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 node 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 generalities 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 level of 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

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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 busways, rail lines, or high-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 subsystems 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 walk links 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

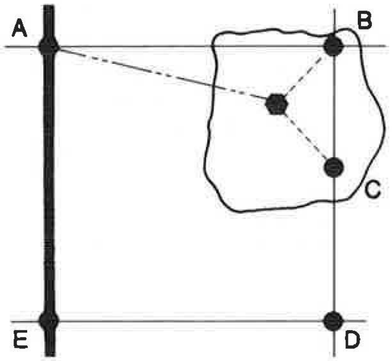

FIGURE 1 Subsystem example.

access link. If this example is typical of other zones in the vicinity of station A, the mode-of-arrival distribution will overestimate driving and underestimate feeder bus.

In the preceding example, the best path was selected irrespective of the characteristics of the zone. In all likelihood, the mode-choice model did consider the characteristics of the zone in choosing between the transit and highway paths. These characteristics may include such aspects as income, automobile ownership, or household size. If the mode-choice model is calibrated to consider the socioeconomic characteristics of the zone in combination with the access mode of the path, the overall demand for the path can be significantly biased. For example, assuming the zone represents a depressed area with little automobile ownership, the fact that the best access to transit is automobile-related may cause the mode-choice model to underestimate the transit demand from that zone to all paths using the rail line.

If the best path from the zone in Figure 1 includes the walk to node C and the bus line from node C to node D, the one-path process will load transit trips to this path. Here again, the path was selected irrespective of the characteristics of the zone. In particular, the mode-choice model is not informed about how many of the people in the zone can actually walk to node C. The assumption is that all households are within a reasonable walking distance of that location. If the zone is large, this assumption is incorrect. Figure 2 shows the coverage areas for the walk connections at nodes B and C. For all of the shaded area surrounding node C, the path of choice is the best path. For people living outside the coverage of node C but within the coverage of node B, the path of choice involves walking to node B and riding from node B to node C to node D. For the portion of the zone not covered by nodes B or C, the only path option is to drive to station A, ride the rail line to node E, and transfer to the bus serving nodes E and D.

The preceding example suggests that there should be at least three paths from the zone to node D. Each of these paths serves a different constituency and has a different probability of choosing transit. The same concept could easily be extended to the previous discussion related to access to the rail station A. The model should consider the drive to station A as well as the walk paths using nodes B and C. This would permit the mode-choice model to distribute the access among the drive and walk options based on the actual differences in the paths as well as the socioeconomic characteristics of the zone. The access distribution should then be loaded to the appropriate paths for performance analysis. The results of the model would, therefore, show a smoother and more logical generation and assignment of trips on the various access options and ultimately on the transit lines.

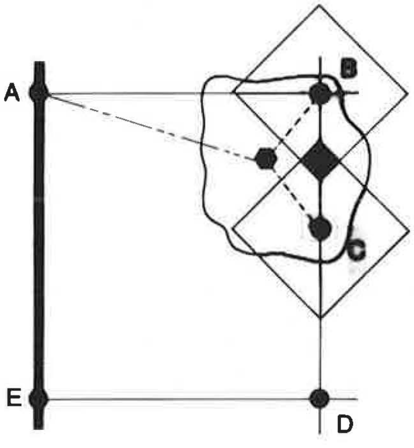

FIGURE 2 Walk coverage example.

MULTIPATH 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 shortcoming 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 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-mi^2 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 can only smooth the results by performing 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 evaluation 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 UTPS by selectively adjusting the parameters in UPATH to generate the desired path. The cost 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 walk options. 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 postprocessing 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 means that each realistic access location and mode serving a particular interchange is 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 mode-choice 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-mode 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.

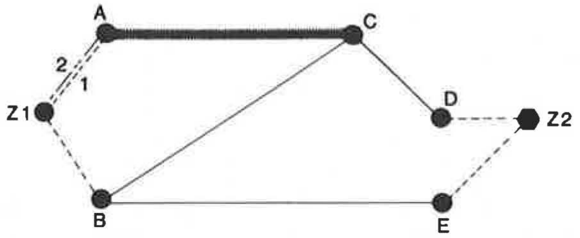

FIGURE 3 Path-building example.

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-F-C-D-Z2. The second-best alternative path from the last node with an alternative path is Z1-F-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-G-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

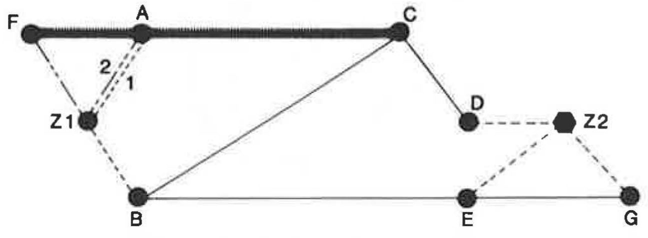

FIGURE 4 Additional path alternatives.

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, distance, 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 distributed among the appropriate submodes. For the purposes of this paper, the remainder of the discussion 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 coverage 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 boardings. The access walk links are also summed independently 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 compared 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 calculations. The path builder used three walk connectors 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 coverage 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 traveling 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.

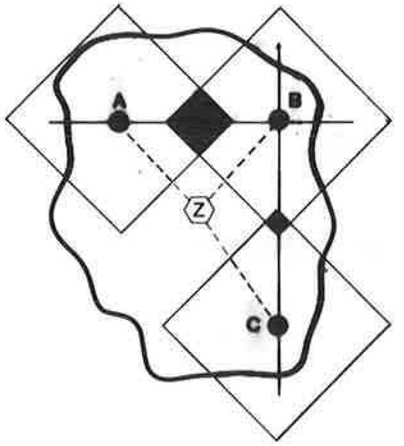

FIGURE 5 Walk coverage and utility.

The utility of the walk access is determined from a composite of the coverage and utilities 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 composite 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 proportioned 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 divided among seven paths on each interchange will generally be small, the trips are stored in hundredths of trips to avoid round-off error in the trip tables.

The seven trip tables from the various trip purposes 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 according 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 distributions are saved for each leg in the network. The access modes include walk, drive, bus, express bus, and rail. The egress modes include walk, bus, express bus, and rail. The result is a single-leg record of all lines of that mode with a distribution of boarding and alighting transfer activities. The combined leg is distributed to the line legs according to the proportion of each leg's service rating 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 according to boarding and alighting activities at each node.

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.

The opinions and viewpoints expressed in this paper are those of the author and do not necessarily reflect the viewpoints, programs, or policies of any federal, state, or local agency.

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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 program 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

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