Modeling MultiPath Transit Networks

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ABSTRACT

In analyzing transit investments, issues related to the distribution among access modes or competing routes are often critical to the evaluation. Presented in this paper is a method of transit path building that permits the consideration of multiple paths in mode choice and network loading. The technique is capable of subzone distributions at the access and egress ends of the trip as well as traditional mode-of-access distributions at the transit stops or stations. Included also is a description of the technique as installed in the Transportation Analysis Process (TAP) used by the North Central Texas Council of Governments (NCTCOG). The model builds the best, second-best, and third-best paths to each mode in the network. Specific criteria related to access and egress links are used to select up to seven trip tables that are then loaded to the paths according to the same criteria. The model has been calibrated and used in regional and subregional planning applications.

The function of transportation planning models is to simulate travel behavior at a reasonable cost. The trade-offs between the complexities of human decision making and computer modeling have resulted in an established set of modeling constructs that adequately address most regional issues. These techniques have been embodied in the Urban Transportation Planning System (UTPS). There are many theoretical shortcomings in the UTPS package, but most professionals would generally agree that the complex programming and data processing required to resolve these shortcomings are not cost-effective. Consequently, the UTPS is a standard in the industry because it adequately simulates regional travel behavior at a reasonable cost and has technical support financed by the federal government.

As the UTPS process gained acceptance and widespread application, the planning emphasis shifted from regional to subregional issues. The alternatives analysis process created a need for comparative ridership forecasting in subarea planning studies. Large macro issues such as the major facilities in a long-range regional plan were replaced by often subtle and subjective distinctions among alternative technologies. To accommodate the demands for detailed forecasts placed on regional agencies by the federal government, planners turned to developing elaborate mode-choice models. In many areas, these refinements adequately addressed the important issues. In other areas, planners were less satisfied with the results. Adding an elaborate mode-choice model to the generalizations and assumptions in the UTPS package seemed incongruent.

Presented in this paper are technical issues related to transit path building and a discussion on how these issues affect mode-choice and network-loading results. The ways in which various agencies have attempted to use the basic tools available in the UTPS package to improve the overall performance of modeling transit systems are described, and the advantages and disadvantages of these techniques are presented. The purpose of the paper is to demonstrate how a relatively simple improvement to the basic UTPS algorithm can overcome many of the problems associated with other techniques and can achieve that objective in a cost-effective and theoretically satisfying manner.

REGIONAL TRANSIT MODELING

In traditional modeling theory, transit trips are generated in a mode-choice model that evaluates the pertinent differences between the characteristics of a transit trip and a highway trip on a particular interchange. The trips are loaded onto a transit network to determine the ridership on a particular line. The UTPS process builds the best transit path between each interchange using the program UPATH. The characteristics of these paths are used in a mode-choice model to generate a trip table. This trip table is loaded to the transit network by the program ULOAD using the best path from UPATH.

There are several assumptions made by this technique that are worth noting. The first is that transit system capacity does not affect a traveler's path selection. Generally, this is a reasonable assumption. Line capacity is often well above ridership forecasts and most transit patrons have relatively few alternative paths available for their particular trip. If the programming difficulties and costs are considered, the decision to accept this theoretical shortcoming is understandable. The complexities of transit path building using trip segments (i.e., boarding and alighting pairs) do not lend themselves to the individual line-segment analysis required for capacity-constrained modeling.

A second assumption is that the characteristics of the best path are sufficient for mode-choice analysis. From a regional perspective, the detail required for adequate mode-choice analysis is primarily associated with line-haul characteristics. A regional zone structure is often aggregate enough to make transit access considerations impractical. The zones are so large that reasonable walk distances have little meaning as far as access or coverage concepts are concerned. The result is a regional mode-choice model calibrated with the explanatory variables available to a regional data base. From a path-building perspective, adequate line-haul information can be obtained from a best-path model.

The third assumption is that all transit trips between any two points will use the best path. The
logic behind this assumption has several dimensions. From a regional perspective, line-specific ridership is only an issue on large line-haul facilities such as buses on all lines, or multi-occupancy vehicle lanes. The best-path loading will reasonably forecast large line-haul facilities. The access and feeder systems are generally ignored in regional modeling because they serve only a supporting role to the purpose of the study. If they are evaluated, it is at a line group or large area level of aggregation. At this level, the obvious inaccuracies of the individual components are averaged away and often show reasonable results.

