Evaluation of Automated Dispatching for Flexibly Routed Paratransit Services

Chris T. Hendrickson, Department of Civil Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania

Computerized dispatching systems may be appropriate for flexibly routed paratransit systems if they can reduce the cost of vehicle dispatching, improve vehicle productivity, or increase the quality of service provided to riders. This paper compares the performances of computerized, computer-assisted, and manual dispatching based on recent experiences in several systems and analyzes the cost parameters of each under various vehicle, rider, and service-area constraints. Although relative data are too limited to allow major conclusions about the cost or effectiveness of different dispatching processes in varying environments, it is concluded that automated dispatching appears to be more expensive than manual dispatching for the present scale of shared-ride, flexibly routed services. However, it is also noted that improvements in the cost, capability, and flexibility of new computers, as well as the growing need for extensive rider and trip-information processing, will be important factors in the future.

Much of the research in automated or computerized dispatching for flexibly routed paratransit systems has been motivated by the hope that computers could reduce the cost of vehicle dispatching or improve the effectiveness with which vehicles are used in a system (or both). In its most extreme form, computerized dispatching represents complete automation of the processes of assigning customers to vehicles and ordering the sequence of stops of the individual vehicles. The only existing system that uses fully automated computerized dispatching is the dial-a-ride system operated by the Rochester-Genesee Regional Transit Authority (RGRTA). Computer-assisted dispatching represents a hybrid system in which the computer may be relegated to the role of record keeper (as in the Ann Arbor Teltran System) or may assume some dispatching functions under the continuing review of a human dispatcher [as has been proposed (1)].

This paper is intended to assess the potential of automated dispatching in the light of recent experience—particularly in the Rochester system—and the development of new matching algorithms and computer software. The first part of the paper compares the performance of computerized and manual dispatching systems, and the second discusses the costs of computerized dispatching.

EVALUATION OF THE PERFORMANCE OF MANUAL AND COMPUTER DISPATCHING

The effectiveness with which a given flexibly routed paratransit system can route its vehicles among patron origins and destinations has an immediate and significant effect on the quality of service provided to the users and the number of patrons that can be served. With more effective routing, it may be possible to increase vehicle productivity or improve the quality of service provided or both. As a result, user volume may increase or the operator may be able to reduce the number of vehicles operating without significantly impairing the quality of service.

To assess the effects of more effective routing, it is useful to consider the interaction between system performance and demand. The experiences of existing systems and an analysis of the performance of flexibly routed systems indicate that the quality of service provided by a particular system declines as the patronage volume increases or as the fleet size decreases (barring simultaneous changes in other service aspects). Quality of service may be thought of as some combination of the travel time (including waiting and riding), comfort, and reliability of service experienced by users. As shown in Figure 1, for example, where increased travel time represents a decline in the quality of service, more effective routing of vehicles results in an improvement in the quality of service (the downward shift in the expected travel time).

The ultimate effects of an improvement in routing depend on the sensitivity of demand to the quality of service and the operator's policies. Figure 2 shows the relationship between the performance of a system and the associated demand function. [Although these curves are illustrative, similar empirically estimated functions can be derived from the work of Lerman and others (2).] The average travel time and volume on the system are given by the intersection of the demand and system-performance functions. If 10 vehicles are currently being operated, then a more effective dispatching process will result in faster travel times (t'_{10} versus t_{10}), higher volumes (V'_{10} versus V_{10}), and higher vehicle productivities ($V'_{10}/10$ versus $V_{10}/10$). If 11 vehicles are currently being operated and the operator both reduces the size of the fleet by 1 vehicle and introduces the more effective dispatching process, then the volume will decrease (V_{11} versus V'_{10}), the travel time will be higher (t'_{10} versus t_{11}), the system operating costs may be lower (depending on the cost of dis-

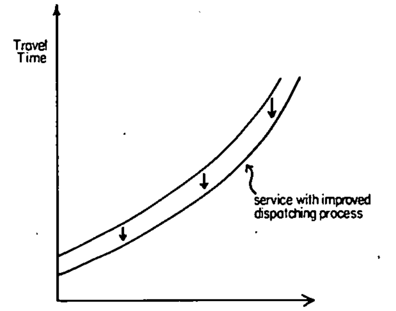


Figure 1. Relationship between travel time and patronage volume with different dispatching processes.

