An Application of Mode-Choice Methodologies to Infrequent Commuter-Rail Service

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The feasibility of commuter-rail transit in the southwest Baltimore corridor was studied by a variety of passenger estimation methodologies. The methodologies selected were required to be applicable to the corridor scale, to be run manually, and to be capable of quick response. They were also required to be responsive to the addition of one or two trains per peak period, changes in station location and accessibility, and changes in costs such as parking charges and gasoline costs associated with the automobile. No one methodology met all of the above requirements. However, two methodologies were adapted to consideration of infrequent rail service (one or two trains per peak period) and applied to the corridor. The first methodology involved the application of a simple graphical technique that related mode split to station distance from the CBD; the second involved the application of a marginal utility model to corridor census tracts. The infrequent service capability was added, in the case of the graphical approach, by applying experience factors, and in the computational approach by relating automobile captivity to the number of trains per peak period. Both methodologies were transferable, without reestimation of coefficients, to the southwest Baltimore corridor. Both approaches could be applied manually in a person-week or less; the need for any greater sophistication than the graphical methodology is seriously questioned.

In many urban areas of the United States, development of commuter-rail transportation is being advocated in lieu of further highway development. This is the case in the Baltimore-Washington corridor where a policy to improve present train service on the Baltimore and Ohio Railroad right-of-way has been adopted. The pressure to improve this service has come from the northeast Washington, D.C., corridor, and little thought has been given to service improvements for the corresponding southwest Baltimore corridor. Although the Baltimore regional plan has recommended that commuter-rail service to downtown Baltimore, using existing rail lines, be given serious study and adequate experimentation, for the most part it has concentrated on two modes of public transportation: a rapid transit system and a mixture of express and local bus service. The question that initiated this study is whether resources should be directed to commuter-rail service in the southwest Baltimore corridor.

Good corridor planning should consider ridership potential. This requires a methodology that is responsive to a number of proposed transportation strategies, such as parking regulation, gasoline taxation, commuter-rail fare changes, and commuter-rail service improvements. Since the number of alternative strategies may be large and the time available for evaluation short (a month or less in a citizen participatory process), the methodology must be simple and easily applied. Models must consider travel time and cost within their structures. For quick response, a methodology should be sufficiently simple to allow for manual computations. Data requirements should be confined to the corridor of interest. Since census tract data are easily obtained, the methodology should be designed to use them directly. Home interview data (other than those obtained in the 1970 census) should not be required. For commuter-rail passenger estimation, the methodology should consider the exact number of peak-period trains under consideration.

DESCRIPTION OF THE CORRIDOR AND EXISTING COMMUTER-RAIL SERVICE

Corridor Description

The southwest Baltimore corridor served by the Baltimore and Ohio (B&O) Railroad is shown in Figure 1. The population of the corridor, from the greater Laurel area to the Baltimore beltway (Interstate 695), is approximately 68 000. Average family incomes in 1969 for corridor census tracts ranged from $10 281 to $12 672 except for one of $16 632. The number of cars per capita is 0.41, a figure almost as high as the 0.44 in Los Angeles (1). There are 21 000 housing units and an average of 1.32 cars/household. A length of approximately 33 km (20 miles) of the corridor has a significant Baltimore orientation (based on newspaper circulation observations). The residential density is generally low, and, except for the Laurel area, existing communities have remained approximately the same size since World War II. The area surrounding Laurel has been part of the fastest growing area of Prince Georges County.

The corridor routes are all very heavily traveled, primarily by automobile, truck, and rail freight. There are two freeways, the Baltimore-Washington Parkway and Interstate 95, and two primary highways, US-1 and US-29, parallel to the freeways. The parkway carries no truck traffic but provides access to the Baltimore CBD. Interstate 95, however, terminates inside the

beltway and leads to an arterial street, requiring a 15 to 20-min drive to the CBD in the peak hour.