From the perspective of cost, best-path loading is a practical reality. Path building—transit path building in particular—is an expensive endeavor. Transit path building is complicated to the critical influence of transfers on path selection. The decision of which link to take next is dependent on the mode and line of the current link. As mentioned earlier, this requires that transit path building be organized around trip segments rather than links. The relatively few links in a transit network are expanded into a large set of potential boarding and alighting pairs before path construction. The number of options that the program must consider is related to the permutation of the number of stops on each line. Therefore, it is highly desirable that transit paths be built only once and used directly in trip loading.

Even if cost is not an issue, there are few benefits in using a multiple path concept on a regional planning study. The only issue that may be important is the mode of access at line-haul stations. Concerns related to the forecasts prepared for several new rail projects in this country have focused attention on the mode-of-access assumptions. Even with a multiple path model, mode of access cannot be accurate on a regional zone structure without a relatively sophisticated concept of zone coverage in the mode-choice model as well as the path selection process. Controlling the mode-of-access results in the network coding phase of the study is perhaps a more cost-effective solution to the problems that have occurred. An awareness of the bias that is created by inaccurate or inappropriate coding is a major step toward minimizing problems associated with the mode-of-access elements of a regional model.

For regional transit modeling, the traditional modeling systems, such as UTPS, achieve the primary objective of transportation modeling. The best-path algorithm can provide adequate results for the majority of regional issues at a cost that is compatible with the accuracy required for mode-choice and network-loading procedures.

**SUBAREA PLANNING ISSUES**

The purpose of subarea planning is to enable accurate forecasts to be made at a level of detail beyond that which is advisable from a regional modeling context. Subarea modeling is the basic process of developing a zone structure compatible with the level of detail of the network to be evaluated. Subarea types of analysis could be performed at the regional level if the network size and total number of zones could be cost-effectively processed. The problem is that the cost of computer processing is closely related to the square of the number of zones. If cost were not an issue, the difficulties in managing the space and core requirements for such large data bases or the human elements of error and limited comprehension make detailed regional planning inadvisable.

A natural outgrowth of these concerns is subarea planning. The problem size is limited so as to be manageable yet detailed enough to produce the needed results. In other words, the basic modeling process is applied on a smaller geographic area. For highway planning, this presents no major difficulties. Some adjustments must obviously be made to trip distribution relationships and correction factors, but this is exactly the purpose. Subarea planning affords the modeler the opportunity to refine regional relationships to more accurately address the area-specific characteristics. The objective is to produce a better forecast in the area of interest. Beyond model validation, there is no significant theoretical difficulty in using a capacity constraint procedure developed for modeling freeways and major arterials to forecast traffic on minor arterials and collectors. It may be desirable to modify volume-delay relationships on low-capacity facilities, but it is not theoretically necessary.

Unlike highway planning, transit planning at the subarea level is not theoretically compatible with regional modeling techniques. Subarea transit issues focus greater attention on the mode of arrival and local service elements of the system. The performance characteristics and distributional concerns of these sub systems are different from the line-haul characteristics of major routes. At the subarea level, it is no longer possible to ignore the submode access and coverage concepts. The mode-choice and path-building models need to incorporate these elements if they are going to be used to forecast demand for each component of the transit system.

In order for a subarea model to accurately estimate demand for transit subsystems, the implications of walking to or from a transit facility must be explicitly incorporated into the model. The two basic dimensions of the walk choice are walk distance and drive opportunities. These are more commonly called walk coverage and mode-of-access issues. Walk coverage is defined as those trips for which a reasonable walk (i.e., 0.5 mi) is available to and from the transit facilities. Mode of access is associated with the subchoice between walking or some form of driving such as park-and-ride, kiss-and-ride, and pool-and-ride.

