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Computer-Assisted Flexible Routing to Increase Usage and Cost Effectiveness of Urban and Suburban Mass-Transit Bus Systems

O. L. Smith

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM-11361

Instrumentation and Controls Division

COMPUTER-ASSISTED FLEXIBLE ROUTING TO INCREASE USAGE AND COST EFFECTIVENESS OF URBAN AND SUBURBAN MASS-TRANSIT BUS SYSTEMS

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Date issued: JANUARY 1990

Prepared by the
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operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

A screening study was performed to assess the feasibility of using computer-aided routing to improve the efficiency and cost effectiveness of mass-transit bus operations. The methodology is intermediate between the conventional fixed route and dial-a-ride concepts. Preliminary technical and economic analyses suggest that significant cost benefits are achievable, depending upon the manner in which the methodology is applied.

1. INTRODUCTION AND OBJECTIVE

Stimulated by periodic (and eventually permanent) shortages of petroleum and by increasingly severe traffic congestion in urban and suburban environments, federal and local agencies have made large capital investments in mass-transit systems. These systems frequently operate in the red, and many are on the verge of financial failure because they are unable to attract a sufficient number of riders. Buses, in particular, often travel long distances with few, if any, fares.

Many potential riders reject local bus transportation because schedules and routes are not sufficiently convenient; the personal car remains the preferred conveyance. Any change in operation that significantly increases the convenience of a bus system by making it more responsive to individual demand would presumably increase ridership. A potential user must be able to catch a bus sufficiently near him when he needs it and have it take him fairly close to where he wants to go. While the full flexibility of a personal car cannot be achieved because of many simultaneous demands on the system, major improvement may be possible by appropriate redesign of the route controls. In all but a few pilot transit systems, present controls are rigid and almost totally unresponsive to the specific and varying needs of riders; the controls are simply a fixed route and schedule.

The need for increased reliance on mass transportation is widely recognized, and a variety of innovative concepts have been studied.[1-6] Considerable attention has been given to personal and multiperson rapid-transit vehicles with some form of automated guidance. Dual-mode concepts service part of a system by traditional methods and part with automated guidance vehicles. These approaches are comparatively major and unproven departures from present practice and would replace all or part of existing systems at major capital expense.

The concept under preliminary screening assessment here is more evolutionary than revolutionary. It is an upgrade of existing operations and therefore entails substantially less capital expense and is less experimental. Its principal feature is a form of demand routing that is responsive to riders within limits and that provides greater scheduling flexibility and should permit servicing a larger area with fewer buses. Demand scheduling has been explored in the dial-a-bus format. The concept considered in this report should be an improvement upon the fixed-route method but is a less radical departure from conventional operations than the dial-a-bus concept.

The next section summarizes the basic methodology and is followed by sections presenting initial technical and economic assessments. The final section outlines further research needed to confirm this tentative analysis.

2. METHOD

Under the proposed flexible schedule (flexschedule) operation, bus routes and timetables are controlled and optimized by a master computer that monitors and integrates the requests of riders and those waiting to ride. Each bus has a set of potential route segments that are assembled in various ways, depending upon demand.

Users transmit requests to the system via call boxes that, in the simplest application, may be ordinary telephones located at stops or places such as the user's home. Dialing a stop number identifies where a user is to be picked up. His destination may be similarly dialed or may be keyed by the bus operator on pickup. The control system merges these requests with others currently in process and schedules a bus to pick up the customer within a specified time and deliver him to his destination within another specified time. The system may be designed to provide user conveniences such as a computerized confirmation message that identifies expected pickup and destination arrival times. In more advanced applications, call devices at stops can be designed to protect against crank calls by accepting a fare, either coins or cards, before scheduling a bus. Notification of pickup and drop times may be made visually rather than audibly.

The control algorithm continuously adapts schedules and routes to demands and eliminates segments currently not needed and/or replaces them with needed segments. Electronic sensors at stops may track each bus automatically, or operators may key in this information. An on-board video screen or graphic device supplies the route to the driver. Because the routing of buses is dynamic, a number of refinements are possible. The best link between any pair of stops will depend upon the prevailing traffic load. The route control algorithm can be programmed with the normal best link between stops as a function of time of day, thereby giving bus operators the best link automatically. Major disruptions such as traffic accidents can be keyed into the controller at the time of occurrence, and the affected buses can be rerouted.

Other refinements of the basic concept may be suitable in particular environments:

1. Outlying stops that are more costly to service may have restrictions that require a minimum number of passengers or an elevated minimum fare.
2. In some communities, there exists a policy of providing preferential treatment to certain classes of users. Such persons may be issued special call and fare privileges that would be honored automatically by the control algorithm.
3. Spatial or temporal hybrid routing may be preferable in some circumstances. High-traffic areas may be serviced by conventional fixed routes, while outlying or low-traffic areas are serviced by flexscheduling. Alternatively, fixed routing may be effective during peak traffic periods, while flexscheduling is more cost effective during low-traffic, night, or weekend periods.

3. PRELIMINARY TECHNICAL ASSESSMENT

The simplified conventional operations bus system of Fig. 1 was used in an initial screening assessment of the flexschedule concept. The single bus, nominally operating on a fixed route, services stops 1 through 12 in the direction indicated by the arrows. The analysis is applicable to larger systems in which buses operate largely independently in sections of the overall service area. More complex analysis is required for interactive buses and routes.

