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Integrating Geographic Information Systems into Transit Ridership Forecast Models

Kamal T. Azar
Joseph Ferreira, Jr.

Researchers have produced sophisticated modal split and transit demand models, including forecasts that are sensitive to the level of service. However, little effort has been made to integrate these models into corridor studies and route alignment analyses since (a) re-routing is itself an extremely complex modeling task, and (b) the results of the demand models are presented in tabular form with no facility to visualize spatial patterns and relationships that, if recognized, would aid in the routing tasks.

GIS tools can be used, together with the demand models, to identify both clusters of city blocks that house families with certain socio-economic characteristics and potential trip destinations conducive to transit use. In other words, GIS tools can be used to better measure some of the factors that are needed by transit demand models. The results of these models can be displayed graphically, enabling analysts to target places needing improved service, evaluate route re-alignment alternatives, and operate more efficient and effective bus lines.

This paper examines how a particular class of model used by transit agencies for estimating ridership can be integrated with GIS tools in order to facilitate such analyses. It also explores the effects of visualization of routes, demographics, and employment data on the process of designing route alignments with better targeting of high transit ridership areas. This paper is part of a research project sponsored by the Region One University Transportation Center, at MIT.

Introduction

Transit operators are under great pressure to limit operating costs and provide efficient and effective services. As a result, it is vital for transit managers to be able to look at their existing services and determine whether they meet the overall objectives of the agency. A lack of appropriate analytical tools for examining the efficiency of services compounds this problem. There is a crucial need for ridership forecasting techniques to help in the examination of existing routes and the planning of new ones.

The objective of this project is to examine the benefits of using Geographic Information Systems (GIS) tools for developing transit

Kamal T. Azar is a Ph.D. candidate and Joseph Ferreira, Jr. is Professor and Director of the Computer Resource Laboratory, Massachusetts Institute of Technology, Cambridge, MA, USA.
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ridership estimation models capable of forecasting changes in ridership which may be associated with changes in bus route alignment and other modifications to the characteristics of a transit service. The transportation literature describes a large number of models developed for the estimation of transit ridership. However, most such models require a considerable amount of data and computational power and are complex enough to make them difficult to use given the resources available to the average transportation planner. Less complex models with decreased data requirements and relatively simpler algorithms also exist. While these models may be less accurate in forecasting the system equilibrium effects of major changes on routes, they can be helpful in analyzing the (quasi-static) effects of changes on individual bus routes and corridors. In this project, one of these simpler models is encoded inside a GIS in order to explore the potential of the geographical capabilities of GIS technology to make such models more user-friendly and flexible.

Selection of Transit Ridership Forecast Model

Four-step travel demand models are generally used to determine transit ridership between each traffic analysis zone of a study area. The sequence of trip generation, trip distribution, modal split, and trip assignment models generate transit trip tables. Calibration models which use on-off passenger counts are used to correct the transit trip tables. See Stopher and Meyburg 1975, Morlok 1978, Manheim 1979 for further reading about the 4-step travel demand models. More recently, the GIS literature has contained many articles related to the potential benefits of GIS in improving the various phases of the four-step travel demand models [Nyerges and Dueker 1988, Nyerges 1989, Lewis 1990, Shaw 1993]. These travel demand models are generally good at forecasting ridership, although sometimes they are not as reliable as desired because of the many assumptions often made due to lack of data. Moreover, the process of data procurement, model calibration, and results validation is so complex that simpler models [e.g., Smith 1979, Batchelder et. al. 1983. Krechmer et. al. 1983, Tri-Met 1983] start to look desirable.

These simpler models are appropriate for exploring short-range, route-level effects where the route alignment and scheduling changes under consideration are local in nature and unlikely to have significant system-wide repercussions that would necessitate recalibration of the trip generation, trip distribution, or modal split patterns. Such situations are the focus of concern in this paper. That is, we are interested in how GIS can help transit planners explore the sensitivity of ridership to local changes in route alignments and schedules by providing interactive tools for re-computing and displaying routes and ridership patterns that are likely to result under various 'what-if' scenarios. In particular, we are interested in models that could predict transit ridership along a route based on the socio-economic attributes of an area, the physical characteristics of a bus route, and the attractiveness of down-route trip destinations. The "Period Route Segment" (PRS) model, developed by Batchelder et. al. 1983, most closely matched these interests and was selected for use in this paper as an example of the type of (simpler) model that could be incorporated into useful GIS tools for exploring routing alternatives.