Figure 1 shows a typical mode-of-access and coverage subsystem. The figure shows two feeder bus lines serving a rail facility. The zone in question has been connected to the network through a drive approach to station A and two other approach routes to nodes B and C. Unless significant bias factors are introduced into the path-building algorithm, the best path to the rail line will always use the drive approach to station A. The time to walk and wait for the bus, travel by bus, and transfer to the rail line will invariably be worse than driving to the station. A one-path model will evaluate the mode choice based on the drive access and will load all trips to this

**FIGURE 1** Subsystem example.
The first technique is perhaps the most obvious. It attempts to remove the need for multiple paths by increasing the zone detail in the vicinity of the facilities in question. This is a normal part of subarea planning. The difference is that the number of zones is not a function of the transit system as much as it is a function of the access issues. Each zone must, therefore, be small enough to reduce the walk options to a single choice. If a walk distance of 0.5 mi is assumed, the zones cannot exceed a 1-mi² area. In areas where parallel service exists, the zones must be divided so as to separate the access between the two lines.

The detailed zone-structure technique attempts to reduce the need for market segmentation and coverage considerations. It will smooth the assignment by providing more detailed and frequent access points. All people within the zone are by definition within walking distance of the access point, so no coverage analysis is needed. Those areas without walk access are provided drive opportunities or no access at all. The technique cannot resolve the distribution between drive and walk options for a particular interchange. It provides only the results by providing more frequent analysis. It is also rigid and time-consuming to construct. For this technique to work, the zone structure must be network-specific. Each network alternative would require a modified zone structure. The computer costs associated with path-building and mode-choice analysis for a large number of zones are exorbitant. The technique improves the results at the expense of time and computer resources.

The second technique is one that attempts to address all of the access issues within the mode-choice model. In this approach, the best path is modified before the mode split. The access portions of the path are stripped away according to various criteria. Only the line-haul characteristics of the path remain. The access alternatives are derived by a separate procedure and are evaluated alongside the line-haul characteristics by the mode-choice model. These access alternatives generally include identification of walk and feeder bus options and alternative park-and-ride opportunities. They also include an allocation of zone coverage and average walk distances. These data are generally prepared by hand and are fairly detailed in nature.

FIGURE 2 Walk coverage example.

MULTI-PATH MODELING USING UTPS

Several techniques have been developed to perform transit subarea planning using UTPS models. Each of these techniques attempts to resolve the problem discussed in the previous section. In this section, each technique will be presented along with a discussion on its advantages and disadvantages. The critique will focus on two measures of effectiveness. The first is the ability of the procedure to address the shortcomings of the one-path approach. The second is the cost-effectiveness of the procedure. In other words, does the technique produce reasonable results on a reasonable schedule for a reasonable cost?

Zone-Structure Techniques

The detailed zone-structure technique attempts to reduce the need for market segmentation and coverage considerations. It will smooth the assignment by providing more detailed and frequent access points. All people within the zone are by definition within walking distance of the access point, so no coverage analysis is needed. Those areas without walk access are provided drive opportunities or no access at all. The technique cannot resolve the distribution between drive and walk options for a particular interchange. It provides only the results by providing more frequent analysis. It is also rigid and time-consuming to construct. For this technique to work, the zone structure must be network-specific. Each network alternative would require a modified zone structure. The computer costs associated with path-building and mode-choice analysis for a large number of zones are exorbitant. The technique improves the results at the expense of time and computer resources.

Mode-Choice Techniques

The second technique is one that attempts to address all of the access issues within the mode-choice model. In this approach, the best path is modified before the mode split. The access portions of the path are stripped away according to various criteria. Only the line-haul characteristics of the path remain. The access alternatives are derived by a separate procedure and are evaluated alongside the line-haul characteristics by the mode-choice model. These access alternatives generally include identification of walk and feeder bus options and alternative park-and-ride opportunities. They also include an allocation of zone coverage and average walk distances. These data are generally prepared by hand and are fairly detailed in nature.
The mode-choice model is provided with all of the basic data needed to conduct the detailed submode analysis. The model can be structured with several nests of drive, walk, or feeder bus options, the trips can be segmented into those with walk opportunities and those without, and detailed reports of the submode analysis at each zone can be produced. What the model cannot do is guarantee that the selected options were actually available for any particular trip. The zone-related access data are not easily correlated with the line-haul path. But perhaps more important, the results of this detailed analysis are never assigned to a transit network. All of the trips on a particular interchange are loaded onto the best path. In other words, the final result has a better estimate of transit trips, but the ridership on any particular line does not show how the trips were actually made. Only through complicated hand analysis is it possible to adjust some of the results to reflect the mode-choice distribution. The process requires considerable time to (a) prepare the access inputs needed for mode choice and (b) hand-adjust the network loading in exchange for a presumably better estimate of total transit demand. This procedure does not produce reasonable network results and the cost of time may be exorbitant.

