A SYSTEMS APPROACH TO SUBAREA TRANSIT SERVICE DESIGN

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The usual transit service design process currently consists of a costly cycle of alternative system designs followed by system testing. A prime deterrent to substitution of optimization techniques is the number and complexity of the parameters that the designer can vary. A partial solution, readily usable with existing analysis programs, is presented. The technique provides a transit-use estimate prior to system design, employing the concept of a ubiquitous transit service in order to avoid prejudicial assumptions as to transit routings. An application involving the design of suburban bus service is described. The technique was used to identify feasible service areas and establish a basic system operating pattern. It was employed in sensitivity analyses to examine alternative fares and service frequencies. The results indicate that the technique has promise as a useful tool in developing improved transit service.

•THE development of structured system design techniques for transit service planning has lagged behind the development of ridership forecasting models. We now have rational and fairly effective means of predicting transit use. Unfortunately little has been done to apply the information gained in forecasting model development to the improvement of design procedures. As a result, we are often better able to evaluate a proposed transit system than we are to design one in the first place.

Paradoxically, it is inherently more important to design efficient and effective transit systems than it is to estimate the ridership with precision. Indeed, good design followed by implementation can be considered as the goal. Good transit-use forecasts, although quite important, are but one of the means to the goal.

The art of transit service design, as now practiced, normally consists of a trial-and-error process of alternative system designs followed by system testing. The process starts by having the system planner investigate the land-use, socioeconomic, and travel-pattern characteristics of the area. With this background information, the planner then proceeds to design transit systems complete with route locations, service frequencies, speeds, and transfer points. The number of alternatives is usually held down by means of policy decisions and design guidelines based on experience. The resultant designs are usually tested by estimating the transit ridership they would attract and by evaluating this in terms of estimated capital and operating costs. In more sophisticated studies, additional tests may be made to measure the increased accessibility provided to specific population groups, particularly the poor.

One of the problems with the present approach is the time and expense involved. If the designs are proved to be inadequate during the testing phase, there is no recourse except to return to the planning phase followed by further testing. Obviously, such a cyclic process, with limited alternatives, inhibits the approach to an optimum system.

A second problem is a lack of knowledge at the start of design as to the amount and nature of transit use possible in the various sectors of the study area. If there is a specific measure available other than that provided by the planner's intuition, it is

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generally the product of an earlier design attempt and is thus biased by the earlier design configuration. Obviously, the selection of route location, service frequencies, and even operating techniques and vehicle types should be made in consideration of possible ridership.

Full-fledged optimization techniques for designing transit systems do not appear to be in the offing. A prime deterrent to the development of such programs is the number and complexity of the parameters that the designer can vary. These include transit route location, service frequency, speed, and fares.

This paper describes a partial design solution, the key element of which is the preparation of transit-use estimates prior to system design. These estimates, and measures that can be derived from them, provide a basis for selecting service areas, corridors, frequency of service, and fares. The technique employs the device of using travel forecasting models to test generalized transit service descriptions against the given characteristics of the area under study.

THE DESIGN CONTEXT

Transit System Design Needs

The technique under discussion was developed during the course of a mass transportation study for the North Suburban Transportation Council of the Chicago area (1). The study was done under an Urban Mass Transportation Administration technical studies grant, and technical monitoring was provided by the Chicago Area Transportation Study.

The study area covered the suburban municipalities in the Chicago commuter shed along the North Shore and the Skokie Valley. A major element of the study called for examination of the feasibility of implementing local bus service and development of recommendations on the form such a service should take.

The study area is characterized by medium-to-low population density, relatively easy intrasuburban movement by automobile, and lack of a single dominant shopping and employment area. Excluding the Chicago commuter movement, which is served by fixed-rail mass transit, the remaining travel pattern is quite dispersed.

Normal guidelines were of little use in developing a local transit system plan. Consider the following examples:

1. Route trunk lines along major travel corridors—there are no readily identifiable intrasuburban corridors.
2. Focus the system on the central employment area—there is no dominant high-density employment center.
3. Provide good service to areas of low income—there are no major low-income areas.