The square-grid arrangement of stops and solid straight lines is pictorial. The drawing shows symbolically the normal route links between pairs of stops. The links may or may not actually be straight, and the route and stop pattern may or may not be square.

The bus travels at speeds such that the average stop-to-stop time is 2 min. At the beginning of the example time period, the bus is at stop 11 with 3 passengers on board who were picked up at stop 6 and want off at stop 5 and 1 passenger who got on at stop 9 and wants off at stop 10. In addition, as indicated by the symbols, there are 5 people waiting at stop 3 to go to stop 7, 4 waiting at stop 5 to go to stop 6, 2 at stop 5 waiting to go to stop 7, 3 at stop 7 waiting to go to stop 5, and 4 at stop 8 waiting to go to stop 10. This initial arrangement of 22 customers was selected at random. They are serviced in one-and-a-fraction route circuits covering 8.5 miles. The bus averages 2.6 passengers/mile and 39 passengers/h. The average wait time for pickup is 14 min, and the average ride time is 15 min, for a total of 29 min on average that these customers spend in the system.

For comparison, a computerized scheduling algorithm was developed that allows customers to be picked up and discharged according to a selected optimization strategy. Algorithms for efficient scheduling investigated in the dial-a-bus and certain demand-guided-car concepts provided a starting point for the scheduling algorithm of this work. Various optimization strategies may be postulated. The one used here finds the pickup and delivery schedule that minimizes the average time all customers spend waiting plus riding, that is, the average total time in the system. The algorithm is general in that pickups and deliveries may be interleaved in any combination (e.g., after any one customer is picked up, others may be picked up or delivered or both before the first customer's delivery is serviced).

As the passenger volume increases, the number of possible route alternatives increases approximately factorially, and increasing amounts of computer time are required to investigate all possibilities. Under such circumstances it is necessary to use an approximate search algorithm that achieves the desired improvement in scheduling without prohibitive computer usage. The approximation developed in this study determines the best route sequentially by looking for the best route segment a specified number of stops ahead (typically three). In comparisons, this algorithm achieved at least 90% of the improvement in scheduling realized by use of the full algorithm. For a passenger volume that would entail considering 10^{12} possible routes and would likely require days of computing, the approximation found a solution in 3 s.

The full (and approximate) algorithm works from a list of currently waiting and riding customers and a matrix of data that provides the travel time of the preferred

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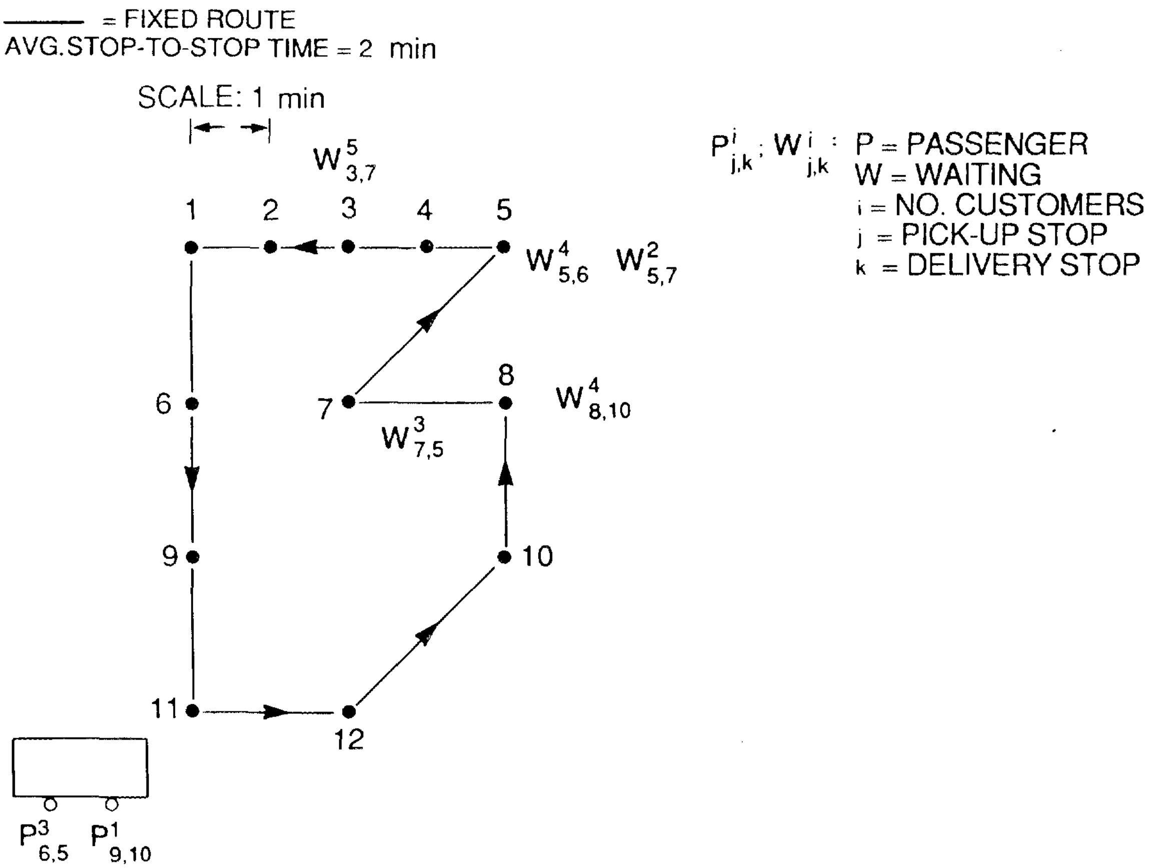

Fig. 1. Reference fixed-route, single-bus system used for preliminary technical and economic analysis. In the time period analyzed, 22 users are in the system. The bus is initially at stop 11 and traverses its route in the direction of the arrows.

route link between every pair of stops. For the study case, the algorithm rescheduled the bus route links as shown by the superimposed dashed lines in Fig. 2.