Multiple-Path Techniques

Perhaps the most comprehensive approach is one that constructs alternative paths, uses them for mode-choice analysis, and loads the corresponding trip table to each path. This can be done with UTPR by selectively adjusting the parameters in UPATH to generate the desired path. The concept of running UPATH generally restricts multiple-path considerations to the best walk path and the best drive path. The characteristics of the two paths are used by the mode-choice program to distribute trips between walk and drive options and to improve the estimate of the automobile-versus-transit probability. The transit share is split into walk and drive trip tables to be loaded to the two networks by ULOAD. The two assignments are merged to produce the final result.

The use of several minimum paths performs particularly well at distributing trips between drive and walks. However, it does not distribute trips among several drive or several walk options. The assumption is that all travelers can and will take the best path. For large zones or dense networks, the distribution among walk or drive options, or both, can be important. In fact, the alternative walk or drive paths may be more attractive than the opposite mode option. The distribution among walk paths is also coverage-dependent. The combination of coverage and path is necessary for a smooth and logically distributed assignment. Smaller zones can help to reduce these concerns but that raises the cost. This process is extremely expensive from a computer resource point of view. Increasing the number of zones would make it much more costly. If care is taken and enough time and computer resources are available, this method can work.

Postprocessing Techniques

A postprocessing technique is a way of adjusting the results to reflect access issues. It assists the hand adjustments that are necessary to smooth and rationalize the performance summaries and ridership estimates. In this approach, the access components of the paths are stripped after loading. The ridership is distributed among the alternative access options by mode- and distance-choice relationships derived from observed data. The access options are developed from the network data and hand-coded paths. The process is generally limited to transit stations because each zone and line-haul access combination must be addressed individually.

The postprocessing approach does not improve on the overall modeling process; however, other techniques could be used in conjunction with this approach to improve the overall results. By itself, there is no correction for access or coverage issues made to the estimate of total transit demand. If the model does adjust demand it will only adjust the access legs and not the line-haul legs. The fact that the process is zone-to-station-related makes it less practical for improving the local and feeder bus components of the transit system. The approach is, however, a relatively inexpensive solution to the station access issues faced by many studies.

A NEW APPROACH TO TRANSIT MODELING

The preceding concerns led the author to formulate a new approach to transit modeling. The approach that was selected resolved many of the problems previously mentioned and maintained the objectives of cost-effectiveness.

The approach takes maximum advantage of an aspect peculiar to transit path building—that of legs. Unlike highway paths where each subsequent link is independent of the previous link, transit paths are dependent. Because of this fact and the logic of a path-building program, the transit system is converted from links to legs. A leg is defined as a trip between a potential boarding and alighting sequence. By converting the network to legs, the path builder can assume that selecting a leg will require a boarding and thus a transfer. A transit path is a short sequence of legs constrained by the maximum number of transfers permitted.

The technique involves a traditional UPATH-like minimum-path-building exercise. As the best path is being built, alternate path information is stored. The key to the process is that the second- and third-best paths to any particular node are controlled by their association with zone connectors (i.e., mode-of-access alternatives). In other words, a path is only considered an alternative to the best path if it serves a different access or egress location (i.e., a different part of the zone) or a different mode of access. In this way, extraneous alternative paths are eliminated. Because the transit paths involve only a few legs, the computational efficiency is not compromised when checking the access link of a potential alternative. The assumption is that the leg or the previous leg must be a zone connector for consideration in the alternative path table.