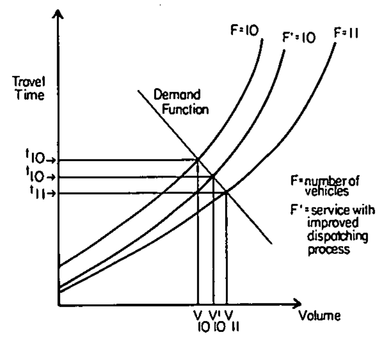


Figure 2. Relationships between travel time, patronage volume, and demand function with different dispatching processes and fleet sizes.

patching versus vehicle operating costs), and the vehicle productivity may be higher or lower (higher if $V'_{10}/10 > V_{11}/11$, lower otherwise). If there is a large improvement in dispatching effectiveness, it is possible that a 10-vehicle fleet could provide a higher quality of service than an 11-vehicle fleet; in this happy circumstance, the volume, quality of service, and vehicle productivity are all higher with the smaller fleet.

Manual Versus Computerized Dispatching: General Considerations

The dispatching process involves receiving requests for service, assigning a vehicle or vehicles to transport individual patrons, and specifying the sequence in which collections and deliveries are to be made. In a manually dispatched system, there may be telephone operators to receive the requests and a central dispatcher to assign the vehicles and the drivers may decide the routing and sequence of stops. A computer may be used for any of these steps, and there may be varying levels of sophistication and interaction between the human and the computer. What is necessary for automation of dispatching is the development of an algorithm or set of computer instructions to assign patrons to vehicles and to route vehicles.

Unfortunately, because of the extremely large number of alternative patron assignments that must be examined; the uncertainty associated with vehicle travel times, boarding times, and future service demands; and the lack of knowledge about the value of different service aspects, computer algorithms for optimal vehicle dispatching are prohibitively expensive. Recently, Psaraftis (3) has used dynamic programming and Sexton (4) has used Bender's decomposition to solve the vehicle-dispatching problem. Psaraftis' work is particularly interesting because it permits the analysis of a wide variety of objectives in forming vehicle routes. However, the practical limits for optimal-routing algorithms are 15 to 20 stops for a single vehicle. Because the routing problem is quite difficult, the prognosis for development of practical optimal-routing algorithms in the near future is poor.

Optimal-dispatching algorithms might be useful in suggesting practical dispatching processes or in evaluating the effectiveness of different routing schemes. Unfortunately, the limitations of the optimal algorithms prohibit the solution of the complicated routing problems that are of greatest interest in evaluating other algorithms. As a result, evaluation of automated dispatching is limited to the direct comparison of dispatching results with nonoptimal algorithms.

The existing and proposed computerized dispatching programs rely on various heuristic or approximation algorithms or on partial enumeration of all potential patron assignments. Consequently, comparisons of dispatching processes are made between nonoptimal alternatives that may be more or less effective, depending on the exact circumstances of particular dispatching processes and transit services.

The differences in the effectiveness of manual and computerized dispatching depend in part on the peculiarities of specific computer algorithms or particular dispatchers. Manual dispatchers certainly vary in performance due to experience or ability. The performance of a computerized dispatching program depends on the effectiveness of the dispatching algorithm used and the extent to which all assignment possibilities are considered. For example, the RGRTA dispatching program includes periodic reassignment of future requests, which tends to improve dispatching effectiveness because past vehicle scheduling decisions are reconsidered and can be improved. However, computer costs increase as additional assignments or reassignments are considered.