Several measures of performance were used to compare the fixed and flexschedule results, all of which indicated substantial improvement with flexible scheduling. The distance traveled by the bus to service the 22 customers dropped 35% (from 8.5 miles with fixed scheduling to 5.5 miles with flexible scheduling). Average wait-plus-ride time decreased 31% (from 29 min to 20 min) primarily because of reduced ride time. The average number of passengers carried per mile increased from 2.6 to 4, and the average number of passengers per hour increased from 39 to 60, representing a 55% improvement in both measures of performance.

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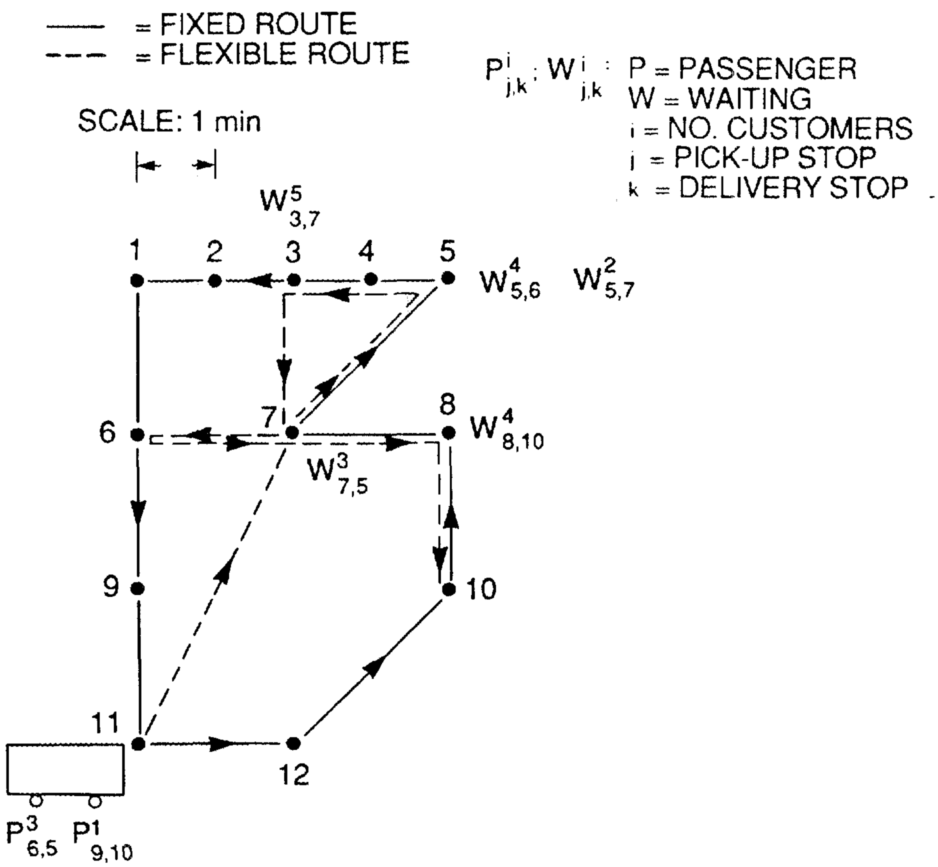

Fig. 2. The reference system with flexible scheduling to service the same 22 customers. The route, selected by a computerized algorithm that minimizes the average wait-plus-ride time of all customers, is indicated by the superimposed dashed line. It begins at stop 11, proceeds to stops 7, 5, 3, 7, 6, and 8, and finishes at stop 10.

Parametric studies relative to this reference flexschedule case were performed to assess the impact of several important system characteristics on the results. First, the geographic size of the system was scaled both down and up without changing either the relative position of stops or the number of passengers. This, in part, simulates flexscheduling in more or less densely populated areas. (Results are shown in Fig. 3.) The distance scaler is relative to the reference case, which appears at scaler value 1 and is labeled 'nominal.' The various measures of performance are relatively insensitive to systems the size of, or more expanded than, the reference case. However, as the system becomes more condensed and the stops are relatively closer together, the improvement of flexible scheduling decreases, as one would expect.

In a second parametric analysis, the effects of passenger volume were examined, and results are shown in Fig. 4. The improvement due to flexible scheduling increases