We expect the value of using GIS technologies to extend beyond providing a map-based 'front end' to the demand model. Even when route, ridership, and demographic data are readily available, calibrating and running the models requires the integration of many layers of information in a useful and meaningful fashion. Merging information about local land use and the socio-economic characteristics with the relevant transit routes and ridership data is quire complex. This complexity is related to the many layers of detailed information that need to be stored and maintained and to the need, on occasion, to investigate the effect of more than one layer at a time. Moreover, as digital land use information and related maps become more common place, it is increasingly likely that some of these layers are generated and maintained outside the transit agency. Hence, there is an increasing need to have systematic and robust capabilities for integrating and managing large sets of geo-referenced data and computing spatial overlays (i.e., combining several layers of information together based on geographic location). This is especially true for analytic tools aimed at providing interactive exploratory capabilities.

Period Route Segment Model

Multisystems[1] developed the "Period Route Segment Model" for the Southern California Rapid Transit District (SCRTD) as part of Urban Mass Transportation administration (UMTA)[2], research aimed at developing and testing improved route-level ridership prediction techniques. This model estimates the A.M. peak and the midday boarding in each direction for every segment of a route based on the characteristics of the route and the service provided. Separate calibrations are developed for each period of time.

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1 Multiplications Inc., Multisystems, the Consulting Division, 1050 Massachusetts Avenue, Cambridge, MA 02138.

2 Now known as Federal Transit Administration (FTA).

Ridership on a segment is a function of three factors, according to this model: (1) a "production factor" related (via demographics) to the ability of an area to produce transit trips, (2) an "opportunity factor representing the ability of areas down route to motivate persons to take these trips along that route, and (3) a "level-of-service factor" related to the quality of the service provided along a route. The general form of the model is:

$$BOARD_i^d = PROD_i * OPP_i^d * LOS_i^d$$

where:

$BOARD_i^d$ is the boarding count on segment i in direction;
$PROD_i$ is the trip production factor in the area around segment i;
OPP_i^d is the trip opportunity factor in direction d from zone i;
LOS_i^d is the quality of service in segment i in direction d.

The production factor represents the ability of the area surrounding a transit route segment to generate trips. Trip production is directly proportional to the number of adults, the total population, the employment, and the route distance in each analysis zone; and is inversely proportional to the level of income in an area. An adjustment factor, based solely on the average monthly rent in a zone, is used as a surrogate for the income level is each area.

The opportunity measure used by the model reflects the capability of area around a transit route segment in the down-stream direction from the origin zone to attract transit trips. It is assumed that passengers are ready to select the transit mode if their destination is at least a 6 minute ride from their origin and at most a 35 minute ride. Transferring passengers are expected to remain on board a second bus for not more than 15 minutes or less than 3 minutes. The opportunity factor is therefore related to population and employment within a quarter mile of the route, for trips between 6 and 35 minutes and (3 to 15 minutes of transfer bus ride time) from an origin.

The level-of-service factor is based on the expected wait time for service and the seat availability on a bus. The wait time is directly related to the average headway between buses, whereas the seat availability is dependent on the cumulative running time of a bus. It is assumed that at peak hours seats become less available as the bus approaches the end of a route.[3] The specific model formulae and

3 Batchelder also assumes that the transit route originates from an area of trip productions and terminates in an area of trip attractions. As a matter of fact, seats may not become less available as the bus approaches (continued on the next page)

variables are given in Appendix 1.

Encoding the Model Inside a GIS

The Period Route Segment (PRS) model requires the computation of several variables which have a spatial attribute. These variables, such as employment opportunities or people living within a quarter mile of a bus line or the stops that belong to routes that generate transfer trips, can be manually calculated or approximated from maps. A GIS system, in addition to its capability of more accurately and quickly computing these variables, is also useful in permitting visual examination of the alignment of transit routes and the results of "what if" adjustments to the characteristics of these routes.

