travel time components in the mode choice model. The transit link factor was increased until transit paths used transit rather than transfer links for longer trips within Centre City San Diego where transfer links are prevalent.

Transfer penalties are added to reflect the cost and inconvenience of transferring. A six minute base transfer penalty is consistent with penalties used in the mode choice model. These penalties were adjusted until model-estimated transfer rates agreed with actual transfer rates.

Tranplan's Transit Selected Summation function is run after building paths to obtain transit time components between TAPs based on the minimum path. Walk and auto access times are added in the mode choice model from transit access files so that access times are not saved.

Tranplan's Load Transit Station To Station function is run to determine the number of timed transfer points encountered between TAP-to-TAP interchanges. Transfer penalties are reduced in the mode choice model at timed transfer locations.

Cash fares are discounted to account for the estimated amount of transit pass usage for each type of service. Discount rates are calculated by dividing total revenue by estimated linked trips. TAP-to-TAP transit fares are obtained from the transit network using Tranplan's Build Fare Matrix function and a SANDAG program to account for San Diego's fare policies. Cash fares are discounted to account for the estimated amount of pass usage for each type of service. Discount rates are calculated by dividing total revenue by estimated linked trips.

Fares on the light rail system are variable, depending on the number of stations traversed. In order to assess rail fares, a list of light rail links is input to Tranplan's Build Fare Matrix function. A SANDAG program looks up a rail fare based on the number of light rail links between TAP-to-TAP interchanges. The program sets the final fare equal to the highest fare encountered over a minimum path. The final fare could be the boarding fare of the first bus, the boarding fare of a transfer bus, or a light rail fare.

Access Procedures

Transit access files are produced along with the transit network described above for each network alternative. These files connect transportation zones with transit access points (TAPs) and are used later on in the mode choice model. A set of three SANDAG programs generates access files.

The first program finds all transit stops within walking distance of each Master Geographic Reference Area (MGRA). The program reads coordinates and elevations of MGRA centroids from the MGRA coverage; stop coordinates and elevations from the transit coverage; and coordinates of walk barriers from a walk barrier coverage. MGRA and transit coverages have already been described. The walk barrier coverage contains arcs representing features such as ridge lines, steep slopes, water body boundaries, freeways, and fenced property lines that could block walk access. Elevations of MGRA centroids and transit stops are determined by overlaying coverages on a 100 foot contour coverage.

A file of trip productions and attractions by MGRA from the trip generation program is read. Straight-line distances are computed between MGRA centroids and transit stops in the vicinity of the MGRA. Elevation differences are weighted by a factor of seven and added to straight-line distances. Connections between MGRAs and stops that exceed the 1/2 mile maximum walk distance or cross walk barriers are deleted. The program writes out records for the remaining MGRA-stop connections with the following items:

- MGRA number
- Zone number of MGRA
- Stop node number
- MGRA-stop distance (feet)
- Home-based productions
- Non-home-based productions
- Total attractions

If no stops are within walking distance of the MGRA, the record contains a zero in the stop number field.

The next program aggregates MGRA level output from the first program to zones, and generates the walk access file used in transit modeling. Route configurations at each stop are stored and MGRA-stop connection records are read for a zone.

For zones outside of Centre City San Diego the first step is to group a zone's MGRAs into areas with similar transit access opportunities, defined as having the same route configurations within a short walk (0-1/4 mile) and a long walk (1/4 to 1/2 mile) of the MGRA. MGRA trip ends are summed for each access area and the percentage of the zone's trip ends in each area is computed. Areas with less than 10% of a zone's trips are grouped with other areas to avoid splintering the data too much. Once access areas have been defined, one or more TAPs are identified for each access area such that access is provided to all routes within 1/2 mile of the access area.

Access opportunities in Centre City are too complicated to represent with the procedures described above. Instead, the closest TAP to each Centre City zone is identified. A Centre

City walk network is coded that allows access to other TAPs in Centre City without explicitly coding each zone to TAP connection.

An ASCII output file is written containing the following data items:

- Zone number
- Sequential access area number
- Sequential TAP number for zone
- TAP node number
- Distance Category (1 = 0 to 1/4 mile or 2 = 1/4 to 1/2 mile)
- Percent of zonal trip ends allocated to access area

There is one record in the file for each zone-access area-TAP combination. Some zones have no entries, indicating that the zone is not accessible to transit by walking. Zones with entries may be partially inaccessible to transit by walking. The part of a zone inaccessible to transit is the difference between 100% and the sum of TAP percentages for each access area in the zone.

The final transit access program generates auto access connections. An Arc/Info "identity" function is run to find the zone in which each park-and-ride lot is located. A SANDAG program reads the resulting lot-to-zone conversion table and zone-to-zone peak period highway travel time tables from the post-assignment process. The program finds travel times from each zone to all park-and-ride lots based on the zone in which each park-and-ride lot is located. Optional time penalties can be coded in the "IPARK" node attribute that are added to network based times. Time penalties are used to prevent parking demand at a lot from exceeding supply. Times are manually coded by comparing supply and demand from a previous model run.

