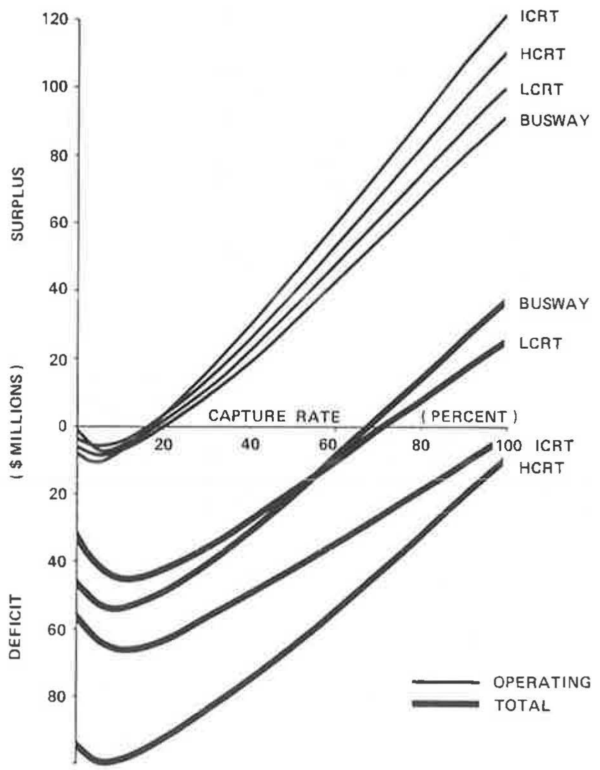
Figure 1. Operating and total annual cost margin for four transit technologies.



Evaluation of Costs and Revenues

Comparison of system revenues and costs demonstrates that all four transit modes would require considerable subsidy at most capture rates. If only operating costs are considered, ICRT would appear to be the most acceptable mode since it would provide "break-even" operation at about the 15 percent capture rate (see Figure 1). Even under a more realistic modal-split ratio of 10 percent, the operating deficit associated with the ICRT option is estimated to be a comparatively low $4.52 million.

When total costs are taken into account, however, the less capital-intensive LCRT system would require the lowest level of public assistance for capture rates up to 30 percent whereas the busway option would result in the lowest deficit for modal-split ratios greater than 30 percent.

RESULTS

The results of the parametric analysis would suggest that a guideway system for the Jacksonville urban area is financially feasible at reasonable capture rates. This is especially true since the plan would be eligible for 80 percent capital assistance and as much as 50 percent of the operating deficit. More detailed testing of a guideway system would thus appear to be warranted. The results also suggest that a technology that includes the elements of ICRT and LCRT is the preferred mode. Had the financial results of the sketch-planning analysis demonstrated that the cost of exclusive transit facilities was prohibitive at reasonable market shares, then capital-intensive options would be eliminated from costly detailed testing.

CONCLUSIONS

Although the analysis performed in Jacksonville represents only a single case, certain conclusions can be drawn about parametric analysis:

1. In view of the increasing concern for testing a broad range of land-use and transit options, there is a need for sketch-planning tools to supplement the accepted testing procedure.
2. Parametric analysis represents a simple and inexpensive technique for assessing the feasibility of exclusive transit facilities and candidate modal technologies in a metropolitan area.
3. An initial screening of transit alternatives can save the expense of a more detailed examination of a transit system or land use that will ultimately prove infeasible. Furthermore, alternatives that successfully emerge from the parametric analysis can be subjected to more rigorous scrutiny than if only detailed testing procedures were utilized.
4. Because parametric analysis does not rely on a modal-split model but assumes various capture rates, it permits alternative evaluation to proceed concurrently with model calibration.
5. Although only a single set of values for each mode was defined for each parameter, the values could be varied to permit sensitivity analysis as well as assess the consequences of different values.
6. The fact that parametric analysis is readily adaptable to computer processing means that many alternatives and parametric values could be tested quickly and inexpensively.

Preliminary Screening of Transit Corridor Alternatives

Ronald W. Eash and Arnold H. Rosenbluh, Chicago Area Transportation Study

Part of a major analysis of transit corridor alternatives done by the Chicago Area Transportation Study is presented. A method was developed to screen out, for further study, a limited number of proposed transit improvements from a large number of suggested alternatives for a corridor. The principles of this screening are (a) that some alternatives are not consistent with patronage in the corridor and (b) that some alternatives are dominated by others. The screening methodology is discussed, and the use of corridor supply and demand functions for evaluation and the estimation of these functions are presented. Demand and supply estimates prepared for several light-

rail alternatives for Chicago's Southwest Corridor are then subjected to preliminary screening.