Some of the variables that are required by the PRS model are readily-available while others require significant manipulation. U.S. Census block group boundaries and related census data are sources of much of the needed information. The transit analysis zones are defined by sets of block groups around a segment of a route.[4] Following is a list of the required variables with the strategies adopted for computing each.

Production Factor

The production measure for each analysis zone is based on the average monthly rent, total population, adult population, number of riders on routes that cross or feed the study route, and the route length within the traffic analysis zone. Rent and population data are available from the U.S. census, whereas the number of potential transferring riders and the route distance need to be computed. As discussed above, the model assumes that the area that produces transit trips is the one within walking distance from a route (i.e., a

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3(cont.) the end of the route. Seat availability can be thought of as a function of the number of trip production points (stops) and trip attraction points which have already been passed. Thus a bus that originates in a residential area will have it seat availability decline until it begins to pass bus stops which also serve some trip attractions (i.e., employment, transfer or shopping) sites.

4 Many metropolitan planning organizations (MPOs) in the U.S. have estimates, at the block group level, on job locations and empoloyment data. Transit planners can refer to their local MPOs for such information. Alternatively, at the cost of reducing the accuracy of forecasts, the analysis can be conducted at the census tract level instead of the block group level.

quarter mile).[5] To estimate the adult and total population that generates transit trips, it is first assumed that the population density is evenly spread and then the buffering capability of GIS is used to compute the number of people in every census tract within walking distance from the bus route.

Many GIS tools have routing capabilities which are useful for calculating some of the other variables. They can, for example, calculate the cumulative length for every arc[6] of a route, which can be attached as an attribute to that arc, and then used to divide a route into segments of a specified length. This capability is first used to determine the segmentation of the route and to calculate the route-distance variable for every analysis zone.

Estimating the number of riders coming from routes that cross or feed the study route is not so straight forward. The PRS model uses the number of riders on cross routes to estimate the number of transfers. The GIS can be used to automatically identify the routes that cross a segment of a route. Alternatively, other available data can also be used to estimate the number of transfers. Ridecheck data, specifically the number of passengers alighting at every stop, are used in our model to determine the number of potential transfers from stops which are within walking distance from every segment. It is true that this variable is not exactly equal to the number of riders on routes that cross the study segment but since the model needs some calibration, as will be discussed later, and since the number of passengers alighting at stops within a quarter of a mile is highly correlated to the number of transfer, this measure can be considered as a reasonable surrogate to the one used by the PRS model.

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5 A better measure for determining the area that produces transit trip is the walking distance from bus stops instead of bus route segments. The GIS has the capability of buffering around both bus stops and bus route segments. However, in many instances, stops are close enough to each other (less than a quarter mile) that the assumption made by the PRS model is quite reasonable. Furthermore, given that the walking distance is a very subjective measure (varies from one to three quarter of a mile depending on individuals), buffering around stops instead of segments does not really add much to the accuracy of the model.

6 In our model, arcs were defined by street intersections. Each arc starts and ends at a street intersection. A bus route segment is a set of consecutive arcs. For bus route studies, segments that begin and end at stops would be preferable. However, it is often useful to define routes in terms of a widely used street network file (such as those provided in DIME and TIGER formats) that are topologically encoded (refer to Azar & Ferreira, 1991). Since the differences are generally significant only for long streets with midblock stops, we have retained the normal street segmentation for this study.

