Analysis of Integrated Urban Public Transportation Systems

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Dramatic increases in transit patronage will require a major restructuring of present transit and paratransit operations to achieve integrated regional systems capable of changing as traffic increases and new markets are penetrated. The integration of new public transportation options such as dial-a-ride, jitney, and subscription bus with conventional mass transit promises significantly improved overall levels of service without increased total system costs. Integrated systems and expansion policies requires that the individual service and cost attributes of each system component must be modeled and the synergisms that result from various service combinations must be evaluated. Integrated system design is significantly more complex than the conventional bus routing and scheduling problem because of the increased number and complexity of available modes. This paper examines a case in which various service policies are evaluated, for parametrically varied demand levels, by using a combination of manual and automated procedures. Major conclusions are that significant economies of scale develop at relatively low levels of increased transit use and that major redesign of system operating policies is required to sustain desirable service levels and costs.

In the last 3 decades America has been sufficiently affluent to absorb the expense of using low-occupancy, small-capacity private vehicles to provide most urban transportation passenger services. In recent years, however, attention has been focused on shortcomings of this policy, such as pollution, congestion, decay of the central cities, lack of mobility for certain segments of society, and inefficient use of energy. As a result, interest in alternative policies has developed. A promising option is the expansion and integration of transit service in a form suitable to the new multinuclear urban environment.

Because different transit modes and operating policies are most advantageous under different conditions, an integrated regional system would consist of a variety of modes, each operating in its appropriate environment. There would be the kind of coordination among these various transit-service components that does not exist in current systems, and it would result in increased efficiency, service, and patronage.

An integrated regional system would be able to respond to both space and time changes in travel volume and patterns. Transit services in different parts of the region would change during the day in response to peak and off-peak travel and over the years in response to urban development and transportation policies. Current institutional barriers to the coordination of system components and to their operational responsiveness would be removed as part of the concept of integrated transit. Economies of scale in some parts of the system (derived from patronage increases) could benefit other parts and thereby increase the range of economically feasible components and enrich the total transit system as it evolves.

Recent studies have investigated the demand for transit service (1), changes in the urban environment and in travel patterns (2), and the operational characteristics of various modes (3), all of which are pertinent to an analysis of expanded and integrated transit. The following key issues, however, have not been fully addressed.

1. What is the full potential of integrated transit for offering high-quality, low-cost service?
2. Given an understanding of its potential, is integrated transit a cost-effective means of meeting the mobility and development goals of a region?

In an effort to fill this void, the U.S. Department of Transportation (DOT) has sponsored a study (4) that attempts to provide preliminary insights into these issues and to develop the basis of a sound methodology for exploring issues in policy and planning analyses.

MODELING APPROACH

In developing a set of models to analyze the impacts of a major diversion, the following criteria had to be considered:

1. Do the models reflect the reality and complexity of an urban environment?
2. Are they adaptable for the analysis of diverse urban areas?
3. Do they respond to changes in policy?
4. Do they provide the analyst with useful information for evaluation?

A typical urban area has a varied distribution of population, employment and activity centers, and transportation facilities, all of which have evolved in response to topography and changing social, economic, political, and technological forces (Figure 1). In order to capture this diversity and inject realism into the analysis, the travel patterns and street network of Rochester, New York, a medium-sized urban area, were used in the analysis. Rochester is typical of many American cities in that it has major employment centers outside the core, topographical constraints, and varying population patterns and highway development (the models developed are applicable to any urban area).

Although the study was a macroanalysis, a hierarchy of 135 zones, 32 districts, variable subregions, and 5 rings was developed to reflect the complexities of trip volumes and patterns. Zones, for example, were used to define regional networks and assign trips. Sample districts created from these zones were used in the analysis of local transit-service options. Rings and subregions were used to present results of aggregate market responses, such as the service levels provided to suburb-to-CBD transit patrons.

The trip data used in the analysis were based on 1970 peak and off-peak volumes and peak modal-split values provided by the New York State Department of Transportation. The purpose of the study was to analyze transit operations as the daily regional modal split increased from 5 to 60 percent. Because the scope of the study precluded supply and demand equilibria, transit patronage was varied parametrically over the 5 to 60 percent range to generate the four study cases shown below.