In addition to the effects of different algorithms and different dispatchers, the circumstances of the paratransit system affect the relative effectiveness of the dispatching process. One may hypothesize, for example, that manual dispatching will become less effective relative to computerized dispatching as the numbers of objectives, alternative vehicle routings, or patrons on the system increase. As any of these service aspects or considerations increase, a human dispatcher will find it increasingly difficult to identify the best decision or to consider the full range of routing alternatives. This hypothesis may be derived from psychological theories of perceptual or cognitive information processing (5). If the dispatching problem is relatively simple, however, manual dispatching may be quite effective. For example, in one set of experiments, manual construction of one-vehicle tours among 10 delivery stops was found to be comparable in effectiveness with several explicit algorithms (6). And, if the computer capacity is limited, manual dispatching may be more effective than automated dispatching as the number of assignments increases. If the available data storage or computational speed are inadequate, a particular computer may be unable to keep up with the dispatching requirements (as occurred with the computer used by the Royal Cab Company in Davenport, Iowa). In any case, one should not expect a constant difference in performance over the full range of operating conditions for particular systems.

Figure 3 illustrates the hypothesis that computerized dispatching becomes increasingly more effective relative to manual dispatching as volume increases. At a relatively high volume (V_h), the reductions may be large in travel time (t_h - t'_h) but, at a low volume (V_l), the reductions in travel time may be small (assuming constant volume). It is likely then, that the conditions under which a service is operating profoundly affect the relative effectiveness of computerized versus manual dispatching.

It is also important to consider the structure or design of the paratransit system. Manual dispatching

Figure 3. Illustration of hypothesis that computerized dispatching is more effective than manual dispatching as volumes increase.

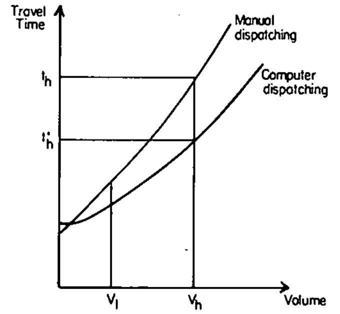
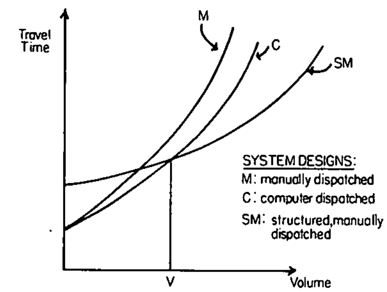


Figure 4. Comparison of travel times with different system designs at various volumes.



appears to be relatively ineffective in a classic or areawide dial-a-ride system in which shared vehicles circulate throughout a service area and multiple origin-destination pairs are served. For example, although a dispatcher in an exclusive-ride taxi system can control a fleet of 100 or more vehicles simultaneously, experience in the Rochester system and elsewhere indicates that a single dispatcher can effectively control only a fleet of 10-15 vehicles in shared-ride service. However, it has been suggested that shared-ride services that are structured either into zones to which vehicles are restricted or into routes from which vehicles may deviate may offer a less expensive service or a quality of service that is comparable to or better than that of classic dial-a-ride systems, particularly at higher volumes or with unsymmetric spatial-demand distributions (7, 8). In such structured systems, routing alternatives are greatly restricted and manual dispatching becomes relatively effective.

If a structured service is desirable over some range of operating conditions, then a comparison of areawide dial-a-ride performance under manual or computerized dispatching is irrelevant within this range. Figure 4 illustrates this point; the curve M represents the performance of a dial-a-ride service that has manual dispatching, the curve C represents a dial-a-ride service that has computerized dispatching, and the curve SM represents the performance of a structured dial-a-ride service that has manual dispatching. At volumes greater than V, the structured service is likely to be more desirable than an areawide dial-a-ride service.

In fact, much of the recent growth in paratransit service has been in systems that impose spatial or temporal restrictions of various kinds. Examples of such restrictions include zonal services, such as the Ann Arbor Teltran System, in which the vehicles are restricted to zones and mainly provide service to or from a single transfer point, and subscription services. Each of these restrictions simplifies the dispatching problem, because of either a reduction in the complexity of dispatching decisions or an increase in the time available for dispatching. Large exclusive-ride taxi fleets adopt a similar strategy by dividing an area into zones and then having a single radio channel and dispatcher for each zone. Unfortunately, although analysis and experience are improving, they are still inadequate to definitely indicate which system designs are the most appropriate under all conditions [some examples of the existing state of the art for design and alternatives analysis can be found elsewhere (9-11)].