Opportunity Factor

Four variables need to be computed for the opportunity factor. The variables are the employment and the population within a quarter mile of the route between 3 and 15, and 6 and 35 minutes of bus ride downstream from the study segment (i.e. $EMPL^{d}_{3-15}$, $EMPL^{d}_{6-35}$, POP^{d}_{3-15}, and POP^{d}_{6-35}). The cumulative length of the arcs is used as the measure of how far an arc is from a study segment. The model uses the average speed of the transit vehicle (i.e., route length divided by total running time), with the cumulative length to identify the arcs that are within a certain range of ride time from an origin segment. The method used to calculate the employment and population number in these zones is to first identify the included arcs then to create a quarter mile buffer around them, and finally to intersect that buffer with the block group boundaries to calculate the proportion of these block groups falling within the buffer and the corresponding number of people or employment in those areas. [7]

Level-of-Service Factor

The average headway of buses and the cumulative running time from the beginning of the route to the analysis segment are the only required variables. The average headway is a variable that can be specified by the transit planner. The model is very sensitive to this variable and ridership estimates can change dramatically between a headway of 10 and 25 minutes, for example. Seat availability is dependent on the cumulative running time of a bus. This is related to the assumption that the PRS model makes, that is, bus routes, in general, run from zones of trip production and end in zones of trip attraction (i.e. from residential areas to central business districts). The cumulative running time can be computed, as above, by using the cumulative length of the route and the average speed of the bus.

Model Results / Calibration

Basemaps and 1990 census data for Boston, MA, were used to

7 The "Journal of Work" data that the U. S. Census Bureau releases contain employment information at the block group level. Some aggregation and manipulation processes need to be done to these data bases before being used to build the PRS model.

build a working prototype. 1990 TIGER line files and census block group boundaries were loaded into ARC/INFO[8] software along with population and employment location data from the 1990 census and selected ridership data and route alignments and schedules for Metropolitan Boston Transit Authority bus routes. Figure 1 shows the road network, subway lines, and municipal boundaries of the study area along with the one bus route (Route 10) that was studied in detail. This route connects a residential neighborhood (South Boston) with Back Bay Station (the northwest terminus of the route). ARC/INFO has the spatial data processing tools required to calibrate and run the PRS model as described in Section 3 above. It also has a macro language that allowed us to build an interactive user interface for computing and graphically displaying the model results. The model requires as input a route file (coverage) and some calibration factors including expected average speed and the headway of buses. The model displays a street map, bus routes, and other features as shown in Figure 1 and prompts the user to point to an end of the route which is to be used as the origin for the analysis. The model then displays the selected route, divides it into modeling segments of approximately one mile lengths[9], and shows the estimated AM peak and midday riderships on each modeling segment plus the total ridership on the whole route for both time periods (see Figure 2). On screen, the modeling segments are shown in different colors so that it is easy to relate the ridership estimates to their physical location. Likewise, the coloring and the use of line weights enable the route segments and buffers to be displayed on top of the road network and the thematicly shaded demographic information (population density in this case) without being too confusing.

The model was originally built to estimate ridership in Los Angeles and its surrounding areas, and this makes the model transferable to California-type cities more easily than to other urban forms. Cities and their residents vary widely, and this results in some of the factors applying to one city but not necessarily to another. The mean rent value, for example, is used to determine the income adjustment factor. The curve used to determine this factor does not necessarily

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8 ARC/INFO is a registered trademarks of Environmental Systems Research Institute, Inc., Redlands, CA. The authors gratefully acknowledge ESRI support for some of this work.

9 The GIS was used to create these modeling segments. The procedure used for defining segments consisted of first starting at one end of the route and then picking indivudal street segments until the target length of each modeling segment is at or just above 1 mile.