An auto access connection is made from every zone to the closest park-and-ride lot. Additional auto access records are created for other lots that are within 15 minutes of the closest lot. An auto access file is produced with each record containing the following data items:

- Zone number
- TAP number of park-and-ride lot
- Time to TAP (minutes)

PITTSBURGH

The travel model set used in the Pittsburgh region addressed transit access through both network representation and treatment of access in a nested-mode choice model. Network procedures are described below. The mode choice model considered the choice between "walk-to-local-bus" and "walk-to-premium-service" at the lowest nest level. The model also considered the "walk-to-transit" vs. "drive-to-transit" choice at an intermediate nest level. Impedance aggregation across choices at all nesting levels was done using a LogSum function.

The following materials are taken from *Methods and Assumptions for Travel Forecasting in Support of Transit Project Planning in the Greater Pittsburgh Area, Port Authority of Allegheny County, October 1991.*

> ***Access To Transit***
>
> Access coding in the Pittsburgh transit networks relies on two components: access-market segmentation and access-link coding. Market segmentation is intended to represent the portion of households and employment in each zone that are within walking distance of transit. This mechanism is important in describing walk-access possibilities in large zones and in areas where severe topography limits walk opportunities. Access links describe the walking and driving times from an individual zone to one or more nearby stops on the transit network.
>
> ***Access-Market Segmentation***
>
> Many of the 990 internal zones in the Southwestern Pennsylvania Regional Planning Commission (SPRPC) study area are fully walk-accessible to transit. Zones within the CBD and most of the core of the region have transit service that is sufficiently dense to provide a transit stop within reasonable walking distance of all locations within each zone. At the other extreme, nearly all zones outside of Allegheny County have no walk access. Potential transit riders must drive to the transit system. Representation of access for both of these situations is straightforward. For a zone with full walk-accessibility, all trips to and from the zone are assumed to have walk-to-transit as an available mode. For a zone with no walk-access, trips produced by households in the zone have drive-to-transit as their only transit possibility, while trips to employment (or shopping, or any other activity) in the zone have no transit option at all.
>
> Other zones are more difficult to represent in the transit network. Large zones may have transit service only along one zone-boundary. Hillsides, rivers, and freeways may impose barriers that prevent an otherwise- reasonable walk trip to a transit stop. The approach for these zones is to hand-code a zone-specific data item that estimates the fraction of households and employment in each zone that has a walk-access option to transit. Walk-access possibilities are defined in terms of the maximum reasonable walking distance. In dense areas, this maximum distance is assumed to be 0.7 mile in the core of the region, 0.8 mile in medium-density areas, and 1.0 mile in outlying areas within Allegheny County. These maximums apply to walk-access for all transit modes. Walk- access percentages are coded in increments of 25 percent, recognizing the uncertainties on the specific distribution of activities within each zone. The same walk-access percentage is used to represent the distributions of both trip-productions and trip-attractions in each zone.

Access Links

The networks include a variety of access-links to represent walking and driving to the transit system. Table A-1 summarizes the six different types of access links and their use in the transit network. Access-modes 0 and 11 are used to represent walk and drive connections between zone centroids and the transit system. These access links are analogous to centroid-connectors in the highway network. Mode 12 is used to permit transfers between specific pairs of stop nodes. This transfer mode is typically used at stations on rail lines or busways to represent transfers between feeder buses and guideway services. Mode 13 is a "wild-card" walk mode that permits walking between and through any nodes in the network. This mode is typically used to represent "sidewalk networks" in dense areas. Sidewalk networks permit the transit paths to use any number of walk options for access, egress, and transfers that would be difficult to represent explicitly in terms of specific node-to-node possibilities.

Modes 14 and 15 are used only at guideway stations. They represent circulation times within the station area (between the park-and-ride lot and the station, for example). These links also "collect" all access and egress at a station, by access mode, to facilitate reporting of assignment results. The mode 15 services an additional purpose where estimated park-and-ride demand exceeds the lot capacity: a time penalty assigned to the mode 15 link can be used to reduce auto-access demand to equal the capacity of the lot.

Exhibit A-1 presents the convention for coding access to transit stations. Mode 0 links connect the two zone centroids both to bus stops on the highway network and to a walk-access (WACC) node adjacent to the station. Mode 11 links connect the zones to the park-and-ride (PNR) node adjacent to the station. All walk-access trips to and from the stations therefore must pass through the mode 14 link connecting the WACC node to the station node. Similarly, all drive-access trips must use the mode 15 link. Bus/rail transfers are permitted on the mode 12 link between a bus stop on the highway network and the rail station. The mode 13 link permits two kinds of walking: (1) transfer walks between buses serving node 1074 and buses serving node 1094, and (2) walk-access from zone 72 to stop node 1074. Identical coding procedures are used at busway stations, as well.