It is now federal policy that any proposed major capital investment in an urban travel corridor that is funded by the Urban Mass Transportation Administration (UMTA) must be subject to an alternatives analysis (1, 2). That study must evaluate different line-haul alignments and modes for use in the corridor and also investigate whether low-cost improvements of the transportation system management (TSM) type can be substituted for a capital-intensive alternative. The policy specifies a number of items to be included in the evaluation, including operating and capital costs, projected patronage, environmental impacts, and energy consumption.

These alternatives analyses have generally combined the methodologies of urban transportation planning and engineering location studies. The studies feature a scaled-down application of the sequential travel demand models developed over the past two decades to project travel demand. Supply characteristics of the alternatives are estimated in a separate engineering feasibility study.

There are at least two major problems, however, in using these conventional methods:

1. Although a large number of alternatives can be proposed for review and consideration, only a handful of corridor alternatives can be tested. A variety of corridor transit alternatives can be generated by considering different modes and major alignment variations within the corridor. One can even propose combinations of modes (feeder bus combined with rail transit service) or alternative types of operation within a single mode (various combinations of express and local corridor service).
2. The travel demand models require a fairly detailed representation of the transit alternative under study but offer the analyst little prior guidance in the design of the supply attributes of an alternative. To estimate patronage, the models require that transit lines and service frequencies be specified. But, since these supply characteristics depend on patronage, there must be some iteration between the specification of supply characteristics and the application of the demand models. In practice, this relation is suppressed to the point where separate agencies are often assigned the responsibility for estimating supply characteristics and attracted patronage for an alternative.

This paper discusses part of a study of alternatives for a travel corridor completed by the Chicago Area Transportation Study. A preliminary evaluation of a large number of corridor line-haul and alignment alternatives led to the selection of a manageable number of proposed corridor line-haul investments for more detailed study. Objectives for this preliminary screening were to identify (a) line-haul alternatives that are not technologically consistent with the demand attributes of the corridor and (b) alternatives that are clearly dominated by another alternative.

PRELIMINARY SCREENING METHODOLOGY

Figure 1 summarizes the methodology used for the preliminary screening of mode and alignment alternatives for a corridor. The first steps at the top of this figure are designed to create a set of corridor demand functions for transit service. These demand functions are general relations between patronage on the corridor line-haul facility and the frequency of service and line-haul travel time. Thus, the demand functions are not dependent on mode; they are, however, created by using conventional sequential models of travel demand.

An initial estimate of the patronage on an alternative is completed by entering these demand functions at the appropriate frequency of service and line-haul travel time. Different alignments and station spacings are taken into account by adjusting line-haul travel times to compensate for changes in access times. A new service frequency is then computed based on the capacity required to accommodate estimated patronage. This latest frequency is then compared with the earlier value of frequency used in estimating patronage. If there is a large discrepancy between the two frequencies, patronage must be recomputed and the procedure iterated until estimated patronage and service frequency agree.

At this point, it may be possible to eliminate some alternatives because the line-haul mode characteristics are such that no equilibrium between corridor travel demand and frequency of service can be attained. Even if an alternative can be eliminated, the entire procedure is repeated until all alternatives are considered. Next, alternatives (called dominated) whose performance is clearly inferior to that of another alternative can be eliminated. The remaining alternatives continue to the more detailed stage of the analysis.

EQUILIBRIUM IN TRANSIT SUPPLY AND DEMAND

The two objectives of preliminary screening rely heavily on an understanding of the supply and demand characteristics that exist in a major travel demand corridor. Some general functions that establish the framework for the preliminary evaluation are shown in Figure 2. The maximum-load-point volume (V) that occurs in the corridor is plotted on the horizontal axis. In a typical radial corridor, this point is located adjacent to the central business district (CBD). The vertical axis shows the frequency of service (F) that is provided by the basic unit of capacity for a particular mode, the individual vehicle, or a group of vehicles combined in a train.

The supply function shown in this figure relates the frequency of service offered by the line-haul facility in the corridor to the maximum-load-point volume. This function implies that, provided there is service in the corridor, some minimum level of service is offered. It also implies that additional service is offered as V increases, depending on the capacity of the vehicle or train of vehicles. Since capacity is added in regular increments, it seems logical that a supply function should have a roughly linear shape over the range of maximum-load-point volumes at which the function is defined.