Despite the inapplicability of standard design criteria and the existence of conditions not normally associated with high potential transit ridership, the possibility of establishing bus operation was not eliminated. Part of the area currently has bus service. In 1968, the year prior to initiation of the studies, two of the local companies carried 15 percent more passengers than in 1955. For the Evanston Bus Company, the number of revenue passengers carried per vehicle-mile was 15 percent above the national average.

Thus, study-area conditions reinforced the need for a systems approach to transit service design. The task at hand was to design a local bus operation with little assistance from the use of normal criteria for planning bus routes and schedules.

Operating Systems Under Consideration

In the design problem posed by the North Suburban Transportation Council project, bus service had to be designed for two basic categories of local trips. The first category encompassed trips taking place entirely within the suburban area. The second category covered feeder trips between suburban households and the stations of the various Chicago commuter railroad and rapid transit facilities penetrating the area.

In an earlier study phase, available bus technology had been reviewed and the conclusion reached that two principal types of service might have application. One type was conventional bus service, connecting such points of concentration as existed with trunk routes. The second type was pulse-scheduled bus service, a scheme most applicable to low-density areas. A brief description of pulse-scheduled service may be of assistance in understanding the design process under discussion.

Pulse-scheduled bus operation is the system wherein all scheduled buses in a given route set start their routes at the same time and place, circulate around the routes, and return to the starting point in time for each successive periodic cycle. The purpose is to bring all buses together at once to allow transferring with minimum passenger delay and to provide service at intervals that can be easily remembered, such as every 30 min.

Like conventional bus operation, pulse-scheduled operation normally provides service on fixed routes, according to a fixed schedule. However, the schedule, not the route, comes first in the operating hierarchy. The schedule is identical for all routes. Once the schedule is selected, pulse-scheduled routes are designed to fit the operating pattern thus defined.

The pulse-scheduled operating technique is keyed to provide a satisfactory level of service where the total amount of bus riding is relatively low. In a pure example, such as found in some small cities, there are no backbone routes or weak routes. The attempt is made to have each route serve an equal number of the riding population, and all areas receive the same level of service. Although originally conceived for service to a single passenger exchange point, the pulse-scheduled concept can be used with multiple-service nodes. A hypothetical illustration of such an operation is shown in Figure 1.

Consideration of the innovative pulse-scheduled concept necessitated feasibility evaluation of this specific type of service. It was also desired that the systems analysis aid in the selection of passenger exchange nodes for the operation.

THE SYSTEM DESIGN TOOL

Ubiquitous Bus System Concept

The first step in the adopted partial solution to structured systems analysis was to describe a generalized bus service. This was followed by evaluation of the service in terms of study-area travel characteristics. The evaluation included preparation of a transit network description, modal-split estimation, spider network summarization of the resultant ridership forecast, and analysis of sensitivity to varying fares and service frequencies.

The transit-use estimate did not only serve to allow identification of potentially feasible service areas and corridors; it also served as a standard against which to measure the performance of specific systems subsequently designed. The method is analogous to the multiple screenline analysis technique used in highway system design.

The need to describe a generalized transit service having no prejudicial assumptions as to specific routes led to the use of a ubiquitous bus service concept. In essence, it was assumed that the bus service was capable of directly serving each potential transit trip with a single ride from trip origin to trip destination along the shortest available highway route.

Obviously, such transit service cannot normally be provided. The assumption of ubiquity serves only as an aid to systematic analysis. However, it should be noted that only the assumption of ubiquity contradicts the characteristics of regular transit service. The assumption of direct travel without transferring was made in response to the nature of the system being designed, a local operation serving mostly short trips. All other standard transit trip characteristics were made part of the service description, including the following: walk to bus, wait for bus, speed of bus, walk from bus, and fare for ride.