Auto access is represented (with mode 11 links) to stations and other "major" park and ride lots only. The "catchment area" of traffic zones served by each lot has been determined from the pattern of auto-access trips reported in the 1988 PAT on-board survey. The catchment areas for new lots are determined by analogy to existing lots with similar locations.

Transit Pathbuilding

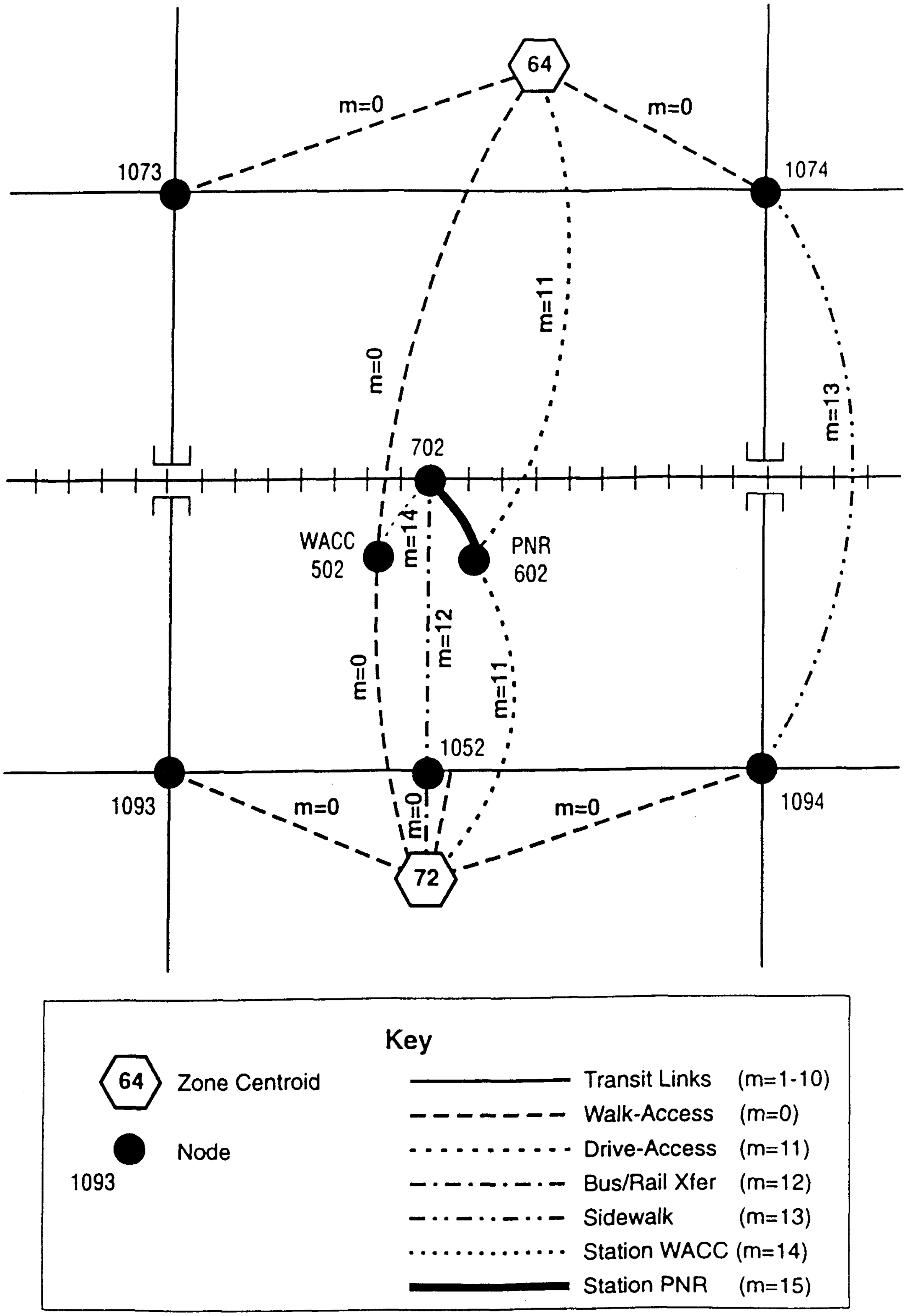
The transit pathbuilding step of the process predicts the specific paths through the transit network that transit riders would use for travel between each pair of zones in the region. This procedure also "skims" the paths to estimate the travel time, fare, number of transfers, and other characteristics of the transit paths. These transit skims represent the transit alternatives in the mode choice model, and change with improvements introduced by each transit alternative.