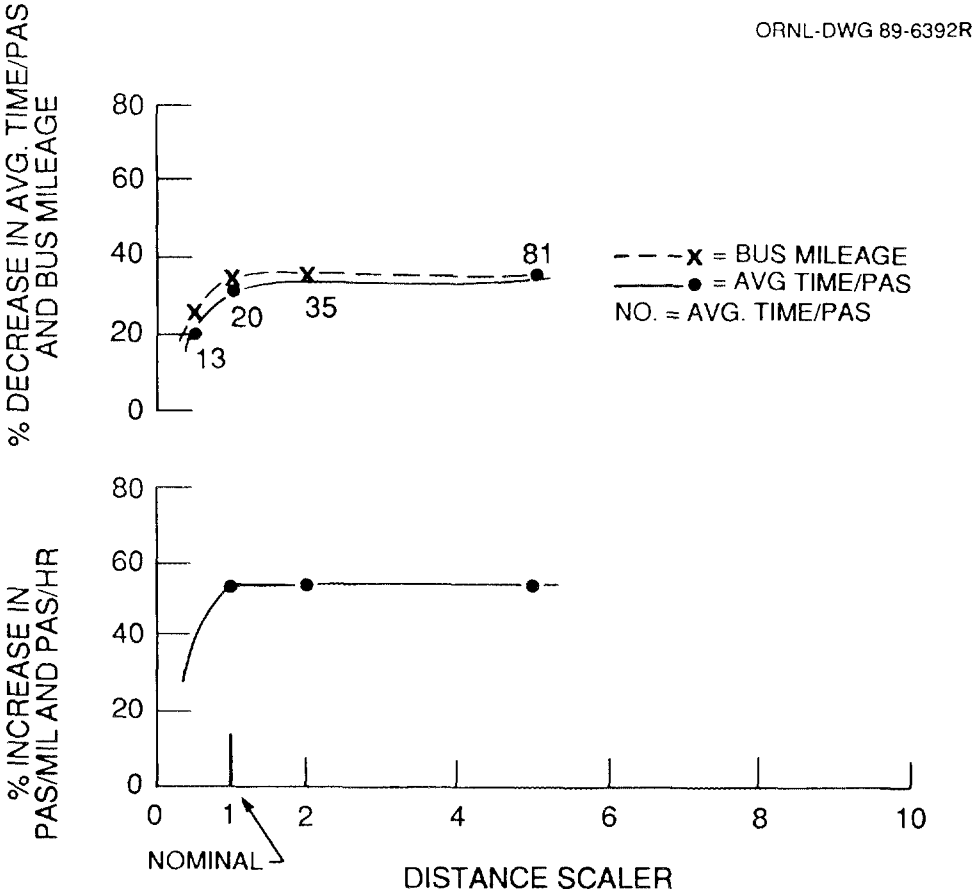

Fig. 3. Parametric analysis of the effect of system scale on selected measures of performance. The reference system has a scale value of 1, labeled 'nominal.' The scale is varied by increasing or decreasing the lengths of all route links.

with decreasing passenger volume. When the volume of passengers is reduced by half from the reference 22 to 10 or 11, improvement in passengers/mile and passengers/hour increases sharply from 55% to 90%; improvements in wait-plus-ride time and bus mileage are about 35% and 45% respectively.

In a final screening study, the effects of routinely servicing a remote, rarely used stop were examined. This simulates, for example, situations in which the bus system is constrained by local mandate to service a stop for one or two possibly disadvantaged individuals. In this study, stop 12 was progressively moved outward so that the fixed-route time to service the stop was incrementally increased by 4, 8, and 16 min, with no fare at the stop. Flexible scheduling ignores this stop when there are no fares. Comparison of the two methods is shown in Fig. 5. When the fixed-route bus must spend ~15 min per circuit servicing the infrequently used stop, the flexible scheduling approach affords an ~200% improvement in passengers/mile and passengers/hour. Bus mileage and average passenger wait-plus-ride time are improved by about 60%. When the stop is less remote, intermediate improvements occur.