Test System Description

Because there was no route structure, travel along the ubiquitous bus system was described by using minimum paths through the study-area highway network. The average local bus-operating speed of 12.5 mph was used as the running time portion of total travel time. The walk time to the bus was combined with the walk time from the bus and assumed to total 8 min for intrasuburban trips. Walk time for feeder trips to rail service was assumed to total 5 min. These figures were derived from an examination of typical street patterns and assumed service at approximately $\frac{1}{2}$-mile intervals.

A series of average wait times was tested with values ranging from a $7\frac{1}{2}$-min wait for the bus to a 30-min wait.

The fare for the bus ride was computed on the basis of two alternative fare systems. One system assumed a 25-cent base fare that was good for 4 miles of travel, with a 3-cent per mile rate thereafter. The second system assumed a 40-cent fare for the first 4 miles and 5 cents per mile thereafter.

Ridership Estimation Model

Estimation of transit use (assuming the ubiquitous system) was accomplished through application of a trip interchange modal-split model to a person-trip estimate for the study area. The person-trip estimate was derived from forecasts previously prepared by the Chicago Area Transportation Study. The modal-choice model had been calibrated in an earlier work phase (2). The choice model was a simplified version of the type that, for each travel interchange, relates percentage of transit to the difference in trip disutility between automobile and transit (3, 4). The estimating curve is shown in Figure 2.

The trip disutility measure employed in the modal-split model was a function of travel time, convenience, and cost. Highway travel times and costs, including parking charges, were based on current conditions in the study area. Transit service characteristics were those defined by the ubiquitous system description.

It is of technical interest to note that the average computer-time expenditure for each of the six service frequency and fare combinations tested was equivalent to no more than the cost of building one set of transit minimum paths. A modification of the modal-split program from the HUD Transit Planning Programs was employed; it was the provision of a table look-up procedure. To aid in the analysis, trips of less than 4 miles were segregated from longer trips. This was accomplished through use of a special assignment program.

STUDY AREA APPLICATION

Alternative System Parameters

Six different combinations of transit fares and average wait times for the bus were tested in applying the ubiquitous bus system design concept to the North Shore study area. These combinations were as follows:

Class	Base Fare (cents)	Wait (min)
I	25	$7\frac{1}{2}$
II	40	$7\frac{1}{2}$
III	25	15
IV	40	15
V	25	30
VI	40	30

The testing of these various alternatives allowed analysis of the feasibility of varying service assumptions and provided the basis for the sensitivity analyses.

Service Feasibility Analyses

The initial objective of the service feasibility analyses, as conducted using the ubiquitous bus service design technique, was to identify those sectors and corridors of the study area that could support local bus service. With this determination made, the analyses were next used in the development of a bus route structure.

Table 1 gives the bus-use forecast for the ubiquitous system, considering only local intra-study-area trips. These forecast transit trips were separately assigned to a spider network to produce transit trip estimates by traffic zone and by corridor.

Short transit trip service was investigated for feasibility by comparing the transit trip-end estimates for each traffic zone, and their related revenue-producing capability, to an average bus-operating cost per unit area. This average cost was developed starting with the diagram of a hypothetical pulse-scheduled bus service shown in Figure 1. The service shown requires one bus per fully developed square mile to provide service every 30 min. Assuming approximately 14 hours of weekday operation, including 6 peak hours during which service would be augmented by 50 percent, each square mile requires 17 bus-hours per day. At $8 per bus-hour, the daily operating cost per fully developed square mile is $136.

Feeder trips to the Chicago rail services were estimated separately and included in the revenue-cost comparison for short trips. Figure 3 shows the results in terms of different ranges of ability to meet operating costs with fare-box revenue.

The short-trip class I designation shown in Figure 3 identifies the area where the revenue produced from a 40-cent base fare would cover the operating cost of providing bus service at a 15-min headway. Class II could support routes operating at a 30-min headway, assuming regular scheduling would allow the wait time for the bus to be perceived at no more than a $7^1/_2$-min average. Class III designates those areas coming within 75 percent of class II requirements.