Table A-1

Access Modes and Their Functions in Coded Transit Networks

Access Link Type	Access Mode	Function
Walk-access/egress	0	2-direction access/egress between zone centroids and stop nodes
Drive-access	11	1-direction access from zone centroids to park-and-ride nodes
Transfer-walk	12	2-direction walk link to permit transfers between pairs of stop nodes
Walk	13	2-direction walk link to permit any kind of walk movement
Station-walk connector	14	2-direction walk link to connect walk-intercept nodes to station nodes
Station-drive connector	15	2-direction walk link to connect PNR nodes to station nodes

Exhibit A-1. Coding Conventions for Guideway Stations (Pittsburgh)



Multiple Transit Paths

Like most software for transit pathbuilding, the MINUTP program TRNPTH identifies the single "best" path between the origin and destination zones. In an area with dense transit services and a mix of both local and guideway operations, this approach to pathbuilding may introduce problems. All trips between a pair of zones is assigned to the "best" path even if it is better by only 10 seconds than some competing path. Consequently, where there are several highly competitive paths, the "all-or-nothing" assignment procedure tends to overlook important trade-offs.

To avoid this problem, the transit forecasting process implemented in Pittsburgh builds three sets of transit paths:

- walk to local service;
- walk to premium service; and
- drive to any service.

Premium service is defined to include light rail and trolley, buses using busways or HOV lanes, and commuter rail (modes 1, 4, and 7). Local service includes all other modes.

For each of the three sets of paths, the transit pathbuilder determines the "lowest-impedance" path among many alternative paths from each zone to all other zones. "Lowest impedance" means simply the path that is most attractive in terms of its time and cost. Mode choice models calibrated in Pittsburgh and elsewhere have demonstrated that travelers find time spent walking, waiting, and transferring to be more onerous than time spent riding in a transit vehicle. Consequently, the pathbuilding procedure uses the general concept that out-of-vehicle time is twice as onerous as in-vehicle time. The procedure uses a set of weights that reflect the differences in a traveler's perceptions of various travel time components. Time spent in a transit vehicle is typically assigned a weight of 1.0, while time spent walking, waiting, or transferring is assigned a weight of 2.0.

Two mechanisms are used to generate the three specific types of transit paths. The first is a TRNPTH feature that permits the selection of walk- or drive-access paths. In runs of TRNPTH that specify walk-access paths, the program ignores any drive-access links that might be available at the production end of the trip. Consequently, only walk-access is possible. Analogously, drive-access runs ignore any walk-access links available at the production zone, and only drive-access is possible.

The second mechanism modifies the general rule for weighting the in-vehicle time on various transit modes. This mechanism is needed in the generation of separate "walk-to-local" and "walk-to-premium" paths. For the "premium" paths, the weight on in-vehicle time for local modes is set to 2.0, rather than 1.0. This adjustment has the effect of discouraging the pathbuilder from selecting a path that largely -- or exclusively -- uses local modes. Similarly, in a separate run of TRNPTH, "local" paths are encouraged by setting the in-vehicle time weight for premium modes to 2.0. This approach is effective in identifying competitive paths, but avoids overreaching to include paths that, while possible, are much longer and are therefore irrelevant.

It is important to recognize the difference in strategies for obtaining different access modes and different walk-access paths. TRNPTH is "forced" to use the desired access mode: if the access-mode is not available for a particular zone, no paths are found from the zone. In contrast, TRNPTH is "encouraged" to find a particular kind of walk-access path. If the best local path is much longer than the best premium path, then the weighting to encourage local paths may not be sufficient to cause TRNPTH to find the local path. In this case, the mode choice model will recognize that a premium path was found in both cases, and will treat local paths as unavailable for the particular zone-to-zone trip.

SACRAMENTO

The procedures described below were used by the Sacramento Regional Transit District for studies conducted in 1992-93 of transit alternatives in the southern corridor. At that time, the modal choice model used by the Sacramento Area Council of Governments was a multinomial logit that treated "walk-access-to-transit" and "drive-access-to-transit" as equal choices along with "drive alone," "2 person shared ride" and "3+ person shared ride." Impedances for each access choice were based on all-or-nothing path building; a walk access market was defined for each zone based on the area within 0.4 miles of a bus stop or 1.0 miles of a light-rail station.

The application in Sacramento of this procedure illustrated a vexing issue in access representation -- how to represent walk-to-transit access properly when both "walk-to-rail-station" and "walk-to-bus-to-rail-station" are logical choices for trips produced within a zone. Typically, zones for which this situation is encountered are relatively large (i.e. greater than a one-quarter mile radius) with a rail station located near the edge of the zone.

The most direct approach to addressing this problem is to divide the zone so that the "walk-to-rail" market area is separate from the "walk-to-bus-to-rail" market area. Both the San Diego and NCTCOG procedures described above use this method. This approach is effective, but can be cumbersome when many alternative alignments or station locations are being evaluated. An alternative approach, considered but not implemented in the South Corridor Studies, involved treating the rail access choice issue in a nest-level of the mode choice model. The choices to be considered in such a choice structure would include both access mode to rail (e.g. walk, bus, auto driver, auto passenger) and, for each access mode, the choice of station.