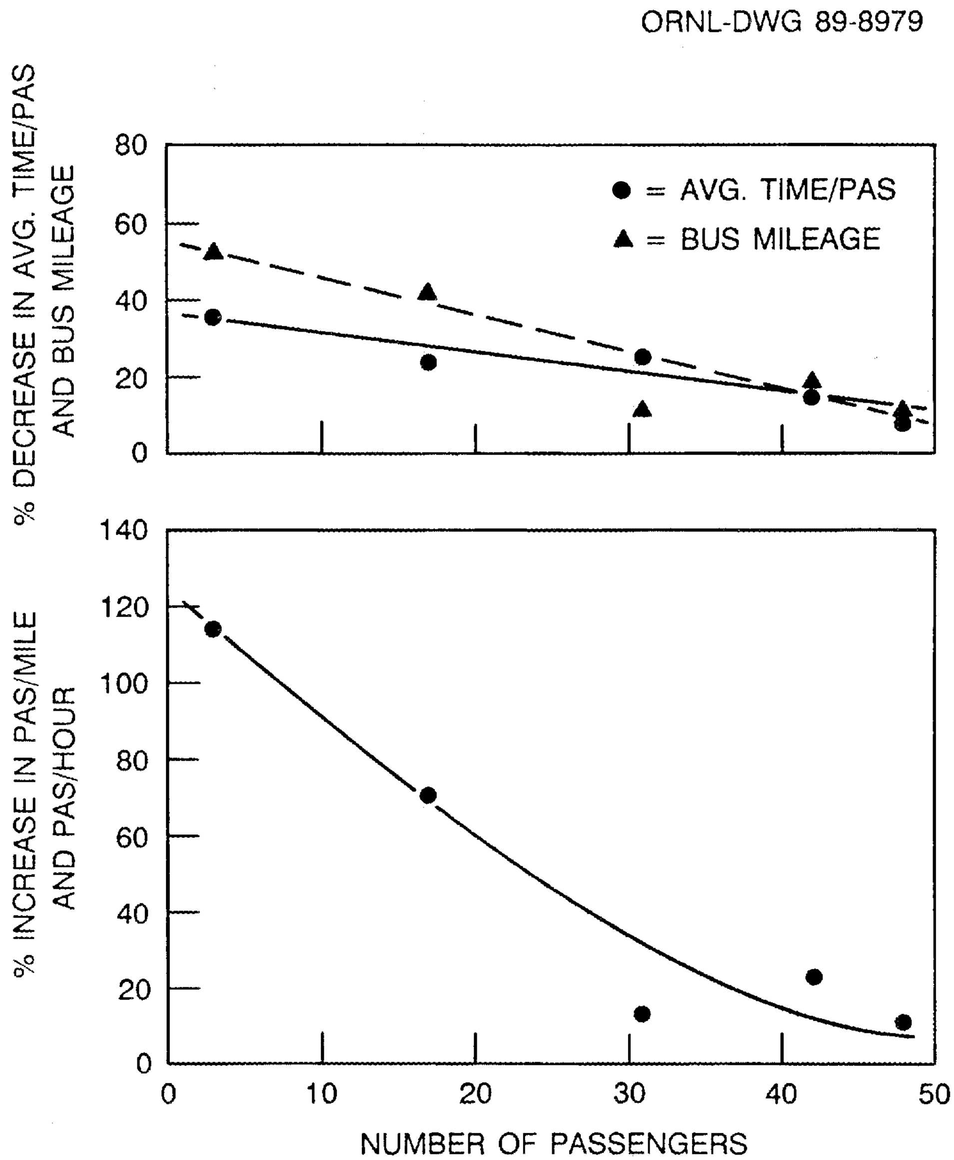

Fig. 4. Parametric analysis of the effect of passenger volume on measures of performance.

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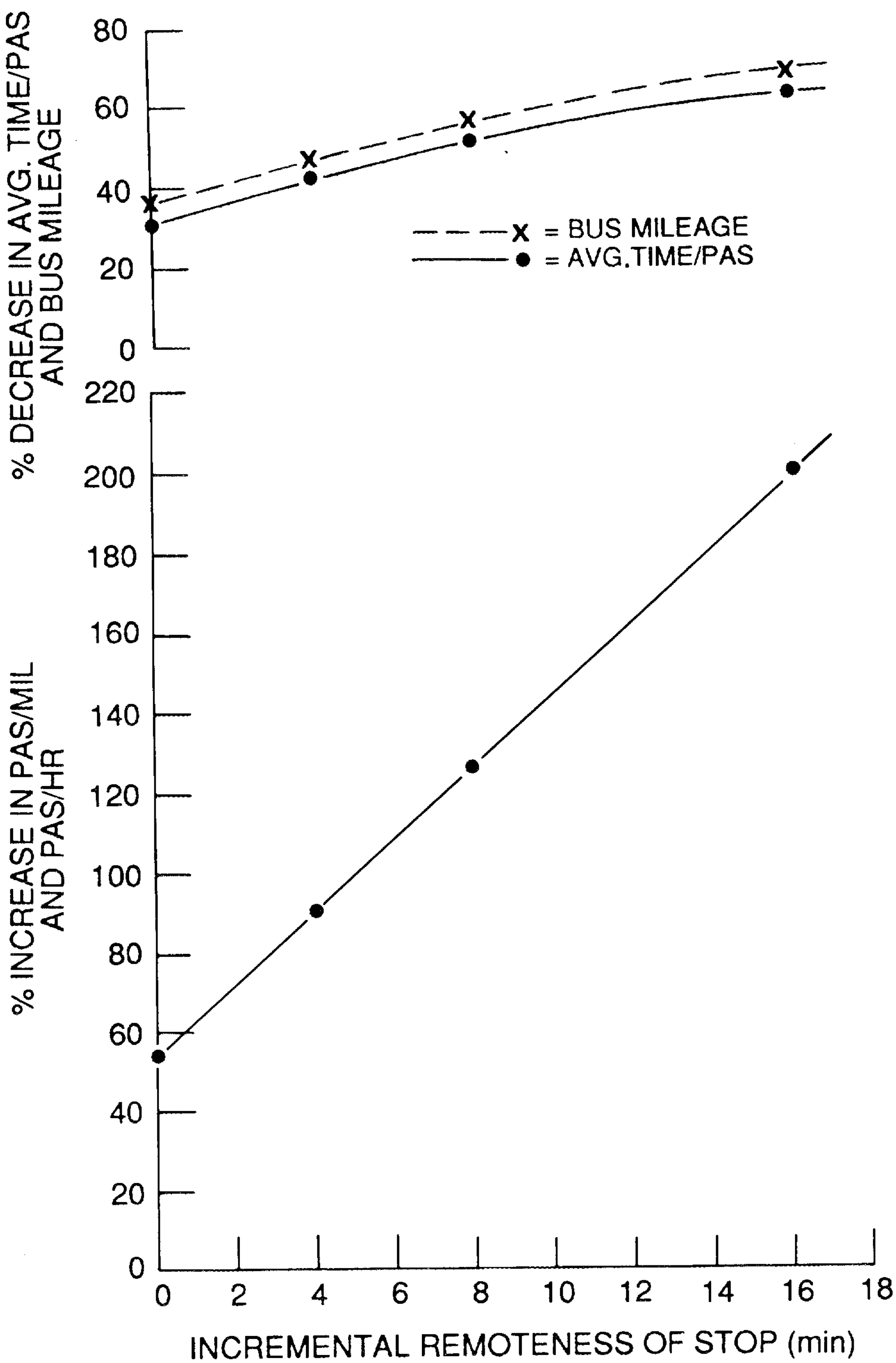

Fig. 5. Parametric analysis of the effect of servicing a comparatively remote, infrequently used stop. Stop 12 is moved outward from the system such that the incremental service time is increased up to 16 min. Measures of performance indicate improvement of flexible scheduling that omits the stop when not needed.