There are two railroads. The Penn Central approaches Baltimore almost directly from the south and then changes direction to skirt the west side of the Baltimore-Washington International (BWI) Airport and enter the city from the west. However, the Penn Central Station is north of the CBD and well out of walking range. The second railroad, the B&O, approaches Baltimore between the two expressways from a southwesterly direction and terminates at Camden Station, approximately 1.2 km (0.7 mile) from the key employment centers of the CBD.

Highway transportation perpendicular to the rail lines consists almost exclusively of primary state highways. There are no freeways at present although several are planned. Thus, there is no east-west accessibility of Interstate standards outside the Baltimore beltway, approximately 8 km (5 miles) from the CBD.

Existing Commuter-Rail Service and Patronage

Passenger service in the southwest Baltimore corridor is maintained by the Penn Central, which has one stop between Washington and Baltimore, and the Baltimore and Ohio Railroad, which has four stops (Riverdale, Laurel, Jessup, and St. Denis).

The location of the terminal stations serving the CBD is extremely important to any ridership estimate. A geographical plot of the origins and destinations of 10 000 Philadelphia area commuters has shown that these commuters used trains only if their CBD destinations were within 10 min by foot or transit from their arrival station (2). The Camden Station of the B&O Railroad is not well situated with respect to the Charles Center, the major employment area in the CBD, for those who presently take the train. A walk of 1.2 km (0.7 mile), approximately 15 min, is typical. The Penn Central Railroad Station, however, is well beyond the CBD, and without shuttle service to meet the trains, this system is not likely to attract potential riders. For this reason, the Penn Central Railroad was not considered an attractive alternative to bus and automobile in the corridor and is not further considered in this paper.

The B&O runs one train, which leaves Laurel at 7:22 a.m. and arrives in Baltimore at 7:48 a.m. In the evening, the train leaves Baltimore at 4:55 p.m. and arrives in Laurel at 5:22 p.m.

Passenger counts and an origin-destination (O-D) survey made in 1973 showed 63 people traveling into Baltimore in the morning and 62 returning in the evening in a train providing 130 seats. The largest number of passengers (23) boarded at the Laurel station, 30 km (18 miles) from the CBD. There were 43 passengers using the Laurel, Jessup, and St. Denis Stations. Almost all respondents were employed in the Charles Center.

MODE-CHOICE METHODOLOGY EVALUATION AND DEVELOPMENT

Evaluation

Mode-choice methodologies have been developed for both intercity and intracity passenger demand forecasting. The length of corridor and the results of the O-D survey suggest that the B&O commuter-rail service is an intracity rather than an intercity service. The majority of fare-paying passengers travel a distance of 33 km (20 miles) or less. Those traveling longer distances, particularly those traveling from Washington to Baltimore, were B&O employees traveling on passes. For these reasons, the intercity methodologies developed for the northeast corridor were considered to be inappropriate here and are not considered further in this paper.

Methodologies presently being used by departments of transportation and highways are limited in their usefulness for commuter-rail passenger forecasting. The principal packages available are those developed by the Federal Highway Administration and the Urban Mass Transportation Administration. These require input data for a network that comprises the entire urban area, whereas in this study only a corridor is of interest. It is difficult to break away from the sequence of trip generation, trip distribution, and mode split when, as in this case, a trip table can be obtained from census data. For the headways greater than 30 min that are common for commuter-rail service, the models are not appropriate. Both packages required a computer and provide exact numerical computations when only a rough estimate may be necessary. The use of the computer places the analysis at a distance from the analyst, which may hide good strategy alternatives that might appear during manual manipulation of the data.