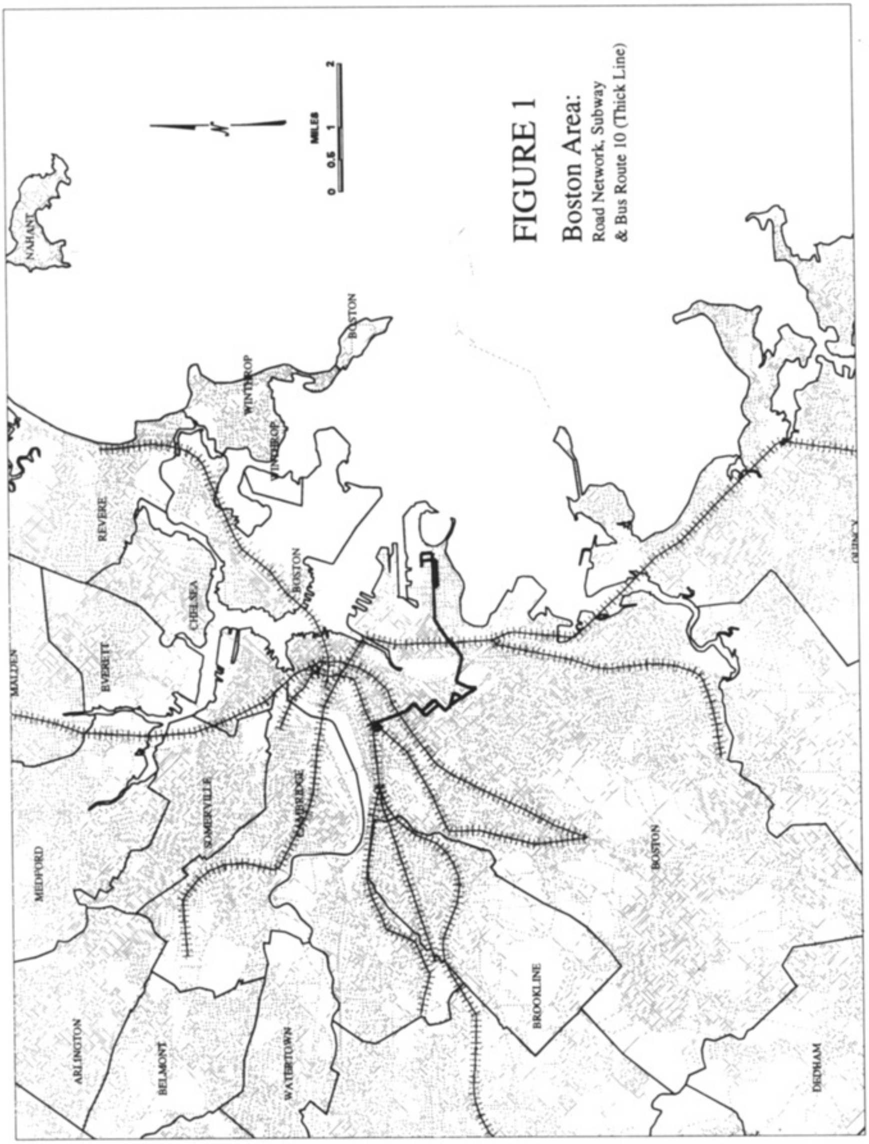

FIGURE 1

Boston Area:
Road Network, Subway
& Bus Route 10 (Thick Line)

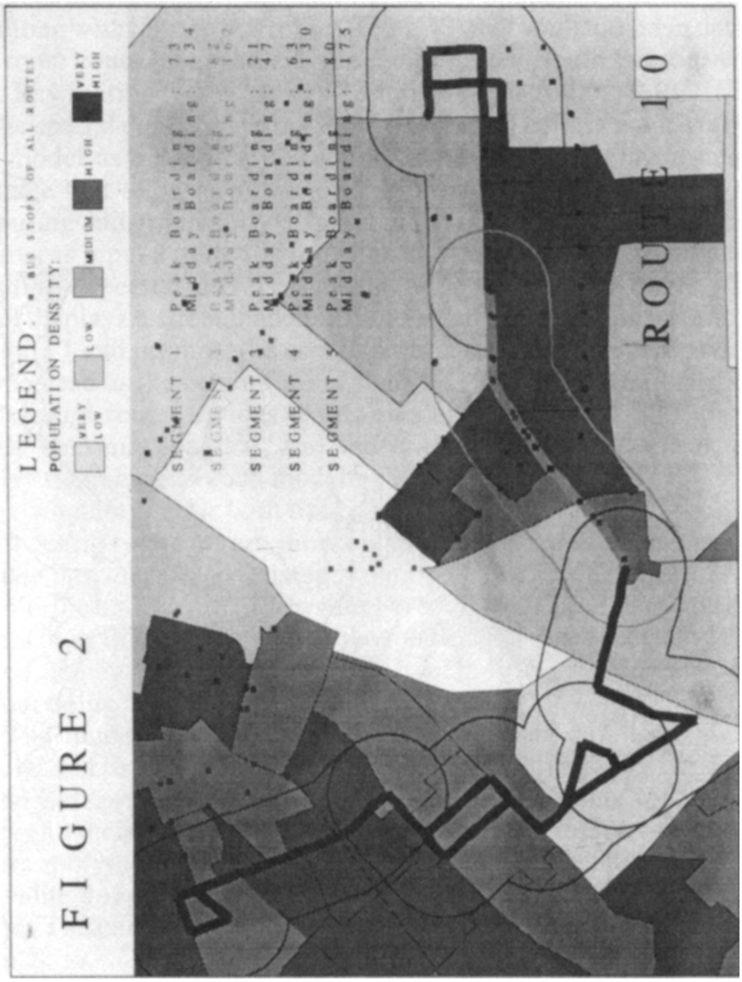
FIGURE 2
LEGEND: • BUS STOPS OF ALL ROUTES
POPULATION DENSITY:
VERY LOW
LOW
MEDIUM
HIGH
VERY HIGH
SEGMENT 1 Peak Boarding: 73
Midday Boarding: 134
SEGMENT 2
SEGMENT 3 Peak Boarding: 21
Midday Boarding: 47
SEGMENT 4 Peak Boarding: 63
Midday Boarding: 130
SEGMENT 5 Peak Boarding: 80
Midday Boarding: 175
ROUTE 10