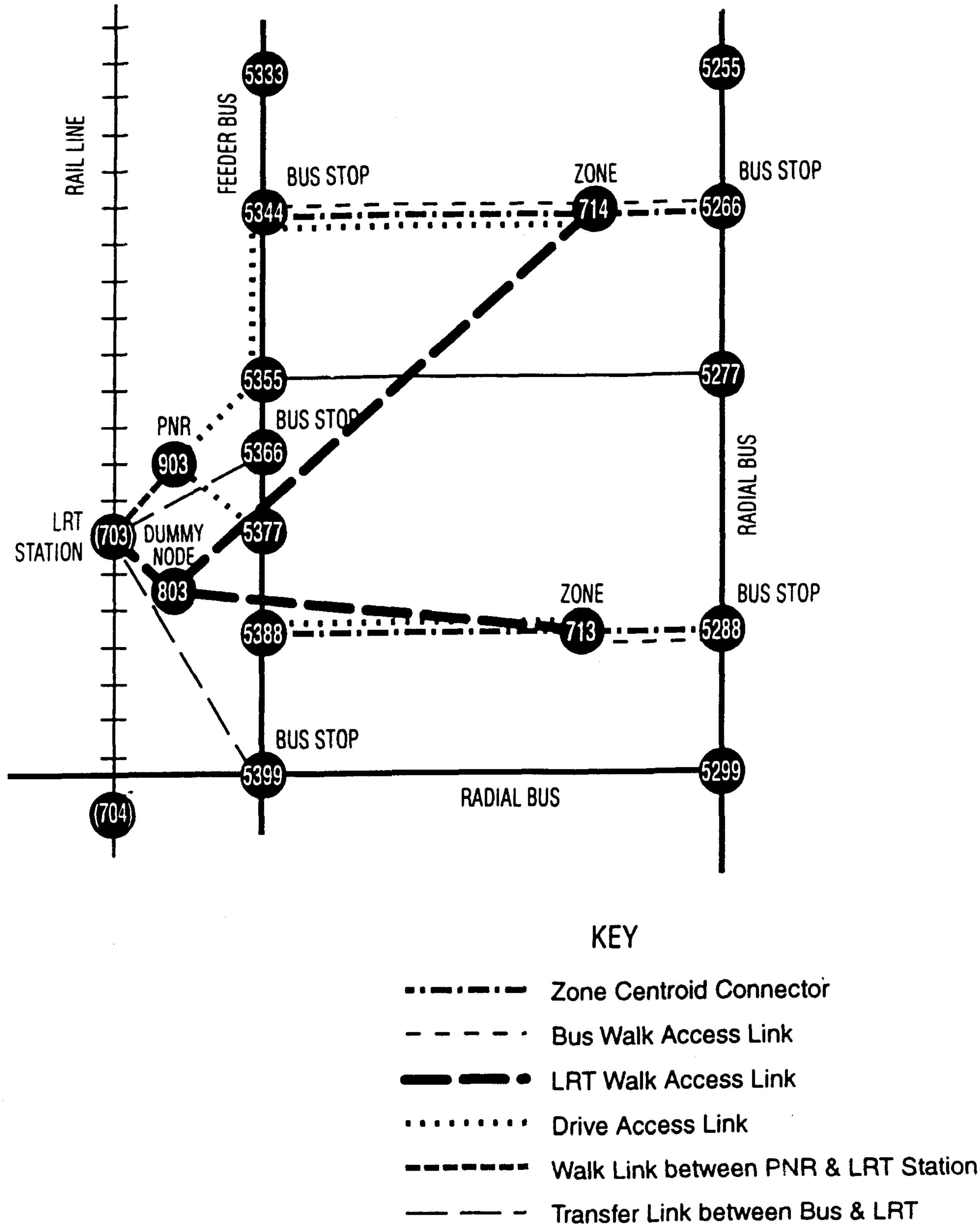
While this approach would permit systematic treatment of the rail access issues, the question of defining the access choices and impedances available to trips produced in different portions of large zones would remain. Zone splitting, either by creating new zones or by estimating the proportion of produced trips within each market group, would be required.

The method adopted involved estimating the proportion of zonal productions within specific market groups and allocating trips by each group to a minimum path derived impedance for "walk-to-transit" and "drive-to-transit" paths. The network coding scheme adopted, depicted in Exhibit A-2, illustrates the coding conventions. It was structured to permit building the appropriate access mode paths and to capture, in assignment, the number of trips using each path.

The Sacramento situation illustrates a difficult issue; the proper treatment of market groups for which "Walk-to-rail" and "Walk-to-bus-to-rail" are feasible options.