Conceptual Development

The methodology of estimating commuter-rail patronage shown in Figure 2 (2, 3) appears to be a logical and simple approach for making quick estimates of travel demand for proposed transportation strategies. It is a deductive methodology that considers the potential market and its characteristics (such as residential density and length of corridor), the competing transportation modes in the corridor, and the frequency of train service, in order to determine the anticipated patronage. However, to use this methodology requires an experienced analyst. For a less experienced analyst, a modal-choice relationship that considers all those factors is required. To meet this need, the methodology was expanded in two ways. The first approach was to test the use of an existing graphical technique in place of the deduce & rail shown in Figure 2. The second (computational) approach was to impose an existing modal-split model on the methodology as shown in Figure 3.

Elements Common to the Two Approaches

Demand Area

The determination of a demand or geographic area over which patronage will be drawn is common to both methodologies. Experience must be the guide for this. A 6-km (4-mile) corridor width based on observations in Philadelphia that suggest most potential riders will not drive more than 3 km (2 miles) perpendicular to the corridor direction has been used (4). In a study of park-and-ride facilities (5), it was found that 50 percent of those using park-and-ride resided within a distance of 4 km (2 to 3 miles) from the lot with 90 percent residing 5 to 10 km (3 to 6.5 miles) from the lot. Since these distances include travel in all directions, their perpendicular component could be close to the 3-km (2-mile) criterion observed in Philadelphia. By analogy with these observations, the southwest Baltimore corridor was defined as being 6 to 11 km (4 to 7 miles) wide, except in Laurel where, to include the entire greater Laurel area, a width of approximately 15 km (9 miles) was used. These limits are compatible with census tract boundaries and are shown in Figure 1.

The total distance of the automobile journey as compared to that of the commuter-rail journey was also

used in establishing corridor boundaries. The criterion here was that the distance traveled by automobile not be greater than the distance traveled by train. In all cases the ratio of automobile distance to train distance was actually considerably less than one.

Data

The 1970 census had enumerated for each census tract the employed persons who journeyed to the CBD. Since commuter-rail service is used for work trips almost exclusively, only such trips were considered in the methodology developed. The total market is 508 persons, of whom approximately 40 percent reside within the demand area for the St. Denis Station, approximately 11 km (7 miles) from the CBD.

The census data also included the number of households having one, two, and three or more automobiles. These data were used to determine the average car ownership per household and per capita for each census tract.

Figure 1. The southwest Baltimore corridor.

Competing Modes

Another step in the methodology common to both the graphical and computational approaches is the identification of modes competing with commuter-rail service. In the graphical approach, experience in other corridors must reflect similar competition, which in most instances includes the automobile and transit bus. In the computational approach, running times, access times, and costs must be determined for all modes.

Elements of the Graphical Approach

Mode-split relationships for the graphical approach are based on a correlation of the commuter ridership, expressed as the percentage of the total number of trips to the CBD, and the distance from the station to the CBD (4). Relationships based on experience in Philadelphia, Chicago, and San Francisco are shown in Figure 4. The selection of the appropriate relationship should be based on the similarity of residential densities and competing modes. The lower commuter-rail percentages represent combinations of low residential densities and strong competition from parallel freeways.

From the mode-split curve, the appropriate commuter-rail percentage is multiplied by the number of CBD employees for each census tract in the demand area to determine the potential patronage. Since patronage determined in this manner is representative of service frequencies of three or more trains in the peak period, it must be reduced for lower frequencies. The following reductions are suggested (2):

No. of Trains per Peak Period	Reduction in Patronage (%)
1	38 to 43
2	53 to 60

Elements of the Computational Approach

Mode-Split Models

There are several additional important characteristics that a commuter-rail mode-split model must have in order for it to be policy responsive. The first is that

Figure 2. The deductive methodology.