The major portion of the class I coverage is that part of the study area already supporting fairly extensive bus service. Much of this existing service is even more frequent than the specified 15-min headway.

Long transit trips were analyzed on a mini-corridor basis, again comparing revenue-producing capability and operating costs. No corridors exhibited a capacity for meeting operating costs on the basis of long trips alone. However, the analysis did serve to identify where local bus service could be aligned to serve significant numbers of longer trips. Two degrees of long-trip significance are shown in Figure 3.

By using the results shown in Figure 3 and the details of the analyses, it was possible to make a number of rational design decisions that would not have otherwise been possible prior to specific route design. For example, it was possible to determine that route design should be restricted to the southerly and easterly portions of the study area. It was decided to design a short-trip orientation into the transit operation because the analyses had shown this to be the major potential trip category as pertains to local intrasuburban transit service. Routes were combined to form trunk services along the corridors having large numbers of long trips.

Sensitivity Analyses

As has already been indicated, the results of applying the modal-choice relations in the six ubiquitous system test cases also provided the basis for sensitivity analyses. These analyses investigated the sensitivity of potential study-area transit use to various fares and service frequencies. The findings were then expanded to include investigation of the revenue-cost ratios associated with the different fares and service levels at given trip densities.

The sensitivity analyses were confined to the short-trip forecasts and thus give results that would not be expected from, say, an investigation of long radial routes into a major central business district (CBD). The analyses made use of the daily bus-operating cost per square mile estimate already discussed. The extra cost of providing bus capacity to satisfy demands not met by the basic schedule was not investigated.

Figure 1. Hypothetical pulse-scheduled bus service diagram.

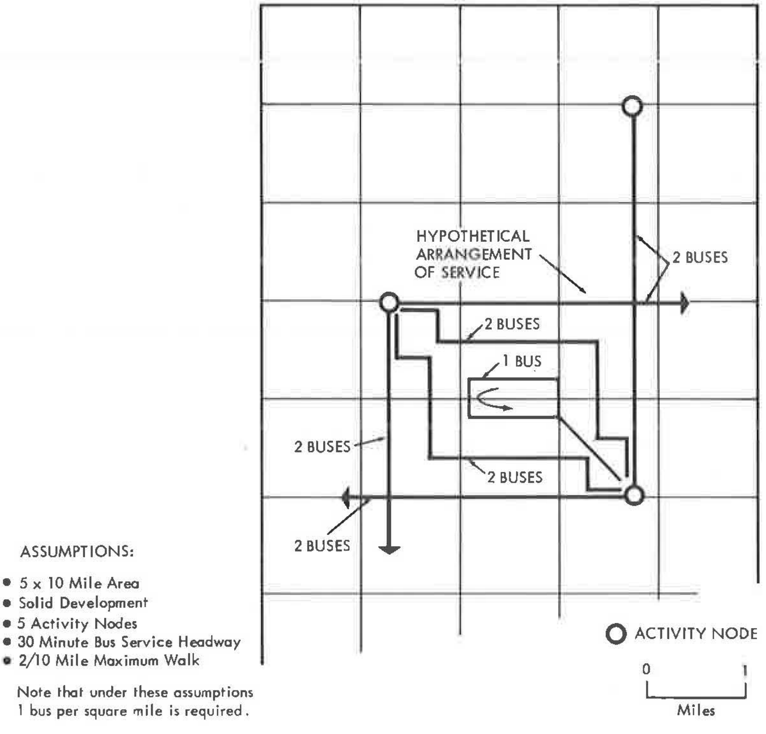


Figure 2. Mode choice estimating curve.