	Regional Modal Split (%)			
Case	Daily	Peak	Off-Peak	Transit Peaking Ratio
1	5	10	3.5	3.6:1
2	15	25	10	3.2:1
3	25	40	20	2.6:1
4	60	77	54	1.9:1

As the regional modal split was increased, it was forecast that growth would occur nonuniformly; i.e., some markets would experience earlier or more rapid growth in transit ridership than others, primarily because of the relative ease of improving service in markets already served by transit. To prepare trip data for the cases given in the tabulation above, a modal-split transformation procedure was developed and applied to the base data on a district-interchange basis to produce a modal-split matrix for each case (4, Appendix A). Figure 2 illustrates the resulting aggregate peak-period penetration of selected markets by transit. For example, when the regional peak modal split is 40 percent, almost all morning peak trips from the city to the CBD are transit trips but only 15 percent of the trips destined for the suburbs are made by transit. To achieve peak modal splits greater than 40 percent, nontraditional markets must be heavily penetrated by transit.

Analysis of Integrated Service

As shown in Figure 3, transit services were modeled in two parts: (a) a regional network of fixed-route bus lines and (b) local transit services providing intrazone service and feeder connections to the line-haul network. Line-haul options were analyzed in terms of specific networks by using the processing and transit-assignment modules of the urban transportation planning system (UTPS) of the Urban Mass Transportation Administration (5). This approach, which was consistent with the use of real traffic data, reflected the interdependence of the transportation system and travel patterns. A range of local service options including doorstep, checkpoint, conventional fixed route, and route deviation were analyzed by using models expanded or developed for this study (8, 9). Unlike the regional network analyzed, the local transit models were based on typical districts with abstracted networks and trip distributions. The results of the separate analyses were combined to investigate the service potential and operating costs of integrated regional public transportation systems. Corresponding estimates of fuel consumption, pollutant emissions, and capital cost were developed by using recent DOT studies (4, Appendix B; 6; 7).

Network Design

Figure 4 shows three sets of options that exist in the design and operation of transit networks to serve increasing transit volumes and changing trip patterns as modal split increases. The first option, the basic configuration of the network (radial versus grid), is highly constrained by the roadway system. Within the basic configuration the spacing or density of routes as well as the outward extent of line-haul services can be varied. These options involve changes in the importance and extent of local transit services. A third set of options involves the connectivity of the network, which can be improved by providing transfer points among high-frequency trunk routes or by providing more direct service between points on the network.

Line-Haul Options

Several options for regional bus operations within a basic network were explored by using a route-based supply model in conjunction with the UTPS network models. The following options were examined: (a) trade-offs between service frequency and vehicle size, which have direct effects on level of service and both operating and capital cost; (b) introduction of express or skip-stop service; (c) use of suburban transfer points; and (d) use of exclusive lanes and other priority measures on expressways, arterials, and downtown streets. The evaluation of some of these options required, in addition to vehicle costs, estimates of conversion and operating costs for fixed facilities (such as exclusive lanes or the hardware required for prioritization schemes). Figure 5 shows the line-haul options in the context of a sample corridor.

Local Service Options

The full range of local service options, from fixed-route to fully demand-responsive service, was evaluated (Figure 6) by using a family of local service models. These models were designed to respond to varying levels and proportions of intrazonal, feeder, and intradistrict trips; varying locations of line-haul stations, transfer points between adjacent zones, and route or checkpoint route density within the service area; mixes of transit access modes, vehicle sizes, and load factors; and varying operating speeds. Within each typical service area examined, heuristic searches were made to identify optimal modes and operating policies based on estimated cost and level of service. The key trade-offs involved were those between vehicle size, walk distance, wait time, and average speed (as affected by circuity and start-stop cycles for boarding).

Dynamically routed services such as dial-a-ride were modeled based on computer simulations and validated by actual data from Haddonfield, New Jersey (4, Appendix C; 9). The models accounted for the impact on bus speeds of dwell times and number of stops per hour, fraction of dead time (percentage of time the vehicle is available for assignment when no demand exists), trip density (demands per square kilometer per hour), analyst-specified constraints on level of service, and fleet and vehicle size. Dial-a-ride was modeled as a coverage service in the off peak and as a supplement to either doorstep or checkpoint subscription service in the peak. The subscription service models, which were similar in framework to the fixed-route and route-deviation models, were extensions of work by Ward (8).