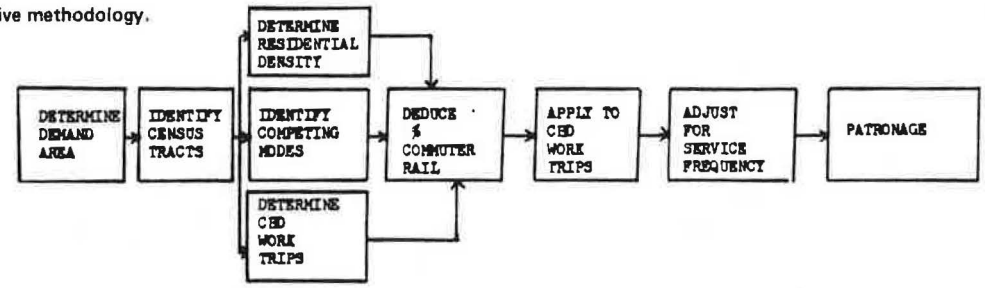


Figure 3. Computational approach for commuter-rail ridership estimation.

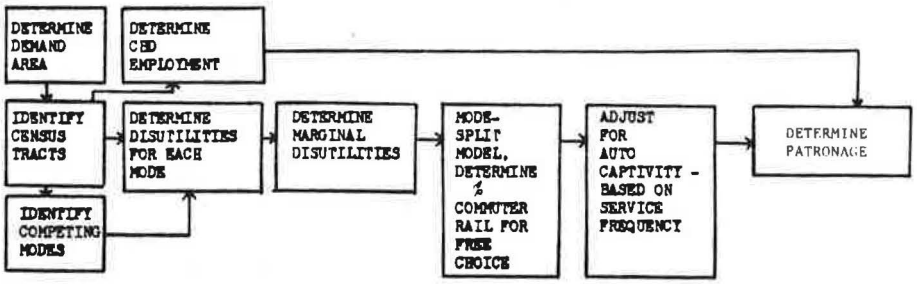
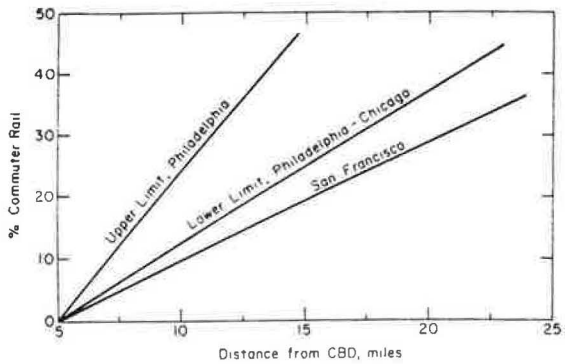


Figure 4. Graphical approach for commuter-rail ridership estimation.



the model must consider low service frequencies as characterized by one or two trains per peak period. The second is that the model should account for income or be calibrated using high-income patronage as commuter-rail studies have shown that commuter-rail patrons have access to a car and higher than average incomes.

The models reviewed are trip interchange or post distribution models. These synonymous terms describe a model requiring knowledge of the trips made between zones. This type of model is advantageous because CBD-employed persons are known for the corridor census tracts.

To meet the need to be policy responsive, the models reviewed were limited to those that considered both travel time and cost. A disutility or impedance is determined for each mode by a linear combination of running times, waiting and walking times, and costs, appropriately weighted by factors derived from previous studies. The greater the disutility, the greater the travel time and cost; hence, the likelihood that an individual will choose the mode is reduced. Thus, the assumption is made that a person rationally measures, for each travel mode, the disutility (such as time and cost) necessary to arrive at a destination, and chooses the mode that will minimize the disutility. There are many models fitting this description (1, 4, 6, 7, 8, 9, 10, 11, 12). Other models based on this premise (12, 13) were not evaluated in detail since their complex structures make manual computations more difficult.

Of the models evaluated, none were capable of considering service frequencies as low as one or two trains per peak period: All accounted for long headways through the waiting time variable. Some (4, 12) were not calibrated for commuter-rail, and one (12) did not consider income directly.