apply to all cities. For example, a mean rent of $500 might be an indicator of a high income zone in some cities and a medium income zone in other cities. Adjustments to this curve need to be made in order to (1) make it match the characteristics of other places; and (2) to update it to the current rent values since the model was developed in 1983.

A detailed re-calibration of the model for a metropolitan area outside Los Angeles was beyond the scope of this paper. However, the required ridership and socio-economic data are generally available and the complexity and accuracy is within the scope of what transit analysts are typically called upon to do.

One of the defects of the GIS-based model developed here is that it is very slow to run. The number of buffering and intersection operations needed for determining the ridership on every segment is large (9 operations). For a route made up of 5 segments a total running time of 70 minutes is required.[10] However, once these operations are executed, the effects changing model parameters route can be calculated in quite a reasonable time (10 minutes) if the route alignment is held fixed. For example, one might change the value of one parameter in some equation or change one of the values for a global variable (headway, for example), without altering the realignment of the route. In this case, the program can provide relatively quick answers.

Another shortfall of the current GIS-based implementation of the model is that when it calculates the total ridership for the whole route it sums up all the riderships for each segment. this problem is better clarified by examining the picture of the buffers around each segment (refer to Figure 2). Notice that there is a large overlap between these buffers, and that double counting of ridership occurs when adding the single estimates for each segment to obtain the overall estimate. The estimates for each segment, taken individually, are correct; but adding them all together to get the total ridership includes each overlapped area twice. This problem could be taken care of by calculating the areas of the overlaps, and then subtracting them off, or by taking longer segments to reduce the number of overlaps and minimize the double counting effect. However, such adjustments would add significantly to the processing time and, often, may not be worth the effort.

Analysis and Conclusions

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[10] These times were obtained using ARC/INFO software version 6.1 running on a 5100 DECstation with both the data and the ARC/INFO software stored locally.

One advantage of integrating PRS-like models with GIS technologies lies in the resulting ability to see how ridership estimates depend upon the spatial relationships between route alignments and demographic patterns. For example, busy routes tend to be those that traverse areas of high residential or job density (for socio-economic groups likely to use transit). The data overlay capacity of GIS allows these models to better integrate information related to the characteristics of city block groups with the geographical layout of transit routes. Using socio-economic information, such as population density, income, race, and the like, as the backdrop for displaying transit routes provides a rich set of information enabling analysts to target specific places or groups of people needing improved services. Low income neighborhoods, high population density blocks, or large employment centers are some examples of the data that analysts use for evaluating and designing transit routes and that can be easily displayed and overlaid as the background for viewing route alignment choices. GIS-based models have the advantage of easily capturing and quantifying this information.