In a large zone containing a rail station, there will be some portion of the zone for which walking directly to the rail station and walking to a bus that serves the rail station are both feasible options. If the maximum walking distance for both bus and rail is considered to be

Exhibit A-2. Example Transit Network Coding Techniques (Sacramento)



the same (e.g. 1/4 mile), a walk access link that connects to a node connected to both the rail station and the bus service will yield the appropriate access time. Market stratification is still required (e.g. walk to rail or bus vs. walk to bus only) in order to determine correct paths and impedances. If the maximum "walk-to-rail" distance is assumed to be significantly greater than the "walk-to-bus" distance (say one mile for walk-to-rail vs. 0.25 mile for walk-to-bus), then there is a significant market for which multiple walk access opportunities exist, as well as portions of the zone that are in the walkshed of neither bus nor rail. This is illustrated in Exhibit A-3.

If the bus line service frequency is high (often the case when multiple bus routes converge on a rail station), the "best" walk-to-transit path for trips produced in the overlapping market area can be walk-to-bus-to-rail.

Any single walk access link for this complex zone would either overstate the access impedance for "walk-to-rail" trips or understate the impedance for walk-to-bus-to-rail trips. Alternative opportunities that could be considered in this instance include:

- Further "splitting" of the zone so that appropriate access links can be coded for each market area.

- Building a variety of transit access paths including "walk directly to rail" and "walk-to-bus-to-rail" as separate "modes" with trips either allocated to the appropriate path based on proportions in each market area, an allocation in a further nest in the choice model, or a combination of both methods.

CHICAGO AREA TRANSPORTATION STUDY (CATS)

In the CATS system, "centroid connectors" linking zones to the transit network are used only to establish zone-to-zone paths and the associated impedances from transit access to transit egress. Access and egress impedances to and from bus stops and rail stations are determined as part of mode choice/access mode choice routines.

For each traffic analysis zone in the CATS region, a distribution of distances to an access bus stop and a distribution of distances to an access rail station is developed. Exhibit A-4 illustrates two such distributions. The distribution reflects the cumulative distribution of the distance that person trip ends in the zone are likely to be from a bus stop or rail station. The distribution is based on the characteristics of development in the zone and the density of transit service.

For example, a zone in which all residential activity was concentrated in a single row of apartment houses fronting on a street with local bus service, would have a steep distribution (i.e. all trip ends would have small access distances). A large zone that has trip origins (residential units) dispersed uniformly throughout the zone, but also had a high density grid of bus services, would also have a steep distribution. A large zone with dispersed housing but served by only a single bus route on one edge would have an extended distribution with long average access distances.

Exhibit A-3. Zone with Multiple Access Markets

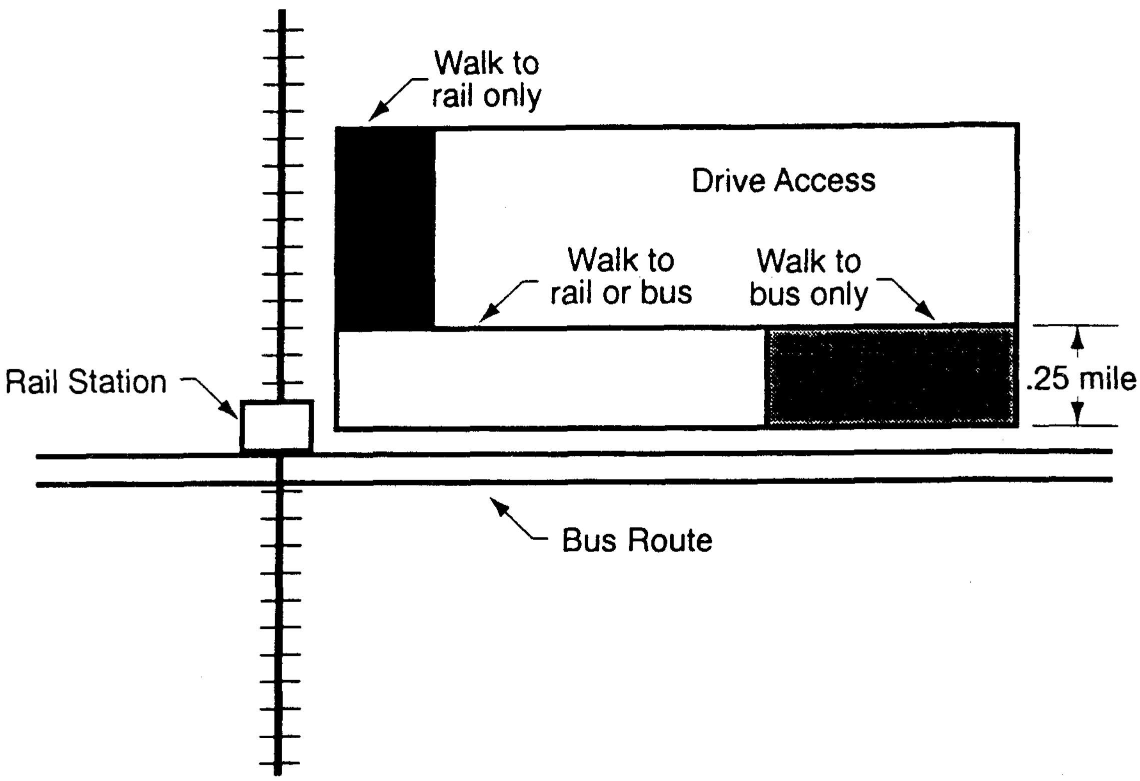
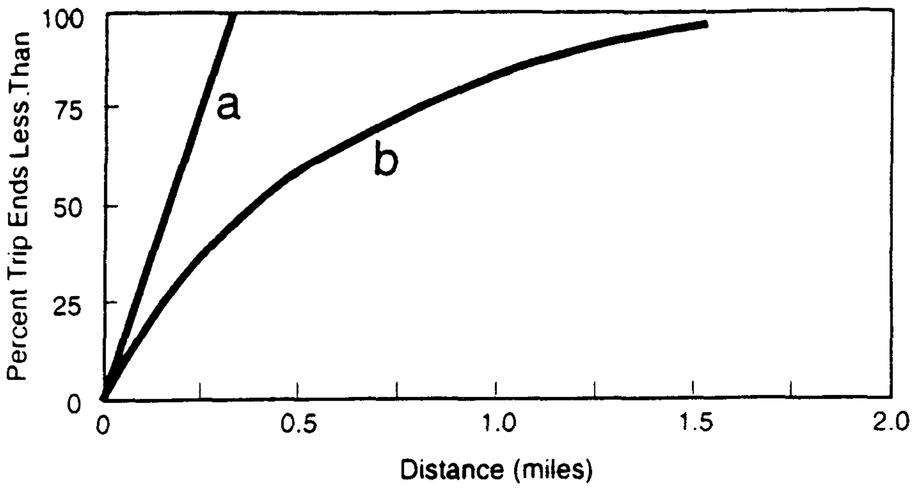