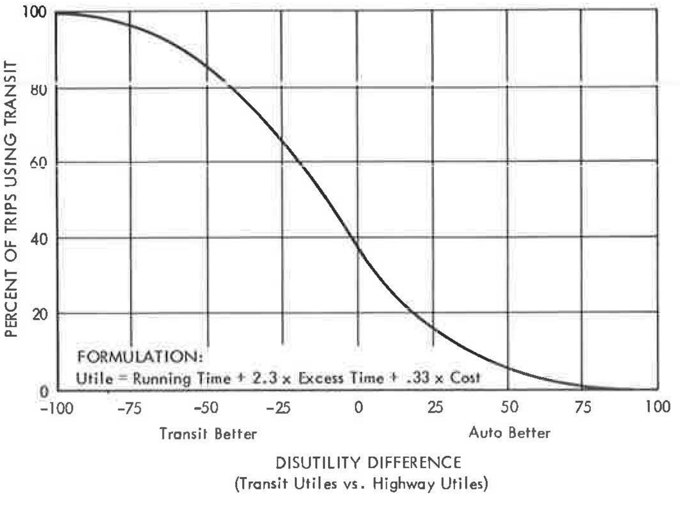


Table 1. Forecast of local-trip bus use.

Class	Headway (min)	Base Fare (cents)	Percent Transit: Short Trips	Percent Transit: Long Trips	Percent Transit: Total
I	15	25	7.8	5.0	6.7
II	15	40	5.9	3.3	5.0
III	30	25	3.0	1.9	2.6
IV	30	40	2.3	1.1	1.9
V	60	25	0.1	—	0.1
IV	60	40	—	—	—

Two alternative sets of assumptions were used in the sensitivity analyses regarding the potential rider's perceived wait time for the bus. For normal bus operation, it was assumed that the average wait would be perceived as being equal to one-half of the bus headway. It was on this basis that the modal-choice model had been calibrated (2). However, analyses were also developed by using the assumption that potential riders might be induced to perceive the average wait as being approximately equal to one-quarter of the headway. This was done because of evidence that the right kind of systematic, easy-to-remember, and well-advertised bus schedule, such as the pulse-scheduled type, might have such an effect. A similar consumer response had been observed in a study-area commuter travel choice of well-publicized and highly dependable commuter railroad schedules.

Figure 4 shows the results of one of the first-order sensitivity analyses. In both parts of the figure, transit use at different base fares is related to the frequency of service provided. The frequency is described in terms of bus headway, the average time interval between buses.

Although transit use is shown as a continuous curve in both parts of Figure 4, it should be understood that the less conservative of the wait-time assumptions is thought valid only when buses are scheduled at even increments of an hour. It should also be noted that the relatively low degree of transit use projected is primarily the result of considering only local trips, in a high-income area, with few significant parking costs and only localized highway congestion.

Although the curves showing the sensitivity of transit use to system parameters are interesting, they do not provide a description of the related feasibility of transit operation. By coupling revenue production and operating cost with the transit-use curves, we can examine the expected revenue-cost ratio in relation to the transit system parameters.

As a preface to reviewing the results, it should be reemphasized that the estimates do not include the extra cost of providing bus capacity to satisfy demands not met by the basic schedules under consideration. The basic schedules tested are adequate at the minimum level of feasibility, i.e., at a revenue-cost ratio in the vicinity of 1. The primary analysis need is thus served. However, revenue-cost ratios that are significantly more than 1 are highly suspect. Capacity analyses and related reestimation of cost would bring these down to a more normal range.

Figure 5 shows the results of examining the revenue-cost ratio for the effect of service frequency. To develop this relation, it was necessary to assume given trip densities representative of the study area. Note that, for the densities used, the optimum headway is 20 min for conventional bus service (perceived wait time is equal to one-half of the headway) and 30 min for pulse-scheduled service (perceived wait time is equal to one-quarter of the headway).

An interesting check on the validity of these results is provided by the detailed data developed in the course of studying transit operation in Tampa, Florida (5). In the Tampa studies, revenue-cost information was developed for each individual bus route. This information is shown plotted against peak-hour service headway (Fig. 6).