The model for the Washington Council of Governments (WASH COG) (11) considers income directly, but is calibrated with an areawide bus system. However, this model also considers automobile and transit captives as functions of transit accessibility and household income. Accessibility is defined as the proportion of jobs within a 45-min transit travel time. Automobile and transit captive rates were deduced from Washington data that considered accessibility at both origin and destination points. Hence, for a commuter-rail problem accessibility would be high for the destination and low for the origin, and household income would be high. For such a problem, automobile captivity is given as 38 percent and transit captivity as 1 percent.

Study Hypothesis

Since the WASH COG model was calibrated from data for a city having an areawide bus system, the frequency of service was much greater than that typical for a commuter-rail system. For this study, it was hypothesized that automobile captivity would be substantially greater for a commuter-rail operation having only one or two trains per peak period. Furthermore, it was assumed that transit captivity would be zero since an automobile is necessary for access to the rail stations.

Development of Automobile Captivity Per Number of Trains Relationship

It is possible to compute the free choice patronage for the commuter-rail and automobile modes for the Laurel, Jessup, and St. Denis Stations using the WASH COG free choice model for work trips by an equation that relates the percentage of patrons using transit to the marginal utility, which is defined as the difference between the automobile and transit disutilities for each census tract.

To determine commuter-rail and automobile disutility measures, the following assumptions were made:

1. Passengers have a 15-min walk from the B&O Station to their place of work.
2. The perceived automobile cost in 1970 was $0.04/km ($0.06/mile) for the automobile mode only trip.
3. For the rail trip, the average patron does not perceive the cost of driving his automobile to the station except for the time taken.
4. The average commuter-rail patron has an income of $15 000/year.
5. The average passenger perceives a wait time of 5 min if he expects the train to be on time. (It was further assumed that a passenger would allow 4 min to find a parking space and to reach the station platform. Hence, a 9-min wait time was assumed for dependable service. Since present patrons feel that the service is not dependable, it was assumed that this increased the perceived wait period from 9 to 12 min.)
6. The time required to drive to a station is assumed to be a component of excess time and is weighted by a factor of 2.5.

Disutilities were computed for the automobile and commuter-rail modes. In general, there were no competing public transit modes, except in the St. Denis Station area. In that area the Halethorpe bus provides service at 9-min headways during the peak hour. The disutilities determined for the bus were approximately the same as those determined for the commuter-rail service even though the commuter-rail trip has a much shorter running time. However, the bus discharges its passengers at the Charles Center with little or no walk and has short wait times due to the short headways. Because these disutilities were equal overall, the commuter-rail patronage determined from the automobile-rail mode-split computation was halved for the St. Denis Station demand area.

The only other public transportation in the corridor is provided by the Greyhound Company, which runs three buses in the peak period along US-1 to its Baltimore terminal. This service suffers as a commuter service because the terminal is considerably north of the CBD. It was assumed, then, that Greyhound does not serve CBD-oriented employment. From the percentage of free choice patrons using the commuter-rail service determined from the marginal disutilities for each census tract, passenger estimates can be generated as a function of automobile captivity as follows:

$$P = \left[\sum_{i=1}^{n} (CR\%_i)(E_i) \right] [1 - AC] \qquad (1)$$

where

P = number of passengers,
$CR\%_i$ = percent commuter rail for census tract i,
E_i = CBD employees for census tract i, and
AC = automobile captivity expressed as a fraction.

To determine the automobile captivity corresponding to one, two, or three trains per peak period, it is necessary to independently determine the patronages for one, two, and three trains. For one train, the current patronage can be used. However, some reduction in patronage must be expected if all passengers are required to pay the regular fares. In a Maryland Department of Transportation on-board passenger survey it was estimated that, of the 43 persons boarding at Laurel, Jessup, and St. Denis, 38 were fare paying passengers. For two and three trains, a factoring process can be used to determine revenue passengers, and, for the revenue passengers determined, the automobile captives can be determined from equation 1. These results are shown in Figure 5. The shape of the curve is reasonable because it can be anticipated that reduction in automobile captivity will be less as the number of trains increases. With such an adjustment the WASH COG model becomes responsive to the policy action of increasing the number of trains.