The second curve shown in Figure 2 ties demand in the corridor, measured at the maximum load point, with the frequency of line-haul service offered in the corridor. This function must be generally convex since travel demand in a corridor is not unlimited; it must reach some maximum level and not increase regardless of the frequency of service offered.

The curves shown in Figure 2 would change depending on the specific characteristics of an alternative. The slope of the supply function would vary as the capacity of the vehicle or train used to provide service changes. The demand function varies because different alternatives feature different line-haul speeds and alignments. An alternative with a faster line-haul speed would have a greater demand than a slower alternative at the same frequency of service.

TECHNICAL FEASIBILITY

Technical feasibility means that the intersection point between the demand and supply functions for an alter-

Figure 1. Methodology for preliminary screening of alternatives.

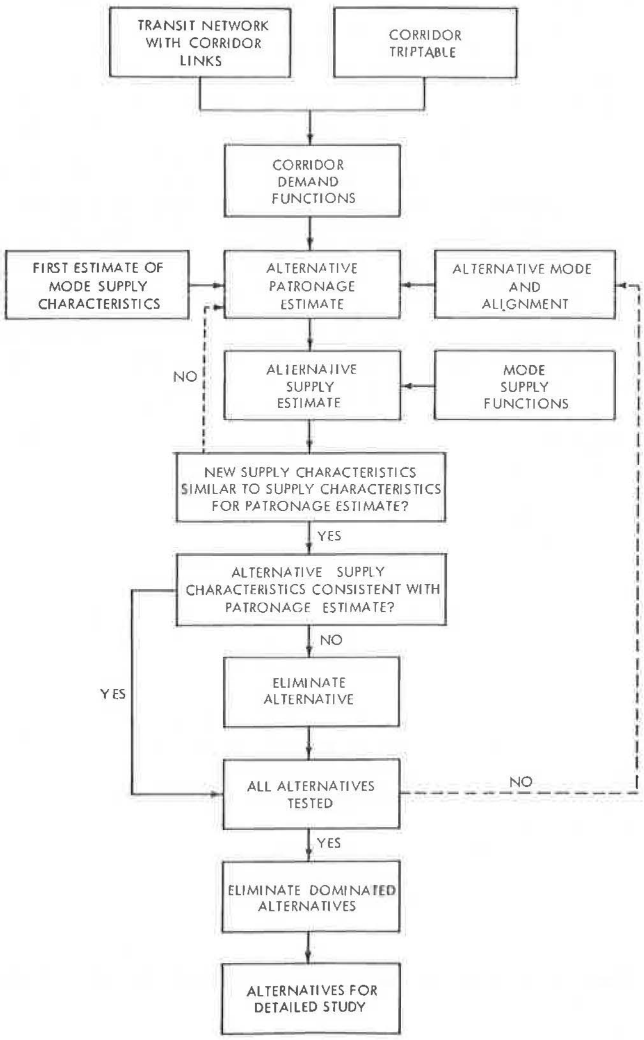
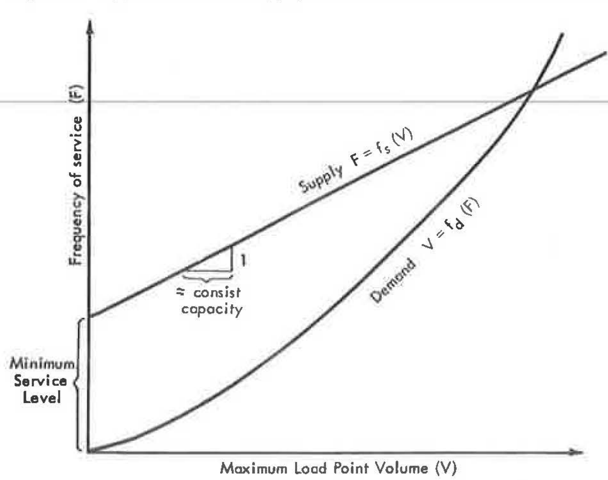


Figure 2. Typical corridor supply and demand functions for transit.



native must be at a service frequency at which the line-haul mode of the alternative can operate. The available technology for the line-haul mode of the alternative must permit a frequency of service that meets corridor demand.