The result of this technique is a series of alternative paths to intermediate nodes on the best path. This path is much smaller; the locations and mode serving a particular interchange are made available for consideration by the mode choice model and to the transit-loading program. The trip tables associated with the path alternatives are interchange-specific and, therefore, are appropriate for loading the logit distribution of the access alternatives of that interchange. The model can address the distribution both between modes and among potential access points simultaneously as fully dependent alternatives.

Because egress options are also considered, a distribution of destinations within the zone is developed. In addition, the characteristics of the trip to the egress alternatives are included in the analysis. The egress alternatives may include line-haul paths different from that of the best path. In
this way, multiple line-haul options are considered. Using the same argument on the various access locations reveals an additional source of multiple path alternatives.

It must be noted that no effort is made to force the consideration of all modes of access or line-haul options. This is not, however, a weakness of the technique, but a strength. In a technique that finds the best walk path and then the best drive path, the data about the second-best walk path and the second-best drive path are ignored. The mode-choice model will only compare the two best paths. When the second- and third-best paths are developed (regardless of mode), the truly bad paths are never selected and therefore are not considered by the mode-choice model. The prescreening of paths keeps the mode-choice model from assigning trips to unrealistic alternatives while, at the same time, concentrating the analysis of coverage and opportunity on all viable alternatives. The mode-choice model can, therefore, assign trips to more than one park-and-ride lot or more than one feeder bus line that is appropriate for the particular interchange.

This approach coordinates multiple-path and mode-of-access alternatives through path building, mode choice, and loading. It requires only one pass through the path-building algorithm and is therefore relatively inexpensive. It serves the needs of mode-choice modeling and produces realistic distributions of ridership profiles even with large zone sizes. The approach serves the needs of the planning community at a reasonable cost.

A MODEL DESCRIPTION

The previous modeling approach has been installed and applied. The latest version of the TAP developed by the NCTCOG includes the multiple-path transit networking techniques presented herein. The approach was developed in direct response to the needs of the Dallas Area Rapid Transit (DART) staff for accurate mode-of-access data at rail stations. The forecasts were performed on a regional forecast zone system of 800 zones. The access distribution within the large zones; between competing stations; and among walk, drive, and feeder bus modes was critical to the analysis. The model that resulted is described in the paragraphs that follow. It has been calibrated and applied with reasonable success.

The transit path-building algorithm used in the TAP model is a typical best-path technique. The minimum cumulative impedance path from each origin to all destinations is determined by the "bush" method of path building. The leg impedance is a function of travel time, distance, cost, waiting time, level of service, and a link-specific bias factor. Each impedance parameter varies by mode and is cumulative. The value of a transfer to a particular mode and the transfer costs are added to the impedance as the path is being built. Mode-to-node transfer prohibitions and the total number of transfers are also considered during path building.

A transit path can typically be described with only three to five transit legs. The relatively few legs that represent the best path and the numerous alternative legs that serve the same path are used by the path-building program to construct up to seven alternative paths. The second- or third-best path to a node is used in conjunction with a set pattern of access and egress alternatives to define the alternative paths. The first path is the best path. The second through fourth paths are constructed from the set of second-best paths to nodes along the best path. The order of inclusion is

1. The first alternative path closest to the destination that is, or whose next leg is, a zone connector.
2. The next alternative path after the first mentioned in item 1 that is, or whose next leg is, a zone connector.
3. The first alternative zone connector at the destination.

The first two alternatives approximate a distribution of access links and the third alternative is an egress option. Paths five through seven use the same inclusion technique with the third-best paths to each node along the best path.

Figure 3 shows an example of the path-building logic. The best path is the drive connector (mode 2) path Z1-A-C-D-Z2. The first alternative path diverts at the last node with an alternative path whose leg or previous leg is a zone connector. In this example, the second path is Z1-B-C-D-Z2 because B-C is the last alternative path. The third path would be the walk connector (mode 1) path Z1-A-C-D-Z2 because this is the second-to-last alternative path whose leg or previous leg is a zone connector. The fourth path is the egress option Z1-B-E-Z2.