If 66 percent automobile captivity is used, the WASH COG model gives the present patronage for the study corridor. However, the appropriateness of such a mode-split relationship for other corridors must be tested. Thus, the model was compared to relationships (1) that describe the variation in percent transit as a function of the disutility for various values of car ownership per capita. For three or more trains and dependable service, a patronage estimate from the Chicago model (9, 10) should compare closely to the patronage estimated using the WASH COG model with 26 percent automobile captivity.

PATRONAGE ESTIMATION

Commuter-Rail Strategies

The following strategies were considered for the improvement of commuter-rail patronage:

1. Increased number of trains,
2. Improved service dependability (to give a perceived reduction in wait time from 12 to 9 min),
3. Increased parking charges (from $36 to $72/month) in the CBD), and
4. Reduced transit access times (by improving station access roads, constructing new stations, or eliminating old ones).

The Graphical Approach

It is a simple matter to compute anticipated ridership patronage from the known market by using Figure 4. The results, given below, indicate the present service carrying 46 fare-paying passengers.

Strategy	No. of Fare-Paying Passengers
One train (present service)	46
Two trains in peak period	59
Three trains in peak period	99

The curve for San Francisco was chosen for use in the study corridor because of similarities in residential density and competing highways. The estimated increases in patronage for two and three trains per peak period were determined by using factors inferred previously (2). The graphical approach does not provide a means to determine changes in demand caused by changes in parking charges or in transit excess times.

The Computational Approach

Travel Forecast for Service and Parking Cost Changes

Travel forecasts were prepared using both the modified WASH COG and Chicago models (9, 10). Present ridership for the Laurel, Jessup, and St. Denis Stations is compared with ridership estimates below.

Patronage Condition	Chicago, 3 Trains	WASH COG, 1 Train	WASH COG, 2 Trains	WASH COG, 3 Trains
Present patronage	75	37	51	85
Patronage if dependability improved	101	42	56	94
Patronage if parking charges increased and dependability improved	90	55	74	123

The improved dependability estimates are comparable to those developed from the graphical approach. There were, however, large differences for the doubling of parking charges, due largely to differences in converting cost to time. (Variation in the value of time with income is considered in the WASH COG model and not in the Chicago model.)

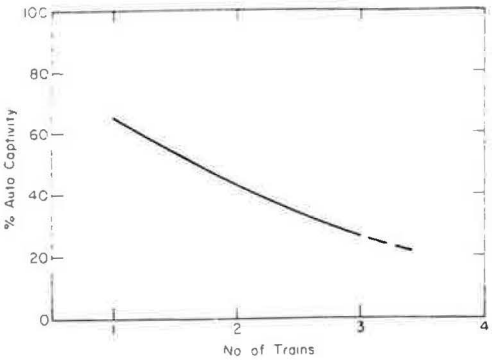
Whatever the strategy, estimates of patronage are low. If increasing the service frequency by adding trains adds only 20 to 30 passengers/train, such increases are not cost-effective. These figures, however, could be useful in estimating additional revenue if trains were deadheaded over the route during peak periods to meet service requirements in Washington.

These estimates for the Laurel, Jessup, and St. Denis stations should be expanded to obtain total patronage by including passengers boarding at Riverdale and Washington. At present, the 20 such passengers are approximately one-third of the patronage. It is not likely that this number will increase for fare-paying passengers, primarily because of the small number of persons who reside in the Washington suburbs and work in the Baltimore CBD.

Travel Forecast for Changes in Station Locations

A close study of population concentrations in the corridor suggests only two possible additional locations for stations. The first was Hanover Road, which would better serve Elkridge, Dorsey, and the area west of BWI Airport. However, forecasts indicate that there would be no overall increase in commuter-rail patronage from this. The second possible station location is the Baltimore beltway at Hollins Ferry Road. The accessibility provided by the beltway would increase the potential market from 508 to 957. However, most of this market is served by Metro transit buses, and, in order for this station to be feasible, transit bus service would have to be reduced. Aside from that consideration, moreover, the practicality of a station only 7 km (4.5 miles) from the CBD is questionable; most commuter railroads have abandoned stations less than 10 km (6 miles) from the CBD.