Despite the fact that the Tampa system does have a CBD on which to focus and serves a population with a lower average income than the Chicago North Shore, the routes that are serviced less frequently than every 30 min all have a revenue-cost ratio of less than 1. Note that the revenue-cost ratios for routes with 30- and 60-min service headways fall very close to the Chicago results for a 25-cent fare and a perceived wait time equal to one-quarter of the headway. In contrast, the results for Tampa bus routes with headways that are not an even increment of the hour fall lower on the scale.

Unlike the North Shore curves, the Tampa revenue-cost ratios continue to increase for shorter headways. This is because the Tampa data are not stratified by trip density as are the North Shore data.

Figure 7 shows the estimated North Shore revenue-cost ratio sensitivity to transit fares. The sensitivity is less than was the case with service frequency. Note how the curves show that relatively higher fares will be tolerated when better service is provided, i.e., at the shorter headways and perceived wait times.

Figure 3. Service feasibility analysis map.

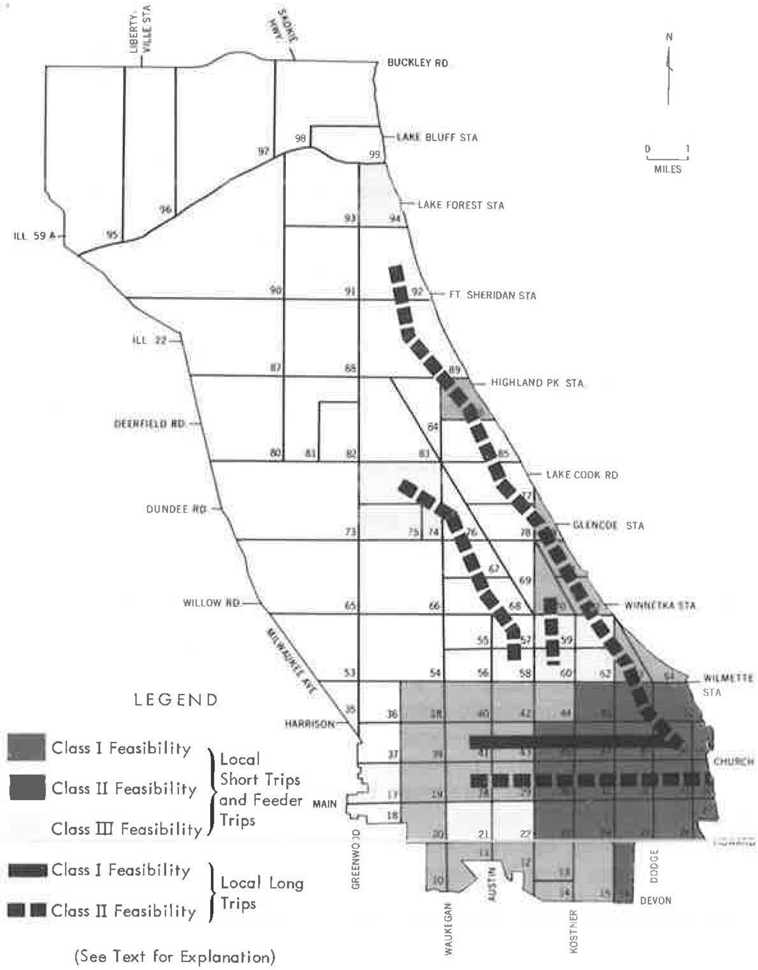


Figure 4. Sensitivity of local bus use to service parameters.