Cost Allocation

Operating costs were assigned to the local and regional service components based on the pro rata share for each service of total vehicle hours and kilometers. Overhead costs were estimated as a function of fleet size. Capital costs were allocated to local and regional service in proportion to vehicle requirements (or other capital equipment requirements) by time of day, which caused peak-hour services to bear the brunt of equipment costs. No attempt was made to estimate the marginal cost of off-peak transit labor; average labor costs were used over the full day.

Evaluation Criteria

The regional transit-service alternatives were evaluated on the level of service provided and the capital and operating costs of the system. The level-of-service measure was door-to-door travel time, which included estimates of access, egress, and wait times optionally weighted to form perceived impedance measures. Transit travel times were compared to existing automobile travel times on a zonal interchange basis in the form of bar graphs showing the percentage of transit trips in the region (or in specific markets) having travel times X minutes better (or worse) than their automobile alternatives. Because of the great variation in trip lengths and patterns, these measures were more meaningful than regional averages of transit travel time. Furthermore, in the absence of demand modeling, these service comparisons enabled the analyst to determine if a modal split and transit service assumptions used in an analysis approximated an equilibrium.

Nonuser impacts such as changes in fuel consumption and in emission levels of carbon monoxide, hydrocarbons, and oxides of nitrogen were also tabulated. Because no attempt was made to explicitly model the impacts of major diversions to transit on the level of service of the remaining automobile users, major additional benefits to automobile users are not included in the evaluation.

Results

The models described above were applied to a wide range of modal splits and system designs, and conclusions were drawn in the areas of economic performance, service levels, and prototypical system operating procedures. A brief summary of the conclusions follows; more detailed results are available elsewhere (4, 10).

Costs

Figure 7 shows the changes in transit-system operating and capital costs as the network is expanded and inte-

Figure 1. Study area.

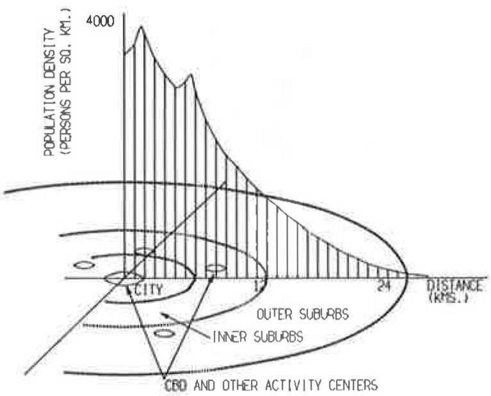


Figure 2. Morning peak trips by market.

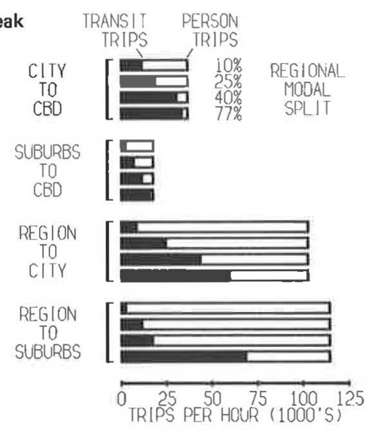


Figure 3. Model of transit service.

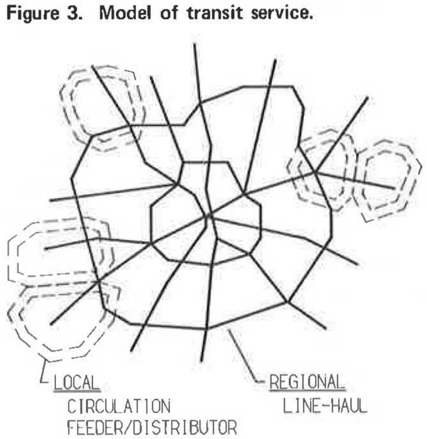


Figure 4. Network design options.