The PRS model is successfully replicated inside the GIS. It is fully automated. One can easily display the ridership estimates and give a textual listing of these estimates for each segment and for the whole route. The strongest advantage of the GIS is that it has the capability of doing spatial calculations needed by the model, such as calculating the number of employees or population within a quarter mile from a route or determining the stops where people might make transfers to the study segment. Since the model is embedded as a small set of generic (spatial and algebraic) calculations inside a general-purpose GIS, the basemaps, routes and demographic data can be independently updated, maintained, and shared for an assortment of multi-purpose applications.

Another advantage of the GIS-based implementation is that ridership estimates are visualized on each segment on the screen relative to their geographical locations. This gives the planner some visual explanation of the results the program is producing and provides a useful means to check the validity of the estimates. Moreover, the visual aspect of the model output is very useful in the planning step of realigning routes based on the results of previous runs. For example, along the prototype route, segment 3 has the lowest ridership compared to the other segments (refer to Figure 2). A transit planner might replace the kinked segment 3 by another more straightened segment. The model can then be rerun and the new estimates compared to current ones. In other words, the visual aspect of the model helps in understanding the relationship between the geographic location of the route and the demographics, and also provides additional suggestions for other "what if" scenarios for the planner to test and explore.[11]

PRS-like models are becoming increasingly useful for route-tuning activities. They provide the ability to test the effect of minor changes to transit routes characteristics on the level of ridership along theses routes. This usefulness is underlined by the fact that the socio-economic data that these models use are now coming more on line. Desegregate demographic information are now collected by local MPOs and are becoming more accessible to transit analysts. Data sharing between agencies is becoming more of a common practice. Highly detailed information (sometime at the individual block or even parcel level) can now be accessed by transit planners as a result of the data sharing. GIS tools are especially useful in organizing and analyzing such detailed information.

These models could also be used as tools in pro-active route planning. They might be used to evaluate the effects of modifications to the characteristics of routes in order to meet equity and social issues requirements. For example, instead of using trial-and-error to change routes and track ridership changes, the demographic data can be displayed in the background and then used to test different routes alignments with the goal of targeting a specific category of people. Furthermore, if addresses of employees of large employers are available, they can be matched geographically on the map and bus routes can be redirected in order to target their residences in the most efficient ways. Bus routes could be designed to pass through large concentrations of employees and through their employment locations. The model developed in this stage can be used to estimate the ridership on these routes, and to display the effects of the proposed changes to current routes.

The biggest limitation of the prototype is its slow processing speed — 70 minutes for the complete analysis of a realigned route on a typical 1992-generation UNIX workstation. Such times prevent the analysis of alternative routes from being the highly interactive and exploratory endeavor that was envisioned. Even the 10 minutes to compute the effects of altered parameters is too long. However, several consideration suggest that time improvements of one or two orders of magnitude will soon be practical. First, technological advances in hardware already enable current (1994-generation) UNIX

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11 In some cases, such 'kinks' result from one-way streets, turn restrictions, limited width roadways, etc. As more and more such characteristics are added to the underlying road network in the GIS, the relative value of integrating PRS-type models with general purpose GIS tools increases.

workstations to be 2 or 3 times faster. Second, the prototype was built using ARC/INFO's AML macro language without any restructuring of basemaps and datasets to speed up the types of computations needed for these analyses. Implementing the PRS model at this upper level of programming results in significant system overhead delays as the various modules and tools of ARC/INFO are invoked to call each computational and graphical function.

Re-writing the model to take advantage of special data structures and/or by calling lower level ARC/INFO functions directly could speed up the process considerably. Of course, such an approach would also defeat the goal of encoding the model using general-purpose GIS tools and standard basemaps and data representations. However, improvements in software engineering and computer science are gradually allowing GIS tools, functionality, and data representations to be repackaged in ways that are more modular, efficient, and conducive to parallel processing and client-server architectures. In the next several years, such improvements are likely to provide an order of magnitude improvement in performance for the types of transit applications we have considered. Hence, these changes and a continued improvement in processing speed can combine to provide a hundred-fold increase in overall speed in the not-to-distant future while enabling the modeling and mapping tools to be distributed more easily to the transit planner's desktop.