4. PRELIMINARY ECONOMIC ASSESSMENT

In the screening economic assessment, a best-estimate comparison is made of the operating costs of fixed vs flexible scheduling. Then, to assess net economic benefits, the cost improvements from flexible scheduling is compared with the capital expense of installing the innovation.

4.1 DEFINITION OF THE REPRESENTATIVE BUS SYSTEM

The bus system used in the screening economic analysis is based upon the average statistics for southern U.S. metropolitan areas with populations in the range of 50,000 to 200,000 people as reported in the June 1988 Biennial Report to Congress by the Urban Mass Transportation Administration (UMTA).[1]

The bus fleet consists of 60 units and operates on a weekday schedule Monday through Friday from 6:00 a.m. to 12:00 midnight with peak periods from 7:00 to 9:00 a.m. and 3:00 to 6:00 p.m. and base periods during other times. The system operates at a reduced level on Saturdays from 6:00 a.m. to 12:00 midnight and on Sundays from 12:00 noon to 8:00 p.m. The peak-to-base ratio is taken to be 1.5. The system is assumed to have 20% spare buses, which is in line with the level preferred by UMTA, and the total number of buses in the fleet is thus 60. Operations are summarized in Table 1. The operator hours/day, which is the same as bus hours/day, is the product of the number of buses times the operating hours/day.

4.2 OPERATING COSTS OF FIXED SCHEDULING

Annual operating costs in the fixed-route mode are estimated two ways. The first assumes that labor costs are the major factor. The representative bus system averages two full-time operating and maintenance employees per operating vehicle at an average wage of $30,000 per employee-year. Assuming an incremental overhead of 40%, the average hourly cost to the system for a 2088 work-hour year is $\$30{,}000 \times 1.4/2088$, or ~$20/h. Table 1 indicates that the system operates an average of 508 bus-hours per day. Thus the daily labor costs are $508 \times 2 \times \$20 = \$20{,}000$, and the annual labor operating cost is $365 \times \$20{,}000$, or ~$7.4 million.

Expenses may be estimated a second way. Using a value of $35/vehicle revenue hour for operating costs (based on UMTA data) gives $508 \times \$35$, or ~$18,000/day and $6.5 million/year, which is consistent with the values in the previous paragraph.

Table 1. Bus fleet operating schedule and operator level

Type operation	Number of buses	Times		Operating h/day	Operator h/day
Base	30	Mon–Fri:	6–7 a.m., 9 a.m.–3 p.m., 6 p.m.–midnight	13	390
	20	Sat:	6 a.m.–midnight	18	360
	15	Sun:	Noon–8 p.m.	8	120
Peak	45	Mon–Fri:	7–9 a.m., 3–6 p.m.	5	225
Spares	15				
Total	60				

4.3 OPERATING COSTS OF FLEXIBLE SCHEDULING

The operating costs of flexible scheduling depend upon the mode in which the concept is implemented. Two principal approaches may be taken:

1. Maintain the same service (area and frequency) with a reduced number of buses.

2. Use the same number of buses and expand coverage to increase ridership and revenue.

Both alternatives will be explored.

4.3.1 *Approach 1*

In this case the same level of service, as measured by the area served and the frequency of servicing stops, is provided by flexible scheduling with a 50% reduction in miles per passenger, which appears achievable from the technical analysis. The reduction in miles per passenger translates directly into a reduced number of buses and operating costs.

Flexible scheduling is estimated to require additional staff to operate and maintain the computerized system. One operator and one maintenance person per shift are assumed. At 2.5 shifts per day and an annual cost per person of $50,000, the added staff costs $0.25 million. From the comparison in Table 2, it is seen that this application of flexible scheduling reduces operating costs by $3.45 million, or 47% annually.

Table 2. Comparison of annual operating costs of flexible vs fixed scheduling for the case of unchanged number of operating buses

	$ Millions	
	Fixed	Flexible
Bus operating cost	7.40	3.70
Added flex staff	--	0.25
Total	7.40	3.95
Net operating cost savings of flexscheduling		3.45

4.3.2 *Approach 2*

Recognizing that wholesale reduction in the number of operating buses may be impractical because of labor and other constraints, an alternative application may be to retain the same number of buses in operation, at least initially, and expand the service area. In the next example, the service area is increased by 50%, and the level of service to both the old and new areas is the same as that in the old area under fixed scheduling. The assumption is made here that ridership increases by 50% as a result of the expanded area. Operating costs remain unchanged since the buses operate the same mileage and hours. Efficiency results from replacing less productive mileage with more productive mileage. Economic benefits result from increased revenue of additional passengers. The economic analysis is based on the UMTA observation that, as a national average, fares on a fixed-route system cover 44% of operating costs. Using the fixed-route cost of $7.4 million from Table 1, the 50% increase in rides from flexible scheduling increases annual revenues a net of $1.38 million, or 19% (Table 3).

Comparison of approaches 1 and 2 shows that the highest economic benefits from flexible scheduling occur in approach 1, in which the number of buses is reduced to maintain the same level of service rather than keeping the same number of buses in operation and expanding the service area. The difference reflects the fact that operator and maintenance costs per bus are high while passenger revenues are comparatively lower and cover an average of only 44% of costs.