In summary, the relative performance of computerized versus manual dispatching depends on the characteristics of the dispatcher (human or nonhuman), the situation of the paratransit system (such as volume level and fleet size), and the design or constraints placed on the system.

Before turning to the evidence concerning the relative effectiveness of computerized versus manual dispatching, the criteria by which to measure dispatching effectiveness deserve some mention. There are many aspects of service that might be important to users, and firm evidence as to actual user preference and trade-offs among different aspects of service is unavailable. Moreover, different segments of the user market are undoubtedly concerned with different aspects of service; for example, immediate service-response time is not relevant to consideration of the quality of service provided to users who make advanced requests. Some evidence exists that dial-a-ride users are generally indifferent between waiting time at home and in-vehicle riding time, so that these indicators might be combined (2). However, the effect of service reliability on demand is largely unknown (12). As a result, a single measure of service quality is difficult to construct.

Real-Time Computerized Dispatching

In real-time computerized dispatching, requests for service and vehicle activities are input to a computer as they occur and the dispatching program makes continual decisions concerning future vehicle assignments. This type of computerized control has been used in the Haddonfield, New Jersey, and RGRTA demonstration projects. The RGRTA system is particularly interesting because there is available information concerning the system performance with both manual and computerized dispatching.

The level of service on the RGRTA system (13) is summarized in Table 1, and essentially similar data are given in a report by SYSTAN, Inc. (14). Unfortunately, there were numerous changes in the RGRTA service between the two periods in which the data reported in Table 1 were gathered. In particular, the number of patrons decreased from 117 to 58/day and vehicle productivity decreased from 3.3 to 2.9 passengers/vehicle-h. However, detailed analysis of the service changes suggests that these changes were offsetting and that travel time might be expected to be roughly comparable between the two periods (15) (that is, the changes in volume, fleet size, and demand density had offsetting effects on service quality).

The results given in Table 1 suggest that computerized dispatching resulted in reduced travel time and more reliable service for patrons requesting immediate service. Also, the predictions of pick-up time that were provided so that users could prepare for vehicle arrivals were improved. Patrons making advance requests for service had slightly more reliable service but longer riding time. Delivery-time predictions also improved. It is likely that the manual dispatcher had been concentrating on minimizing riding time, because the introduction of the computer increased average riding time while decreasing overall travel time. The computerized program used for dispatching in Rochester is a refined version of the algorithm originally proposed by Project CARS at Massachusetts Institute of Technology (16) and implemented in the Haddonfield demonstration project. It is a relatively large, sophisticated

Table 1. Comparison of quality-of-service indicators: RGRTA system.

Indicator	Manual[a] Value	Manual[a] SD	Computer[b] Value	Computer[b] SD	Improvement (%) Value	Improvement (%) SD
Immediate service requests						
Avg wait time (min)	29.7	20.4	17.4	10.2	41[c]	50[c]
Avg ride time (min)	5.5	16.2	6.3	8.5	-13	47[c]
Avg travel time (min)	35.2		23.7		33[c]	
Advance service requests						
Avg deviation from requested pickup time (min)	7.1	15.3	4.2	10.9	40[c]	29[c]
Avg ride time	10.6	7.1	13.1	7.3	-23	3

[a] Based on 624 trip observations made between October 20 and November 20, 1976.
[b] Based on 776 trip observations made between March 1 and April 19, 1977.
[c] Indicates that the hypothesis that the service aspects are identical could be rejected at the 95 percent confidence level.

and well-coded program and requires a substantial amount of data storage and computation time on the DEC system used (17).