Figure 5. Automobile captivities and train service.



Travel Forecast for 1980 Travel Conditions

A limited study was conducted to determine the impact of more congested highways; 1980 travel speeds provided by the Maryland Department of Transportation were used with 1970 demographic data. The forecasts showed commuter-rail passenger counts increasing by only 15 passengers. Even though the peak-hour travel speed from Laurel to the Baltimore CBD is forecast to be 29 km/h (18.5 mph) on the Baltimore-Washington Parkway, the impact on commuter-rail patronage will be small because of the congested east-west arterials leading to the commuter-rail stations.

THE NEED FOR A MODEL

A comparison of patronage estimates made by the graphical and computational approaches shows the differences between the two approaches to be very small and provides evidence that the graphical approach is good enough to be used in an initial approach to determining passenger demand.

COMPARISON OF RESOURCE REQUIREMENTS

Both the deductive and modeling approaches were conducted manually using Maryland DOT highway maps and regional traffic assignments, census publications, published transit schedules, and a desk calculator. The state DOT traffic assignments were not necessary to the success of the study. Average speeds, and hence average times, could be judged from the road classification, speed limit, and density of development.

An estimate of the person-hours required to do two analyses is given below.

Task	Graphical Approach	Computational Approach
Determine demand area Identify census tracts Determine CBD work trips Identify competing modes	16	16
Determine residential density Select mode-split curve	4	
Determine disutilities for each of 11 census tracts for each mode		24
Determine mode split for each of 11 census tracts Correct for one or two trains per peak period, if necessary Determine patronage for each census tract and total ridership	4	4
Total	24	44

A generous amount of time is allowed to the first four tasks of assembling materials. The computational approach time requirements are almost double those of the graphical approach because of the time required to determine travel times and disutilities for each mode.

CONCLUSIONS

The question of allocating greater resources to commuter-rail transit in the southwest Baltimore corridor was answered by the very small market of 508 persons. Unless the demographic characteristics of the area were to change drastically, the potential of commuter-rail transit could never be exploited. However, the study did demonstrate the successful manual application of several mode-choice methodologies and the response to a number of policy options relating to infrequent service.

Commuter-rail corridors can be characterized by residential density, competing parallel freeways, and terminal station location relative to the CBD. Patronage experience in corridors defined by these characteristics can provide a valuable guide in planning rail service for other corridors. Such experience has been described (4) by a function that relates distance from the CBD to the percentage of the market using commuter-rail transit. Estimates of patronage determined from this graphical approach can be factored from past experience to determine the effects of low-frequency service. This methodology can eliminate the need for a more sophisticated model and be applied with approximately 24 person-hours of effort. However, the relationship is based on past experience and is tied to time, cost factors, comfort, and convenience experienced in the past. Also, there is no way to determine patronage changes resulting from changes in accessibility or parking charges. These limitations may require a more sophisticated approach such as disutility models.

Of existing post-distribution, mode-split models, those using utility models are responsive to policy and planning issues such as parking taxes, transit fares, station location, and road access to rail stations. One such model, the WASH COG model, can be adapted to low-frequency operations by adjustments to automobile captivities and the development of a relationship between automobile captivity and the number of trains in the peak period.

This model can be applied at the corridor scale by using CBD employment for corridor census tracts. Detailed transportation zone data or regional networks are not required. Because of the narrowness of a commuter-rail corridor and the resulting few census tracts involved, the entire computational process can be done by hand. The model can be applied to a 32-km (20-mile) corridor in a person-week of effort. The model exhibited transferability without recalibration in its application to a Baltimore corridor.

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