4.4 CAPITAL COSTS OF IMPLEMENTING FLEXIBLE SCHEDULING

The capital cost of installing flexible scheduling in the representative system of 60 buses with an average of 30 operating daily is estimated here for two hardware configurations that differ in the type of communication provided for customers to schedule buses. In the first case, an ordinary telephone link is used and buses are scheduled to a stop by dialing the stop number from a phone at the stop (or elsewhere). This approach has the advantage of using off-the-shelf hardware, but it does not provide protection against crank calls. The second configuration requires telephones designed with special features at added cost. First estimates of the capital expenses for both are

Table 3. Annual increased revenue from flexible scheduling when the number of buses remains unchanged and the service area expands to increase ridership by 50%

	$ Millions
Gross increased revenue	1.63
Increased staff cost	- 0.25
Net increased revenue	1.38

given here, with the strong caveat that they are necessarily very preliminary and require further detailed investigation. Most software costs are assumed to be covered in research and development of the flexscheduling concept.

All 60 buses in the fleet are provided with the necessary on-board hardware. Each is equipped with a dynamic display map to indicate the route to the driver and a radio link to the scheduling network. Each of the average 30 operating buses is assumed to service 20 distinct stops for a total of 600 stops that require hardware. Each stop is equipped with a phone affixed to a stand or small shelter and a static display map to show customers the selectable bus stops. Central control equipment consists of two computers (one of which is a backup to minimize disruptions), primary and backup two-way radios of sufficient power to cover the service area, and a transmitting tower.

4.4.1 *Configuration 1*

In this arrangement, standard telephones are used to schedule buses. Best-estimate principal costs, in terms of equipment and installation components, are shown in Table 4. The equipment cost of $695,000 consists of $270,000 for stop hardware and installation, $93,000 for bus equipment, and $332,000 for control equipment. A 100% contingency allowance is added to cover the significant uncertainty in capital cost estimates, bringing the total projected cost of this configuration to $1,390,000. The contingency allowance will be addressed in greater detail in the discussion of capital cost recovery.

4.4.2 *Configuration 2*

This configuration is the same as configuration 1 except that the standard phones are replaced by specially designed telephone instruments that provide important features such as acceptance of fare coins and cards, protection against crank calls, electronic display of the time a bus will arrive at the stop and reach the requested destination, and automatic bus-tracking sensors. These devices are estimated to have incremental development and procurement costs of $500 per unit. Thus, for 600 units the incremental capital cost is $300,000. Allowing the same 100% contingency addition, the total capital cost for this configuration is $1,990,000, or 43% more than the standard phone configuration.

Table 4. Capital and installation costs for equipping 60 buses and 600 stops with flexscheduling hardware

Item	Unit cost ($) Equipment	Unit cost ($) Installation	No. units	Total cost ($)
Stop equipment:				
Telephone	50	50	600	60,000
Stand	100	100	600	120,000
Display map	75	75	600	90,000
Total				270,000
Bus equipment:				
Display map	750	150	60	54,000
Link radio	500	150	60	39,000
Total				93,000
Control equipment:				
Computer	100,000	10,000	2	220,000
Radio	5,000	1,000	2	12,000
Tower	50,000	50,000	1	100,000
Total				332,000
Total configuration				695,000
100% contingency allowance				695,000
Total cost				1,390,000

4.5 CAPITAL COST RECOVERY FROM COST IMPROVEMENTS OF FLEXIBLE SCHEDULING

It is instructive to estimate the length of time required for the flexible scheduling cost improvements to pay for the capital costs of the hardware configurations in each of the two methods of flexible scheduling investigated. In this analysis the capital equipment of the preceding section is depreciated over a 10-year period, which is consistent with the longevity currently expected by UMTA for new buses. No allowance is made for inflation in hardware replacement after 10 years because the procurement cost of electronic equipment, once developed, has historically tended to remain relatively stable or even to decline over time. Hardware costs are the principal component of capital expense here and may offset rising installation costs.

Table 5 indicates that capital costs may be recovered most quickly (in 5 months) if flexible scheduling is implemented with regular telephones and the number of operating buses is reduced while the existing level of service is preserved. The use of advanced design phones with a reduced number of buses extends the recovery time to 8 months. Longer recovery times occur if the number of buses in operation remains unchanged and the service area is expanded to improve revenues; recovery occurs in 14 months with regular telephones and in 20 months with advanced design phones.

Table 5. Capital costs and time to recover under two modes of flexible schedule operation and installation of regular or advanced design telephones ($K)

	Reduced number of buses		Expanded service	
	Reg. phones	Adv. phones	Reg. phones	Adv. phones
Annual Operating cost savings	3450	3450		
Annual increased revenue			1378	1378
Annual depreciation	104	149	104	149
Annual Net savings	3346	3301	1274	1229
Capital cost	1390	1990	1390	1990
Time to recover capital cost, months	5	8	14	20
Break-even contingency %	4800	3300	1800	1200

In this analysis a 100% contingency factor was applied to the capital cost estimates to allow for uncertainties. The magnitude of this factor was selected on the basis of historical accounts of the amounts by which capital cost projections of technological innovations are commonly underestimated; rarely are such costs overestimated. It is instructive to extend the analysis further and determine how large the contingency (uncertainty) factor must be before the cost recovery break-even point is reached and the flexschedule concept loses its apparent economic advantage. Assuming that new equipment has a service life of 10 years, the break-even point is defined as the total improvement in revenue provided by flexschedule cost improvements over the 10-year depreciation interval. Capital costs greater than that amount would be higher than the improvement in operations. Contingency factors for the break-even point are listed in Table 5. The results indicate that much larger capital cost contingency factors, ranging from 4800% with regular phones and a reduced number of buses to 1200% with advanced phones and expanded service, must be applied before the savings from improved operations are negated by capital expenses.