This first requirement is shown in the upper part of Figure 3. The dashed line indicates the technically feasible range of service frequencies that are possible with the alternative's mode. The supply-demand intersection occurs well above a feasible service frequency. This could be remedied by changing the technology of the mode, considering a larger vehicle, or connecting a number of vehicles into a train. This would decrease the slope of the supply curve so that the intersection occurs below the feasible boundary shown in Figure 3.

A second aspect of technical feasibility is that the supply-demand intersection point must be at a satisfactory level of corridor demand. This usually implies that the equilibrium travel demand carried by the proposed line-haul facility must exceed existing line-haul patronage. This is shown in the lower portion of Figure 3, where the curves intercept to the left of the dashed line for current maximum-load-point patronage. The investment has the effect of decreasing the total amount of transit travel that takes place on the line-haul mode and forcing some of the original corridor riders to travel more circuitous routes in other competing transit corridors.

DOMINANCE OF ALTERNATIVES

In the preliminary evaluation of alternatives, the analyst must look for cases in which one alternative is dominated by another. This strategy leads to the diagram shown in Figure 4. The demand-supply relations for two alternatives are shown in this figure. The intersections of the two sets of supply-demand functions are such that equilibrium demand for the first alternative is greater than the equilibrium corridor demand for the second alternative. In addition, the frequency of service required for the second alternative is greater than the equilibrium service frequency of the first alternative.

The second alternative could be screened out if (a) the cost of a unit of capacity for the second alternative is greater than or equal to that of the first alternative and (b) other total weighted costs of the second alternative exceed those of the first alternative. One would anticipate that dominance of alternatives would most likely occur when two alignments of the same line-haul mode are compared since costs and technology would be almost directly comparable. Here, the definition of cost is a general index of the negative benefits of a project.

Note that the intersection between the supply and demand curves is not really a single point. Because of the crudeness of the estimating procedures used in determining demand and supply in this preliminary evaluation, it is more correct to speak of an envelope around this intersection. Again, the method is designed only to eliminate those alternatives that are clearly infeasible or dominated.

ESTIMATION OF CORRIDOR DEMAND AND SUPPLY FUNCTIONS

Corridor demand functions are developed by using available travel data from home interview surveys and the conventional travel models from urban transportation planning. The program steps to prepare the corridor demand functions are shown in Figure 5. Two sets of base data are required in this process—a transit network file and trip records from home interview surveys.

Figure 3. Two types of screening of alternatives.

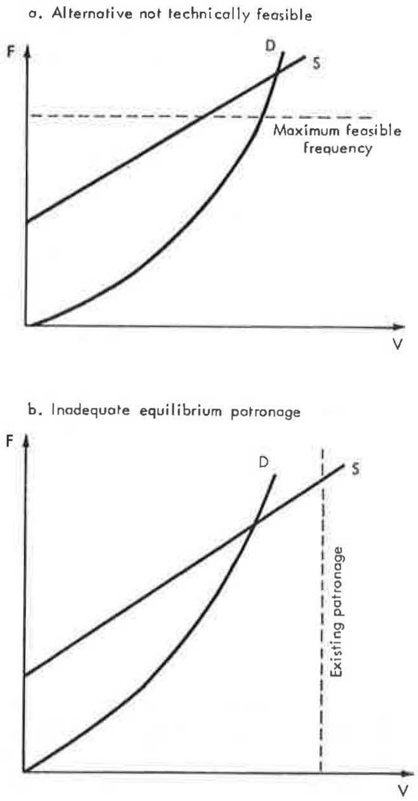
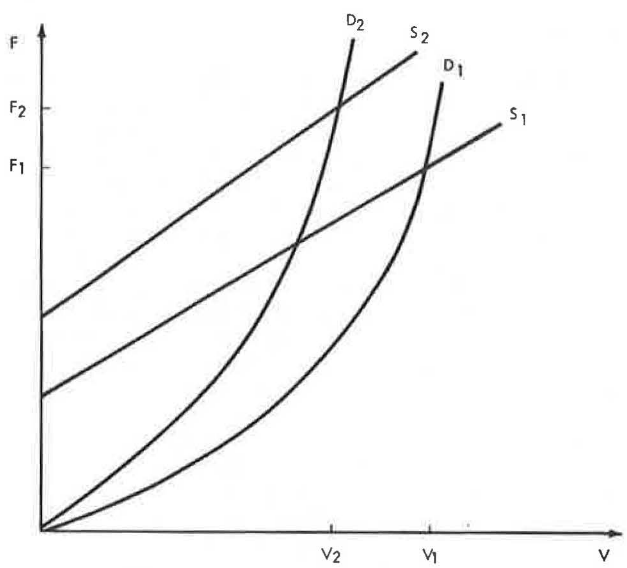


Figure 4. Dominance of alternatives.