To take this example to the next logical step, Figure 4 adds the third-best path options to the network shown in Figure 3. The best path is Z1-P-C-D-Z2. The second-best alternative path from the last node with an alternative path in Z1-P-C-D-Z2. This would be used as the fifth path. Because there are no other logical paths from node A, the sixth path would be missing. In other words, not all interchanges will have seven path options available to them. The seventh path would be the egress option Z1-B-Q-Z2.

After the best and alternative paths are constructed, the path summary files and reports are generated. The node-and-mode string representing the best path is stored for path loading. The second- and third-best alternate branching nodes are saved as needed. From these three arrays, up to seven paths are reconstructed during path loading. The zone-to-zone summary files are also generated. The mode-choice model requires, at a minimum, the cumulative impedance and the access codes for each path. Access codes include the access mode and link number, the

![FIGURE 3 Path-building example.](image1)

![FIGURE 4 Additional path alternatives.](image2)
first transit mode, the last transit mode, the level of
service, the principal mode (i.e., the mode with
the greatest cumulative contribution to distance),
and the number of transfers. The mode-choice model
may optionally require in-vehicle travel time, dis-
tance, cost, or out-of-vehicle travel time skims.
These data are available only for the best path.

The mode-choice model is an aggregate nested logit
model with accessibility segmentation. Each origin-
destination interchange is first evaluated at the
transit and highway submode level. A combined utility
is then used to determine the highway-versus-transit
shares. The highway and transit share is then dis-
tributed among the appropriate submodes. For the
purposes of this paper, the remainder of the discus-
sion will focus on the implications of the multiple-
path algorithm on the mode-choice and path-loading
programs.

The accessibility segmentation process involves
dividing the trips between the share of the zone that
is accessible to transit by walk or drive and that
which is only accessible by driving. The walk cover-
age is the sum of the coverage of each unique walk
connector identified by the seven paths. A separate
sum is made for local and express-mode first board-
ings. The access walk links are also summed independ-
ently from the egress walk links. The sum of the
local mode coverage at the access zone is tested
against the maximum allowable local coverage for that
zone. The express mode at the access zone and the
local and express egress coverage are likewise com-
pared with the appropriate maximum coverages. If any
of the maximums are exceeded, the coverage of each
link using that particular access or egress class is
factored down to the maximum. The resultant coverage
for any particular interchange will not exceed the
maximum by access or egress and local or express
categories. The walk-access coverage is the maximum
sum of the local and express options for each walk
link. The egress coverage is the corresponding sum
at the destination zone. The maximum number of trips
on the interchange covered with walk access is the
minimum of the walk access and egress coverage.

Figure 5 shows an example of the walk-access cal-
culations. The path builder used three walk connec-
tors in constructing the seven paths. The shaded
coverage areas for nodes A, B, and C are summed as an
estimate of total coverage. In this example, the
coverage beyond the zone boundary and in overlapping
areas should be subtracted from the estimate of total
coverage. This is done by factoring the total cover-
age back to the maximum coverage permitted for the
zone.

In the example shown in Figure 5, the best path
used node B. Because the coverage for B is not larger
than the total coverage for the zone, the transit
utility for the best path will only apply to the area
covered by B. The utility experienced by people
travelling from A or C will be different from B. The
weighted average utility is the utility of the path
through B, weighted by the full area it covers, and
the utilities of A and C, weighted by the total area
minus the area of B, divided by two.

The utility of the walk access is determined from
a composite of the walk and utility of each
access link. A comparison between the best single
access link coverage and the total walk-access
coverage is first made. If the single coverage is
equal to the total, the walk utility is the utility
of the best walk path. If the single coverage is less
than the total coverage, the walk utility is based
on the ratio of the single coverage to the total
coverage. This ratio multiplied by the best walk-path
utility is added to a percentage of the remaining
walk-path utilities. The percentage is 1 minus the
ratio divided by the number of additional walk-access
links. This method attempts to capture a weighted
average utility based on overlapping coverage.

The composite walk utility and coverage and the
drive utility and coverage are compared with the com-
posite highway utility in two parts. The first part
represents that portion of the zone that has walk and
drive options. The number of trips affected is equal
to the walk coverage of the interchange. The second
part represents that portion of the zone that has
drive access but no walk access. The number of trips
affected is equal to the positive difference between
the drive coverage and the walk coverage.