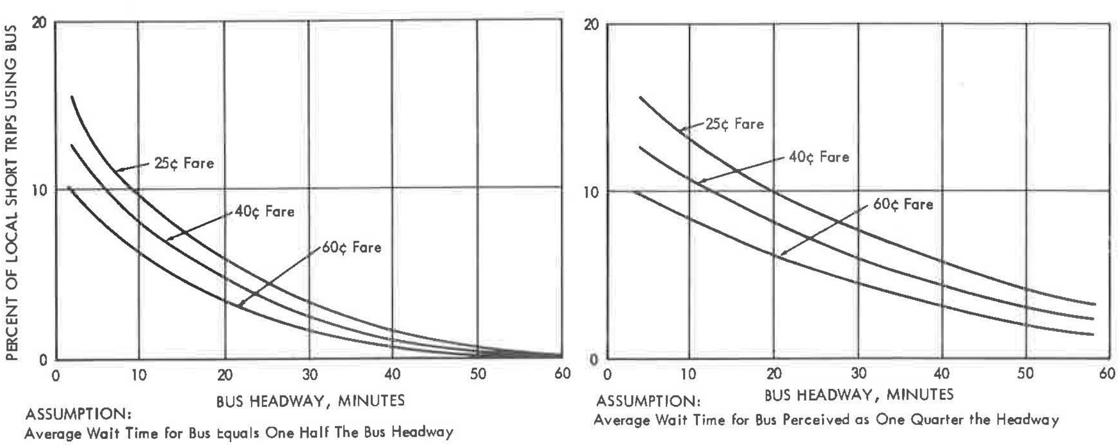
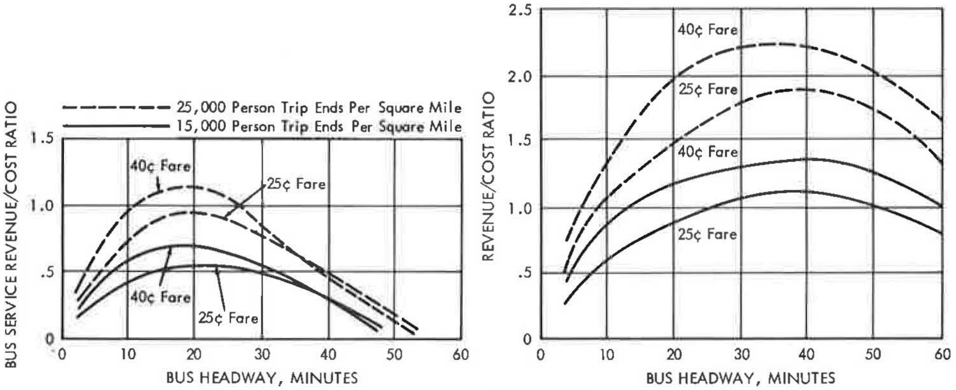


Figure 5. Sensitivity of revenue-cost ratio to service frequency.



ASSUMPTION:
Average Wait Time For Bus Equals One-Half the Headway

ASSUMPTION:
Average Wait Time For Bus Perceived as One-Quarter the Headway

Figure 6. Tampa revenue-cost ratio versus service frequency.

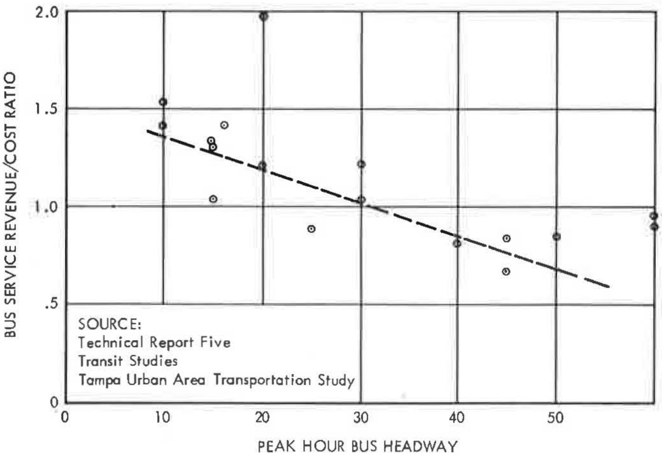
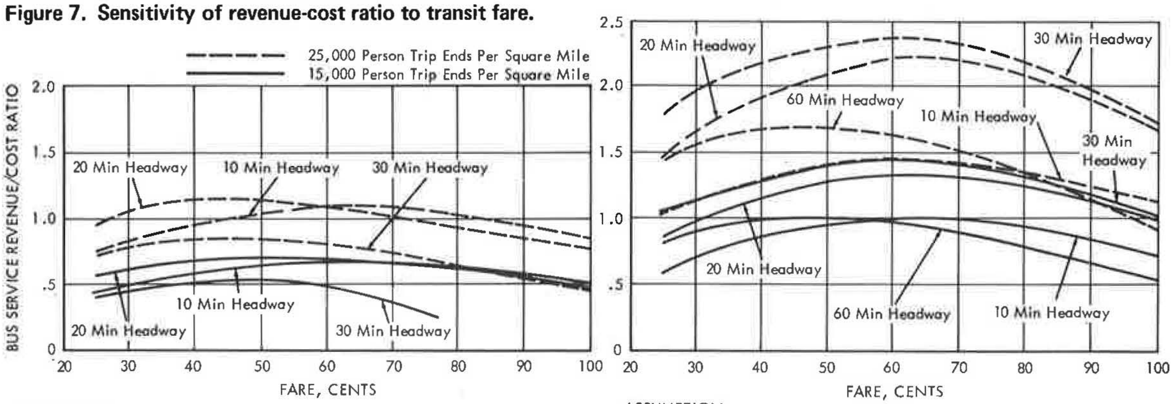