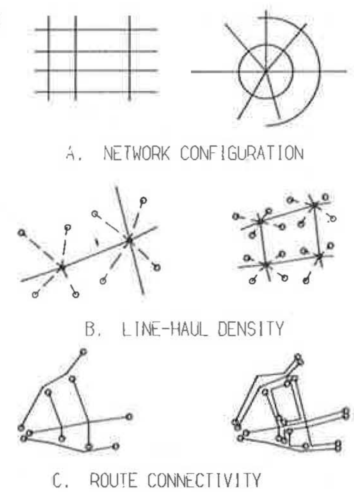


Figure 5. Line-haul service options.

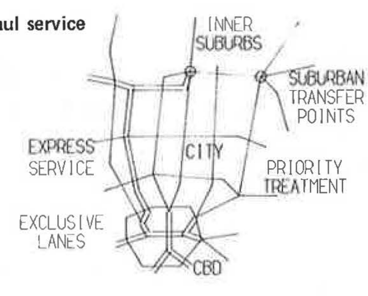


Figure 6. Local service options.

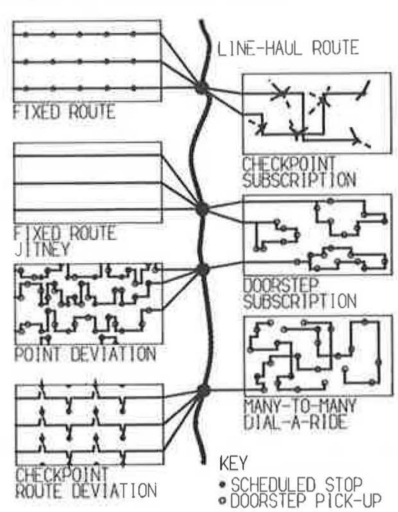


Figure 7. System costs versus modal split.

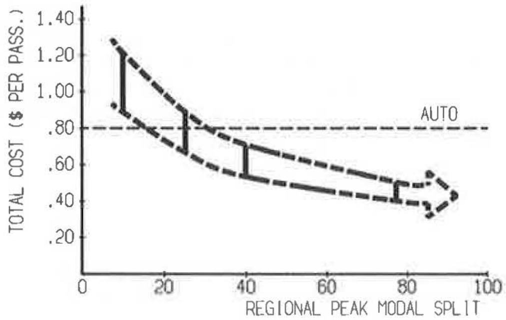


Figure 8. Alternative transit investment policies.

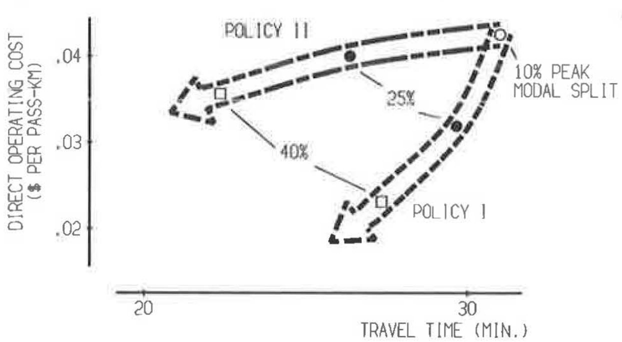


Figure 9. System levels of service.

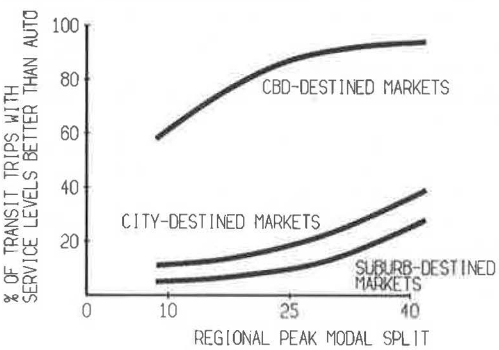
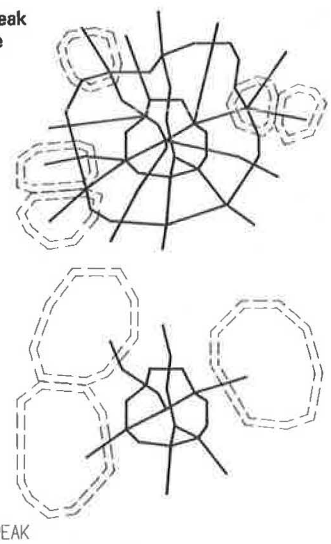