The transit share from each segment is propor-
tioned back to the appropriate paths according to
its contribution to the segment utility. For the
walk and drive segment, the trips are first divided among
walk and drive paths accorded to the composite walk
utility and drive utility. The drive share is added
to the transit share from the drive-only segment to
obtain the total drive share. The trips on each walk
or drive link are distributed according to their
share of the total walk or drive utility. Trips are
also proportionally divided among the paths using a
common link. The final result is a trip table for
each path. Because the number of transit trips di-
vided among seven paths on each interchange will
generally be small, the trips are stored in hun-
dreds of trips to avoid round-off error in the trip
tables.

The seven trip tables from the various trip pur-
poses are summed and loaded to the paths constructed
by the path-building program. The trips are first
posted on each leg of the corresponding path. The
node-and-mode sequence of the best, second-best, and
third-best paths to each node are traced back to
the access and egress mode criteria previously
discussed. Data regarding the node numbers, mode,
previous mode, next mode, and volume are stored for
each leg of each path. The one-way leg file is then
merged with the legs of each path. Access and egress
mode contributions are leveraged for each leg of
the network. The access modes include walk, drive,
express bus, and rail. The egress modes include walk,
b express bus, and rail. The result is a single-
leg record of all lines of that mode with a distri-
bution of boarding and alighting transfer activities.
The combined leg is distributed to the line legs acco-
cording to the proportion of each leg's share contrib-
uting relative to the sum of the weight of all legs.
The leg data are then summed and posted on each link
of the line. Reports are generated that summarize
the ridership in both directions on the link accord-
ing to boarding and alighting activities at each
node.

FIGURE 5 Walk coverage and utility.
CONCLUSION
The technique for multipath transit network analysis as presented in this paper and as installed in the TAP is a significant improvement to the generally accepted algorithms. It provides substantially more data for mode-choice modeling and is capable of posting the results of that analysis on individual lines. It also handles the mode-of-access issues related to subzone distributions and competing access and egress locations. These improvements are cost-effective. The model applications developed for the TAP process are no more expensive to use than a single application of the UTPS counterparts. The technique achieves the objective of improved theoretical modeling at a reasonable cost of time and computer resources.

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Estimating Cost Savings Attributed to Improvements in Railcar Reliability and Maintainability for the Chicago Transit Authority
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ABSTRACT
The findings of an analysis of railcar fleet reliability and maintainability for the Chicago Transit Authority (CTA) and the development of cost models to assess the cost effectiveness of railcar rehabilitation and replacement program alternatives are presented. Data files and extensive discussions with CTA maintenance personnel provided the basic data on maintenance and operations; detailed cost data for each railcar series were also provided by the CTA. Reduction of the data yielded reliability-maintainability factors such as mean time between failures, mean time between maintenance, mean time between inspections, mean time to repair, mean time to maintain, and mean time to restore. Using this information and a previously developed modeling approach, models for estimating cost savings attributed to improvements in mean time to maintain and mean time between maintenance were prepared for the 2200, 2400, and 2600 Series of railcars for the CTA fleet. Models for estimating fleet capital cost savings as a result of improved railcar reliability and maintainability were also prepared. Specific suggestions for using these models in maintenance practice to estimate cost savings from alternative actions were presented.

The authors recently completed a project for the Chicago Transit Authority (CTA) that was aimed at answering a number of questions regarding current CTA railcar maintenance practices and evaluating alternative programs that include overhauls, rehabilitation, and replacement (1). As part of the project, the authors carried out an analysis of CTA fleet reliability and maintainability to establish the cost effectiveness of rehabilitation and replacement pro-

gram alternatives; this aspect of the project is reported on in this paper.

RAILCAR PERFORMANCE EVALUATION
Transit properties generally collect the same basic types of information relating to transit vehicle operation and maintenance (2). These include data on revenue service incidents, periodic inspections, and maintenance activities. Vehicle maintenance data are also generated in the same basic manner at most properties: a vehicle problem is reported in revenue service or is discovered during maintenance, the