Figure 7. Sensitivity of revenue-cost ratio to transit fare.



ASSUMPTION:
Average Wait Time For Bus Equals One Half the Headway

ASSUMPTION:
Average Wait Time for Bus Perceived as One Quarter the Headway

With the aid of these various sensitivity analyses, and taking into account other factors such as public service implications, we selected fares and service frequencies for the final bus system analysis in the study area. It was decided that no services should be considered that could not support a 30-min headway. Fares were recommended at a 35-cent base rate with a 10-cent zone charge at approximately 3-mile intervals.

System Design Results

The local-service bus system designed by using the ubiquitous system analyses performed quite well when routes and schedules were specified and then tested by application of the travel models. The final test system was planned as having a network of primary trunk routes augmented by a system of supplemental routes on the pulse-scheduled principle. The test system would require approximately 30 percent more buses than are currently deployed in the study area and would serve 63 percent more miles of streets. The ridership projection, based on both local and commuter trip categories, indicated that stabilized present-year use would be 62 percent more than existing study-area bus patronage.

This forecast was derived by using the estimating curves; i.e., the curves provided descriptions of observed reaction of study-area residents to the present bus service. A supplemental projection was made by assuming a perceived wait time equal to one-quarter of the headway for the pulse-scheduled bus services of the plan. With this assumption, total use was estimated to be 115 percent above present ridership.

Using the conservative ridership estimates and a route-specific cost analysis, we forecast that the transit revenues derived from the expanded service would, at 1969 cost levels, pay for 98 percent of the operating cost including depreciation. In light of this finding, the proposed system appears to be practical as well as potentially attractive to study-area trip-makers. It is felt that use of the technique described in this paper contributed substantially to the design.

CONCLUSION

Use of the ubiquitous bus system concept as an aid in planning transit service appears to have many advantages not found in normal design methods. Areas having potential for transit service can be quickly identified. By applying the concept to the sensitivity analyses of transit-operating parameters, we can determine the feasible ranges of fares and headways. The cost of adapting the design concept to computer technology is low when compared with the expense of forecasting use and costs for fully designed alternatives.

Analysis of larger and more complex systems that the example described here would require more detailed assumptions to properly describe a generalized transit service. Varying speed assumptions might need to be employed. It might be necessary to include rules that describe the number of transfers to be encountered for different types and lengths of trips. Specification of existing fixed right-of-way facilities would have to be included. There appears to be no inherent reason, however, why the ubiquitous system concept would not, in some useful fashion, be applicable to most transit service design problems.

The ubiquitous system design technique is, of course, only a partial solution to full system optimization. Nevertheless, it is a first step forward in achieving a structured approach to transit system planning. The results of its application in the example discussed here give promise of its being a useful tool in developing improved transit service.

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