Both data files must conform to the same system of analysis zones and be in the standard Urban Transportation Planning System (UTPS) formats (3) for processing as shown in Figure 5.

The next step in Figure 5 is to add a series of continuous links that run the length of the corridor to the original transit network file. Minimum-travel-time trees through the network are then produced by using the UTPS program UPATH, and home interview trip tables are assigned onto the network by using the ULOAD program. Both person- and transit-specific movements can be assigned to the network. Finally, the movements over the corridor links are summed by using TCORSM, a brief program written especially for the project.

Nine separate combinations of frequencies and line-haul speeds were used to estimate corridor patronage. Headways of 1, 5, and 10 min were paired with 32.2-72.5-, and 112.7-km/h (20-, 45-, and 70-mph) line-haul speeds. Patronage as a function of headway and line-haul speed was then fit to these estimates of patronage.

Supply functions for bus and rail rapid transit were developed in a study at the University of Pennsylvania (4, 5). Several regressions were fit to observations of service frequency versus maximum-load-point ridership by using data from the Chicago Transit Authority (CTA). For CTA bus operations, the peak-period supply relation from the Pennsylvania study is

$$f_B = 4.65 + 0.0136p \quad (1)$$

where f_B = buses per hour during the peak period and p = maximum-load-point ridership per hour during the peak period.

Two separate sets of supply regressions for CTA rail transit operations were prepared in the Pennsylvania study. One equation estimates the number of trains per hour, and a second estimates the number of cars in these trains. The equation for peak-period train frequency is

$$f_R^T = 9.94 + 0.000\,58\,p \quad (2)$$

where f_R^T = trains per hour during the peak period. The corresponding supply regression for cars per hour is

$$f_R^C = 10.27 + 0.011\,41p \quad (3)$$

where f_R^C = cars per hour during the peak period.

Supply function regressions for the remaining modal alternatives—new technology and commuter rail—were not developed in the Pennsylvania study. Supply functions for these modes were assumed to be based strictly on capacity. For a new technology, this assumption is probably correct. Such a mode would likely be demand responsive, and minimal service without demand would not exist (the supply function would intercept the origin). It is more difficult to estimate the supply function for commuter rail since commuter-rail operations in Chicago vary from transitlike operation to a frequency of only one or two trains per day. To develop a single supply function for this range of operation is probably impossible.

USE OF PRELIMINARY SCREENING TO EVALUATE LIGHT-RAIL ALTERNATIVES FOR SOUTHWEST CORRIDOR

Three alternative light-rail alignments were considered in the analysis of alternatives for Chicago's Southwest Corridor. These alignments and the location of the corridor are shown in the map in Figure 6. All of the alternative light-rail alignments make some use of existing railroad right-of-way in the corridor. Except for sections that are in the Chicago CBD, the alignments are to be on grade-separated right-of-way.

The major features of these light-rail alignments are as follows:

1. Alternative 1 begins on the west at Harlem Avenue, runs eastward on existing railroad right-of-way to Western Avenue, and continues north to another rail right-of-way. Finally, this alternative continues northeasterly along the existing rail line before it turns northward to a terminal that connects with the existing

Figure 5. Preparation of corridor travel demand functions.