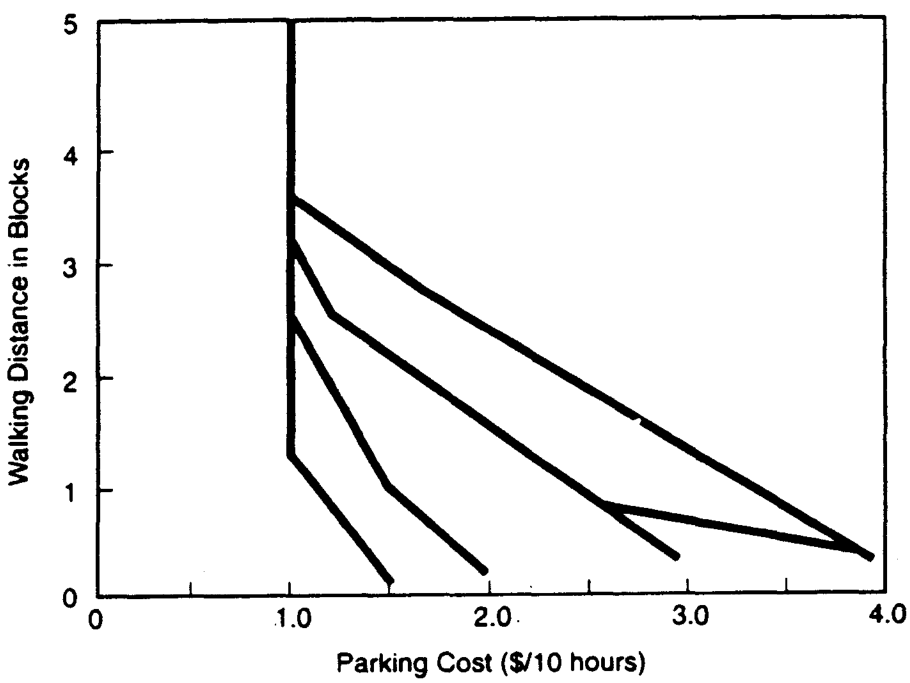
Exhibit A-4. Typical Distributions of Distance to Nearest Bus Stop (Chicago)



Curve a = 1 square mile zone
4 miles of bus routes in zone
Zone fully developed

Curve b = 4 square mile zone
1 mile of bus route in zone
Zone sparsely developed

Example CBD Parking Cost and Walking Time Trade-off Curves (Chicago)



Different curves are for separate groups of CBD zones.

A submodel that considers the nature of occupied land within each zone and the transit services available is used to generate a separate set of access distance distribution functions for each zone. A set of default distributions for zones of various types is also used. In addition, manual examination and adjustment is applied as necessary.

The mode choice/access choice/egress choice model treats each trip separately. If there are 50 trips from I to j, each of the 50 trips is considered separately. The transit impedance from I to j is developed using standard path building routines. The access and egress impedances from the path are then discarded. A Monte Carlo simulation is then applied for using each of the access and egress distributions -- access distance to bus and access distance to rail based on the zone I distribution functions and egress distance from bus and rail based on the zone j distributions. The resulting distances are converted to generalized cost and added to the appropriate path impedances. A relatively simple choice model is then used to assign each trip to either a bus or rail path and, using the full mode choice model, to either transit or highway.