Figure 10. Daily peak and off-peak service configurations.



grated to serve increasing shares of peak-period trips. Significant economies of scale are apparent, contrary to the belief that the industry can only attract new riders by increasing average costs. The sources of these economies are

1. Increases in backhaul and other non-CBD-oriented trips to improve line-haul load factors;
2. A decline in the peak-to-base ratio as modal split grows;
3. An increase in transit travel speeds and reliability as facilities are dedicated, which results in improved line-haul vehicle productivity;
4. Use of larger vehicles as modal split increases to improve labor productivity without a decrease in the level of service; and
5. Provision of good local service by means of (a) low-cost, fixed-route operation at higher modal splits to reduce the unit cost of feeder service and (b) checkpoint and fixed-route services instead of doorstep services at low modal splits.

Figure 7 implies that modal split need not increase very much to produce economies of scale. In fact, such economies rapidly diminish after moderate modal shares are reached. There is not likely to be a threshold modal split at which direct benefits increase rapidly. The potential for transit-system cost and service benefits is greatest in the range of modal splits just slightly above current values. These benefits are the reverse of the disbenefits that in recent decades have accompanied decreased transit patronage.

Service Levels

The planner has a variety of investment options in trading system economies of scale for improvements in service. Figure 8 shows two policy options explored in the analysis of line-haul operations. In policy 1 the economies of large vehicles and dedicated facilities combine to achieve a 50 percent reduction in unit costs and a 15 percent reduction in travel time. In policy 2 potential economies in vehicle size are reinvested in additional, denser routes to enable a 33 percent reduction in travel time and a slight reduction in unit costs; the result is a fleet more easily adapted to flexible services in the off peak. It is not yet known whether options exist that would yield greater service improvements at higher unit costs.

Figure 9 shows the distribution of service improvements achieved in policy 2 in comparison to automobile travel. It is clear that, although significant service improvements can be achieved in all parts of the region, transit service cannot match the automobile for many interchanges within nontraditional markets.

Operating Policies

The key to providing integrated transit service is a range of operating policies that adapt to the changing travel environment. Not only do trip patterns vary over the day but transit trips are also on the average much shorter (between 15 and 30 percent) in off-peak periods. The results of combining the previously discussed attributes of the local transit system with shorter trips and greater dispersion of travel patterns in off-peak periods suggest that the following scenario is likely to be highly effective in providing efficient, high-quality transit service at ridership levels resulting from major diversions to transit (Figure 10).

During the peak period an extensive regional line-haul system is operated with a mix of medium and large vehicles. Travel oriented toward major activity centers including the CBD is served by express vehicles operating on dedicated rights-of-way. Arterial services within the city receive the benefits of signal and lane prioritization schemes. Major transfer facilities are established in the inner suburbs and thus the travel time for long trips not oriented to major activity centers is reduced. The line-haul system is fed by a system of fixed-route and subscription buses operated in small local service areas. During off-peak periods a radically different transit system is operated. The regional line-haul system is reduced in both scope and density. In contrast, the local service areas grow to accommodate the majority of trips within their boundaries. The longer off-peak trips are served by coordinated transfers either between these expanded local service areas or to the basically radial line-haul network. The local service is operated in either demand-responsive or route-deviation fashion depending on the travel densities encountered. Inner city districts continue to rely on the line-haul system of local service.

AREAS FOR FUTURE RESEARCH

The range of options examined in this preliminary analysis does not do justice to the rich variety of alternatives available to transit planners. For example, this study focused on highway-based modes; light and heavy rail technologies, shuttle-loop transit, and other automated-guideway options could not be considered. Such capital-intensive options might result in economies of scale continuing to be derived well beyond a daily modal split of 25 percent. At the other end of the range of options, local transit services such as dial-a-ride and point-deviation bus service were provided by using paid-labor alternatives. Options using in-kind labor, such as car- or van-pooling, are likely to improve system efficiency, especially during peak commuting periods.

A major concern is, of course, the need to determine whether the transit service levels provided can sustain the assumed modal splits. However, before a major effort is made to examine the demand side of integrated regional public transit, more research is needed to develop a better understanding of the full service and economy potential of integrated transit operations.

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