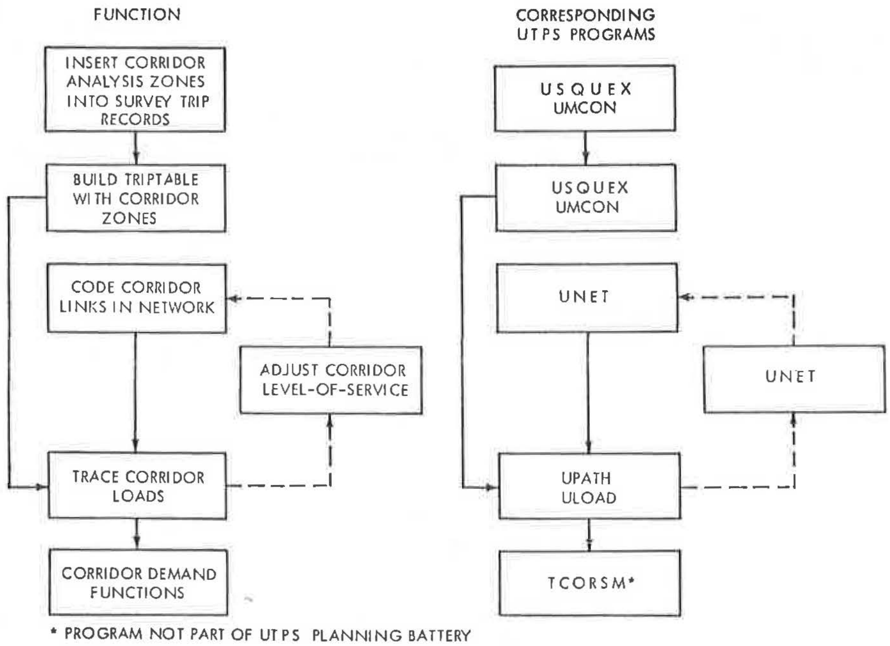
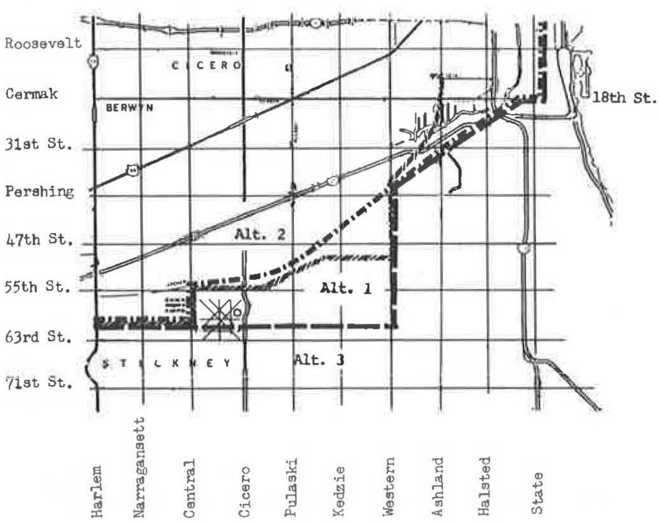


Figure 6. Light-rail alternatives for Chicago's Southwest Corridor.



Douglas Park rail transit line.

2. Alternative 2 follows the same alignment as alternative 1 until it reaches Pulaski Road, and then it continues northeasterly along Archer Avenue to Western Avenue where the alignment changes to an adjacent rail right-of-way. The alternative continues along the rail right-of-way to 18th Street, turns east to connect with State Street, then runs north along State into the downtown area.

3. Alternative 3 begins at 59th Street and Harlem Avenue, goes east on 59th under Midway Airport to Western Avenue, and turns north along Western. It then connects with the rail right-of-way adjacent to Archer Avenue at Western and continues into the downtown area on the same alignment as that used by alternative 2.

The U.S. standard light rail vehicle is the assumed vehicle for all alternatives. It seats 68 passengers and has a maximum speed of 89 km/h (55 mph). A 20-s station dwell time is assumed. If one assumes this dwell time and normal vehicle performance, an average speed of 40.8 km/h (25.2 mph) results when stations are spaced at 0.8-km (0.5-mile) intervals, and an average speed of 56 km/h (34.6 mph) is attained at station spacings of 1.6 km (1 mile) (6).

Demand Functions

A summary of data from several of the corridor demand runs is given in Table 1. The table gives the peak 2-h inbound trip interchanges between nine points in the corridor and the Chicago CBD. For the interchanges given, four different combinations of line-haul travel speeds and headways are assumed: Line-haul speeds of 32.4 km/h (20 mph) and 72.9 km/h (45 mph) are paired with 1- and 5-min headways. Interchanges given in Table 1 are only existing transit trips assigned onto the corridor links that run along Archer Avenue and do not include any divertible automobile trips. Numbers of interchanges given in the table correspond to patronage at the maximum load point just east of Halsted Street.

Direct application of these demand estimates to the alternatives is not possible since the alternatives differ in several important ways from the abstract corridor links used for the demand estimates. The values given in Table 1 must be adjusted for the different station spacings, slightly different alignments, and different line-haul speeds and headways of the alternatives. Demand estimates are based on a line-haul facility that has access at 1.6-km (1-mile) intervals and an Archer Avenue alignment; these characteristics do not agree with any of the light-rail alternatives. Headways and line-haul speeds other than those given in Table 1 must also be interpolated.