Prescheduled Computerized Dispatching

Computer algorithms can also be used to schedule systems that require advanced (usually overnight) reservations. Dispatching for these services does not require continuous decisions, and scheduling daily vehicle activities can be performed at a time when a computer used for other purposes is available. Similarly, the pressure in these services for immediate human decisions is lower, and manual dispatching tends to be fairly effective. Sexton (4) has developed an heuristic algorithm for subscription bus scheduling that has been used by a Baltimore, Maryland, paratransit system for the elderly and handicapped. Preliminary results were reasonable and comparable with those of manually produced tours, but the algorithm is still experimental and has not been adopted for regular use. Prescheduled dispatching has also been used for school bus routing (18-20), again with results comparable with those of manual dispatchers. However, because the heuristic algorithms occasionally result in poor tours for individual vehicles or violate (uncoded) constraints (such as vehicle capacity or U-turn prohibitions), manual inspection and improvement is often used to verify the computer results. The contribution of automated routing of prescheduled services is expected to come from reductions in dispatching costs.

Reliability of the Dispatching Functions

Both computerized and manual dispatching systems are subject to interruptions. In a manual system, dispatchers have breaks from work (e.g., for coffee or lunch), take vacations, and require sick leave. In a computer-based system, the computer hardware or software may malfunction, power may be lost, or communications may be disrupted. In the Rochester dial-a-ride system, computerized dispatching was unavailable 10 percent of the time between June 1976 and June 1977, even with five DEC System 10 computers available in the time-sharing system used for dispatching (13).

The Rochester system, however, used an experimental dispatching system and a long-distance communication link to the computer facility, and reliability might be higher in systems that used local computers and extensively tested dispatching systems. Current proposals for computerized dispatching systems would rely on local, dedicated computer systems, although the backup capability of such systems would be less than that of the Rochester system. Provision of a backup computer to perform vehicle dispatching would certainly improve the expected reliability but would also increase the costs of the dispatching system.

In the Rochester system, manual dispatching was used whenever computerized dispatching was unavailable. A continuous record of all requests and assignments was printed in the system control room to enable a manual dispatcher to identify the system state whenever computerized dispatching was unavailable. The transition from computerized to manual dispatching required some time in which the manual dispatcher familiarized himself or herself with the state of the system, and user level of service deteriorated in those periods. Moreover, the cost associated with retaining sufficient personnel to perform the manual dispatching was incurred. Unfortunately, no data on the extent that the level of service deteriorated or on the number of patrons affected by transitions is available.

COSTS OF COMPUTERIZED DISPATCHING

As described above, there are three different alternatives for dispatching processes—computerized, computer-assisted, and manual. It is important to note, however, that the computer-based systems also fulfill a record-keeping function that would otherwise require additional labor and resources. The computer system represents a joint cost between the record-keeping and the dispatching functions. Thus, the comparison of computer-based versus manually based dispatching should properly include a comparison of computer-based versus manually based record-keeping systems (or information processing).

The information-processing functions that have been computerized include reservation-information storage and retrieval (as in Ann Arbor) and dispatcher-vehicle radio communications (as by the Diamond Taxi Company, Montreal, Quebec). These functions can use well-known computer and management science techniques. Systems that have 1500 or more daily orders may be candidates for the introduction of computer-assisted dispatching, regardless of the desirability of automated dispatching (5).

The major cost elements of the different types of dispatching systems are summarized below.

Cost Element	Manual Dispatching	Computer-Assisted Dispatching	Automated Dispatching
Computer lease or purchase and maintenance		Yes	Yes
Backup computer		Possible	Possible
Service-area data base		Possible	Yes
Communications equipment	Yes	Yes	Yes
Control-room personnel	Yes	Yes	Yes
Manual record keeping	Yes		
Start-up (e.g., analysis and disruption)		Yes	Yes

Computer-assisted dispatching does not usually require a backup computer. But, in addition to the costs of computer leasing or purchase, computerized dispatching systems require more skilled or highly trained control-room personnel, and the higher salaries of such personnel should be included as a cost attributable to the computerized dispatching system. In addition to the costs of computer operation, automated dispatching requires the collection of an area data base and the design of appropriate computer software. For example, computerized dispatching requires an address-locator program in order to identify the origin of a patron request. The software for automated dispatching may be largely transferred between locations (the Urban Mass Transportation Administration has sponsored the development of the computer program used in Rochester with this objective). However, reprogramming the computer algorithm may be necessary in response to changing conditions or objectives.