This process is repeated for all trips for all I-j combinations.

PUGET SOUND REGIONAL COUNCIL

The Puget Sound Regional Council has implemented a procedure for analysis of choice of park-ride location using a technique referred to as "matrix convolution." Matrix convolution refers to a procedure in which elements of two matrices are used in a mathematical function in order to produce an element of a new matrix. In general terms, a convolution operation may be described as:

$$M3_{ij} = f(M1_{ia}, M2_{aj})$$

To analyze park-ride lot choice, the Puget Sound Regional Council developed networks in which park-ride lots under consideration are treated as "zones" in both the highway and transit networks. This permits using standard network analysis software to determine the impedance from all origin zones (i) to each park-ride lot (p), and the impedance from each park- ride lot (p) to each destination zone (j). The values of I_{ip} are computed based on the highway network. The values of I_{pj} are computed based on the transit network. The resulting impedances I_{ip} and I_{pj} are stored in matrices and can easily be manipulated to compute the total impedance I_{ij} associated with each park-ride lot choice. The values, in turn, are used in a logit based choice model.

DULLES AIRPORT CORRIDOR MODEL

This model has recently been developed for use in a Major Investment Study for the corridor leading to Dulles Airport from Washington, DC. This model incorporates and extends procedures used by the San Diego Area Association of Governments (SANDAG) -- separation of access to and egress from transit from identification of the path from transit boarding to transit deboarding location -- and the Puget Sound Regional Council -- use of a matrix convolution and a park-ride location choice model.

Allocation of transit trips among submodes and choice of access mode (and location) to each transit option are treated as nests in a multinomial logit model. The transit submodes consist of local bus and three "premium" transit options -- express bus, rail and commuter rail. The access options considered are:

- Local Bus

  -- Walk to transit
  -- Drive to formal or informal park-ride location

- Express Bus

  -- Walk to "station"
  -- Feeder bus to "station"
  -- Park-and-ride to "station"
  -- Auto passenger to "station"

- Rail

  -- Walk to "station"
  -- Feeder bus to "station"
  -- Park-and-ride to "station"
  -- Auto passenger to "station"

- Commuter Rail

  -- Walk to "station"
  -- Feeder bus to "station"
  -- Park-and-ride to "station"
  -- Auto passenger to "station"

"Stations," which include both rail stations and major express bus access/egress facilities, are treated as "zones" permitting paths to, from and between stations to be constructed using standard network analysis software. Three sets of "paths" are built using fairly standard path building procedures:

- Walk to local bus
- Drive to local bus
- Walk to premium transit

Since "stations" are treated as zones, this procedure yields walk-to-bus-to-station, drive-to-bus-to-station and walk-to-station paths and impedances for each station. In addition, drive-to-station paths and impedances are developed using the highway network. Egress from station paths and impedances are developed in a similar manner. To reduce processing time, a limited number of "station" options are retained for each procedure and attraction zone.

The impedances associated with the up to 65 separate and unique paths possible for each i-j movement can then be developed by matrix processing procedures within the mode choice routines. The access mode choices, and resulting travel volumes, are determined within the mode choice model.

In addition to developing impedances for numerous access mode/transit mode combinations, the procedure also uses market segmentation of both production and attraction zones to define the choices available to travelers. Up to five market stratifications are used for each zone:

- Short walk to premium station
- Long walk to premium station
- Short walk to bus
- Long walk to bus
- Drive only

These areas are defined so there is no overlap. A "short walk" is defined as up to 0.3 miles; a "long walk" is from 0.3 to 1.0 miles.

APPENDIX B

SOFTWARE VENDORS

The representation of transit services for travel demand analysis is achieved using software specifically developed for this purpose. A number of software suites have been developed by commercial vendors and are in use by planning organizations. Each software suite has specific capabilities and specific procedures for network representation, path choice and mode of access analysis. Users of this document seeking to implement a specific transit access representation method should check with software vendors to determine if the approach can be achieved in a given software suite and the detailed procedures.

A number of commercially available software suites offer the required capabilities. Vendors of several software packages known to have the necessary capabilities are listed in this Appendix in alphabetical order. Other packages offered by other vendors may also have the necessary capabilities. Address and phone numbers were compiled in early 1998.

CONTACTS: SOFTWARE PACKAGES

EMME/2
Michael Florian
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fax: (514) 369-2026

MinUTP, Tranplan and TP+
Urban Analysis Group
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Danville, CA 94526
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fax: (510) 838-1372
e-mail: general@uagworld.com

System2
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fax: (703) 820-7970

TransCAD
Caliper Corporation
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Newton, MA 02161
phone: (617) 527-4700
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fax: (703) 780-7874

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