The contingency factor analysis may be interpreted alternatively to indicate that substantial uncertainties in other quantities such as estimated fixed operating costs and flexschedule cost improvements are tolerable.

It should be noted that there are capital cost savings associated with implementing flexible scheduling under the reduced-number-of-buses approach. Fleet size may be permanently reduced, and the long-term cost of bus replacement is correspondingly reduced.

5. CONCLUSION AND PROPOSED ADDITIONAL RESEARCH

The Phase I technical and economic screening study reported above indicates potential benefits from flexible scheduling of mass-transit buses. The level of benefits appears to be sensitive to the manner in which the technology is applied. For a given system, the optimum approach may be a hybrid application in which the level of service is expanded somewhat to increase ridership and the number of buses is gradually reduced in parallel with the normal rate of attrition of operators, thereby minimizing the impact on current personnel. Further detailed investigations are needed to more fully explore the feasibility, desirability, and affordability of the concept.

5.1 PHASE II RESEARCH

Flexscheduling may be applied as (a) a retrofit to existing bus systems, (b) an addition to planned systems, and (c) a stimulus for new systems that were previously impractical. The following research and development tasks are directed toward evaluating flexscheduling in these contexts. The first two tasks are an assessment of existing systems to provide a basis and data for the development and concept evaluation in Task 3. Task 4 provides a teaching tool to help potential users understand the concept, and Task 5 assesses the hardware needed to implement the concept.

Task 1. Appropriate existing bus systems must be analyzed to determine characteristic routing in order to provide a specific basis for simulating flexschedule improvements. To establish the potential scope of flexscheduling, the study should cover a range of bus operating environments including (a) small, intermediate, and large communities; (b) low-, medium-, and high-rider-density areas; and (c) dispersed and consolidated boarding-point grids.

Task 2. A detailed survey of a representative cross section of potential riders may provide data on which to base an optimum control algorithm. This includes, for example, determination of how long the time intervals for a given stop may be and still be acceptable to most riders. The trade-off is that the longer the interval, the greater the flexibility of the system and the less acceptable the average wait will be to riders.

Task 3. A major task is the development of a simulation model that includes the adaptive control strategy. The algorithm developed in the Phase I screening analysis is a basis for a model, but it must be expanded to treat (for example) multiple-bus scheduling. Complexities such as overlapping bus service areas need to be considered to find the best overall system operating strategy.

The model may be used to design and evaluate engineering aspects of the concept and to make cost assessments. Within the framework of the model, various user attitudes may be assumed, alternative scheduling algorithms can be tried, and operating costs of flexschedule vs fixed schedule routing can be compared. The model may be used to determine the types (size, structure, etc.) of communities in which the system makes financial sense. Conversely, the model can be used to test different types of control strategies for a particular community. Areas without bus systems but with present or potential need can be examined to determine whether flexscheduling may be a practical solution.

Task 4. An on-line interactive simulator with graphics should be developed to demonstrate the concept for potential sponsors and users.

Task 5. Specific hardware required to implement the concept must be analyzed for technical feasibility and capital cost; the latter is needed also for the overall financial assessments of Task 3. The objective of this task is to determine the best choices and configuration and identify where equipment design may be needed. Important application hardware includes (a) the system computer, (b) the wire or wireless communication link between computer and call stations, (c) the wireless communication link between computer and bus, and (d) on-board display of the current route.

System reliability is a key factor in determining whether such an automated system succeeds. Loss of communication with a bus could inconvenience many users, and a computer failure could default the entire system. Redundancy should be built into the system to reduce the likelihood of failure.

5.2 PHASE III RESEARCH

If these detailed studies confirm the potential applicability of flexscheduling, a pilot study using hardware and control algorithms should be undertaken to test the concept in the field. This will demonstrate user response, among other things. It is critically important to make the concept truly user-friendly for the typical rider and the bus driver. Also, system reliability may best be determined in field studies.

REFERENCES

1. *The Status of the Nation's Local Mass Transportation: Performance and Conditions, Report of the Secretary of Transportation to the United States Congress*, U.S. Department of Transportation, Urban Mass Transportation Administration, Washington, D.C., June 1988.

2. *Public Transportation Network Status Report*, Crain & Associates, Los Altos, Calif., May 1984.

3. R. F. Kirby and G. K. Miller, *Short-Range Public Transportation Improvements, Final Report*, DOT-I-84-14, The Urban Institute, Washington, D.C., February 1983.

4. M. B. Meyer and N. H. M. Wilson, "The Use of Simulation in the Design of a Dial-A-Ride System," *Proc. Summer Computer Simulation Conference, July 12–14, 1976, Washington, D.C.*

5. C. Carstarphen et al., "Simulating an Urban Jitney System," *Proc. Summer Computer Simulation Conference, July 12–14, 1976, Washington, D.C.*

6. A. M. Yen and A. G. Chambliss, "Simulation of Operating Strategies for Automated Urban Transit Systems," *Proc. Summer Computer Simulation Conference, July 21–23, 1975, San Francisco.*

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