Patronage on Alternative 1

The next step (see Figure 1) is to estimate patronage at the maximum load point during the peak period. An initial headway of 1 min is assumed for the light-rail line-haul alternative. If one starts at Harlem Avenue and works toward the CBD, the first trip interchange is between Harlem Avenue and the CBD. This movement

Table 1. Demand data for the Southwest Corridor.

Speed (km/h)	Headway (min)	Number of Trip Interchanges to CBD From: Harlem	Narra-gansett	Central	Cicero	Pulaski	Kedzie	Western	Ashland	Halsted
32.4	5	674	513	576	773	1866	1112	2518	406	1654
32.4	1	674	513	576	773	2136	1112	3949	979	2895
72.9	5	674	513	576	1172	2917	3259	5234	-	5225
72.9	1	826	513	576	1172	3063	3391	5915	217	5649

Note: 1 km = 0.62 mile.

requires a trip of 17.8 km (11 miles) along alternative 1. Using an average speed of 56 km/h (34.6 mph) means that the line-haul travel time on alternative 1 is 19.1 min. It takes another 11 min to reach the CBD by using the existing Douglas Park rapid transit.

But note that the alignment of this alternative is not along Archer Avenue when it intersects Harlem Avenue; it is 0.8 km (0.5 mile) south of Archer at this point. Thus, some users will travel less distance to reach the line-haul service, and some will be forced to travel farther than the demand estimates assume. To correct for this, an estimate is made of the proportion of users whose line-haul access has been improved and those whose access has been worsened. This can be done well enough by simply reviewing data on population or dwelling units in the approximate service area of the station. Line-haul travel times for each group are then adjusted to reflect their access situation.

For the interchange from Harlem Avenue, 40 percent of the patrons are estimated to benefit from the alignment being 0.8 km (0.5 mile) farther south and 60 percent to be farther away than if the line were on Archer Avenue. The time adjustment is computed by assuming that access to the line-haul service is by feeder bus service, which travels at 16.2 km/h (10 mph). Individuals with improved line-haul access save 3 min whereas those with worse access have 3 min added to their travel time. The line-haul speeds to be used in the demand estimates work out at 42 km/h (25.9 mph) for the group with improved access and 34.3 km/h (21.2 mph) for those with poorer access. These speeds are computed by dividing the distance along the Archer Avenue alignment used in the demand estimates by the adjusted travel times.

The demand values given in Table 1 are interpolated in the following way. First, although it is not necessary at this point because of the assumed 1-min headway, demand at headways different from those shown in the table must be estimated:

$$D_v^h = D_v^5 + (D_v^1 - D_v^5)[(5 - h)/4] \tag{4}$$

where D_v^h = peak 2-h travel demand at headway h and line-haul speed v and h = line-haul headway (min). The next interpolation is for line-haul speed:

$$D_v^h = D_{v_1}^h + (D_{v_2}^h - D_{v_1}^h)[(v - v_1)/(v_2 - v_1)] \tag{5}$$

where v_1, v_2 = base line-haul speeds in Table 1. For the interchange from Harlem Avenue to the CBD, the demand at 42 km/h (25.9 mph) equals 710 trips. The demand at 34.3 km/h (21.2 mph) is 680 person trips.

Finally, the location correction is applied by weighting the above two demand figures according to the fraction of trips in each category:

$$D^1 = \lambda D_{42.0}^1 + (1 - \lambda)D_{34.3}^1 = 0.4(710) + 0.6(680) = 690 \tag{6}$$

where λ = the fraction of trips with improved access to the line-haul facility.

Working through all the interchanges to the CBD gives the following demand values for alternative 1:

From	Interchanges to CBD
Harlem	690
Narragansett	510
Central	580
Cicero	790
Pulaski	2 150
Kedzie	960
Western	3 800
Ashland	1 110
Maximum load point	10 590

Patronage at the maximum load point (just before alternative 1 connects with the existing Douglas Park service) is approximately 10 600 riders in the peak 2-h period.

At this point, the analysis has dealt only with light rail stations spaced at 0.8 km (0.5 mile). Yet, within alternative 1, closer station spacings may be considered and the calculations in the table above repeated. A change in station spacing can be approximated by adjusting the line-haul speeds in much the same way as a shift in alignment was approximated.