As the improved speeds (and modularity) become practical for desktop systems, there will be ever increasing value to using general-purpose GIS tools for supporting exploratory studies of route alignment options. Increasing amounts of spatially-referenced land use data will be available for metropolitan areas, and improved computing speeds will make it practical to consider more complex demand models and to take advantage of improved user interfaces for exploratory analyses (involving, e.g., context-dependent highlighting and blurring or 'direct manipulation' interaction).

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Appendix

The following are the formulations of the model for each period:

$$BOARD_i^d = PROD_i * OPP_i^d * LOS_i^d$$

where:

$BOARD_i^d$ is the boarding on segment i in direction d;
$PROD_i$ is the trip production factor in the area around segment i;
OPP_i^d is the trip opportunity factor in direction d from zone i;
LOS_i^d is the quality of service in segment i in direction d.

A.M. Peak:

$$PROD_i = 0.015\, DIST_i \left[\left((AFAC_i)(ADULT_i) + 0.339\, XRIDER_i\right) / DIST_i\right]^{0.813}$$

$$OPP_i^d = \left[EMPLOP_i^d + 0.75\, POPOP_i^d\right]^{0.296}$$

$$EMPLOP_i^d = \frac{\left(ORIGBD_i * EMPL^d_{6-35} + 0.339\, XRIDER_i * EMPL^d_{3-15}\right)}{ORIGBD_i + 0.339\, XRIDER_i}$$

$$POPOP_i^d = \frac{\left(ORIGBD_i * POP^d_{6-35} + 0.339\, XRIDER_i * POP^d_{3-15}\right)}{ORIGBD_i + 0.339\, XRIDER_i}$$

$$ORIGBD_i = AFAC_i * ADULT_i$$

$$LOS_i^d = WTFAC_i^d * CTFAC_i^d$$

Midday:

$$PROD_i = 0.0079\, DIST_i \left[\left(AFAC_i * POP_i + 0.339\, XRIDER_i + 0.144\, EMPL_i\right) / DIST_i\right]^{0.813}$$

$$OPP_i^d = \left[0.21\, EMPLOP_i^d + POPOP_i^d\right]^{0.277}$$

$$EMPLOP_i^d = \frac{\left(ORIGBD_i * EMPL^d_{6-35} + 0.339\, XRIDER_i * EMPL^d_{3-15}\right)}{ORIGBD_i + 0.339\, XRIDER_i}$$

$$POPOP_i^d = \frac{\left(ORIGBD_i * POP^d_{6-35} + 0.339\, XRIDER_i * POP^d_{3-15}\right)}{ORIGBD_i + 0.339\, XRIDER_i}$$

$$ORIGBD_i = AFAC_i * POP_i + .144\, EMPL_i$$

$$LOS_i^d = WTFAC_i^d$$

where:

$DIST_i$ is the length of segment i;
$AFAC_i$ is an income adjustment factor in zone i;
$ADULT_i$ is the adult population in zones around segment i;
POP_i is the total population in zones around segment i;
$EMPL_i$ is the number of employments in zones around segment i;
$XRIDER_i$ is the riders on routes that cross or feed into segment i;
$EMPLOP_i^d$ is the employment opportunity in zone i in direction d;
$POPOP_i^d$ is the population opportunity in zone i in direction d;
$ORIGBD_i$ is an orignating boarding term for zone i;
$EMPL_{6-35}^d$ is the employment within a quarter mile of the route in direction d between 6 and 35 minutes of bus ride time from segment i;
$EMPL_{3-15}^d$ is the employment within a quarter mile f the route in direction d between 3 and 15 minutes of bus ride time from segment i;
POP_{6-35}^d is the population within a quarter mile to the route in direction d between 6 and 35 minutes of bus ride time from segment i;
POP_{3-15}^d is the population within a quarter mile of the route in direction d between 3 and 15 minutes of bus ride time from segment i;
$WTFAC_i^d$ is a wait time factor in segment i based on service frequency in direction d;
$CTFAC_i^d$ is a seat availability factor in segment i in direction d.