Supply Characteristics of Alternative 1

The supply function for light rail is adapted from the bus supply function. The constant term in the bus regression is assumed to hold for the light-rail alternative, but the coefficient for the independent variable, maximum-load-point patronage, is decreased because of greater vehicle capacity (90 persons/car is used as crush capacity) and the ability to couple vehicles into trains. The revised equation for the light-rail alternative is

$$f_{LR} = 4.65 + 0.0111\ (p/n) \tag{7}$$

where

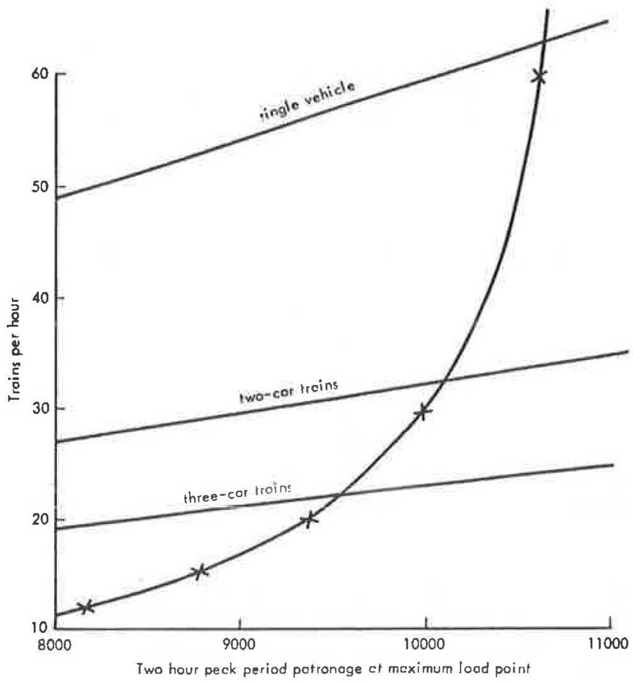
- f_{LR} = light rail trains per hour,
- n = number of vehicles in a train, and
- p = maximum-load-point ridership per hour during the peak period.

In Figure 7, the supply functions are plotted on the same graph as was the demand curve for patronage at the maximum load point. The demand curve for the first light-rail alternative is calculated by repeating the calculations given in the table above, assuming different service frequencies. The supply functions in Figure 7 are for one-, two-, and three-car trains. The three points of intersection between the demand and supply curves indicate where the amount of service offered is consistent with corridor patronage.

Evaluation

The first light-rail alternative has now passed through

Figure 7. Patronage and supply characteristics of light-rail alternative 1.



the initial level of screening. Some evaluation has also taken place. One can clearly conclude from Figure 7 that operating light rail trains with more than three cars is undesirable. The three points of intersection between supply and demand are also acceptable from both (a) the supply side, in that frequency of train operation is technically feasible, and (b) the demand side because more patrons are attracted by the service than by the existing corridor service.

To continue to evaluate the alternative, one determines whether any of the intersecting points between supply and demand is dominated by another intersecting point. But, in this example, clear dominance probably does not occur because of the trade-off between frequency of service and patronage. Operating costs are probably moving in opposition to user savings. Figure 7 does offer guidance when one is considering which alternatives should be compared with one another. For example, the modest drop in patronage caused by going from one- to two-car trains may be overwhelmingly offset by savings in operating costs. To complete the preliminary screening, the analysis of Figure 7 is directly extended to include other modal alternatives.

ACKNOWLEDGMENT

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Method for Highway Location Selection

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The professional costs associated with developing, tabulating, and evaluating alternatives in the execution of a highway location planning study have now become large enough to be considered a problem. A method is presented that minimizes the wasted efforts (and project costs) associated with testing in location planning studies and at the same time makes the study process more accurate and precise. This method of highway location selection offers the transportation planner a computer-assisted technique that can generate and then search through a large number of generated highway locations to identify optimal solutions. The traffic analysis zone is the basic element of which generated locations are composed. Zone deficiencies are determined for each zone and then used to determine zone-pair connectivities that represent the degree of importance of connecting deficient zones by a highway. A measure of effectiveness, defined as the aggregate connectivity of a location divided by its length, is used to approximate benefit/cost ratios in evaluating each generated location. The process also includes methods to account for highway-related costs (or benefits) of social, environmental, and economic impacts. This process allows an estimate of the highway benefits of a large number of location alternatives without running traffic assignments for each generated location.