Experience in Rochester and elsewhere has indicated that the introduction of computers does not result in reductions in the number of dispatching personnel (5). Labor resistance to personnel reductions, the need for backup dispatching capability, the effort required to input information to the computer and monitor its performance, and a variety of other managerial tasks performed by dispatchers precludes reductions in labor costs. Consequently, the costs associated with dispatching tend to increase with computerization. However, computers can provide the capacity to dispatch more vehicles and handle greater patronage volumes, so that the unit cost (cost per trip) of computerized dispatching may be lower.

Costs of computerized dispatching in excess of those incurred by manual dispatching depend largely on the capacity and speed of the computer used and the initial cost of assembling a suitable data base. Colvin and Wilson (13) estimated the costs of a dedicated minicomputer or a midisized computer that had sufficient capacity for the dispatching software used in Rochester as approximately $8500/month (1978 dollars) including all terminal equipment, peripherals, software, and maintenance. For the Rochester average monthly dial-a-bus ridership of 12 500, this is approximately $0.70/passenger trip; at the cost per vehicle hour of operation in Rochester, this cost of computer services may also be thought of as representing 425 vehicle-h of operation, or approximately two 8-h vehicle runs/weekday. These costs are in addition to the personnel who take user requests and provide manual dispatching in case the computer fails. It is estimated (1, Table 4-1) that the conversion of a 50-cab, manually dispatched exclusive-ride taxi service to a computer-dispatched shared-ride service would entail additional dispatching costs of $14 797/month plus $3929/month for digital communication equipment (in 1976 dollars). Computer-assisted dispatching and prescheduled computerized dispatching have smaller requirements for computer capability than does fully automated, real-time dispatching, particularly if otherwise underused computers may be used (such as during the night).

With a dedicated or otherwise-underused computer facility, the incremental cost of dispatching a new patron is generally quite low. Thus, the average cost per passenger for dispatching decreases as the number of patrons increases. At some point, however, the calculations and data storage necessary for dispatching will approach the capacity of the computer, which leads to long delays in assigning new patrons or to malfunctions. Unfortunately, little information is available on the capacity of existing systems or of planned minicomputerized dispatching systems. It is reported that the current capacity of the Rochester dispatch system has been approached, leading to delays in accessing the computer system (5). If so, then the planned minicomputerized dispatching systems must use an algorithm that has a lower computational burden. The new minicomputerized dispatching process planned for the Rochester system has a design capacity of 50 vehicles and 150 passengers at any given time. Planned expansions of the Rochester system and a proposed system in Orange County, California, will provide additional evidence concerning the actual capacity and capability of less-expensive automated dispatching systems.

One conclusion is evident, however. Automated dispatching is more expensive than manual dispatching for the present scale of shared-ride, flexibly routed services, unless the costs associated with the computer can be reduced by at least a factor of two. In the Rochester system, a capacity for manual dispatching was maintained as a backup system, so that the costs of computerized dispatching were added to the normal manual dispatching costs. Thus, the relevant management question is whether or not computerized dispatching provides benefits in excess of its additional costs. These benefits must take the form of more effective dispatching and information processing.

TENTATIVE CONCLUSIONS

This section summarizes some tentative conclusions in regard to the dispatching process, the effectiveness of computerized dispatching, and the potential of automated dispatching.

Performance of the Dispatching Process

1. Different dispatchers and dispatching algorithms should be expected to perform with different levels of effectiveness even under identical conditions. For example, the expected effectiveness of computerized dispatching is related to the amount of computer services that are available and the sophistication of the algorithm used. Thus, general conclusions based on observations of one dispatcher and one computerized dispatching system may be erroneous.
2. The relative effectiveness of manual and computerized dispatching is unlikely to remain constant over the range of operating conditions that may be seen in practice.
3. It is impossible to construct a single index of dispatching effectiveness because of the variety of user groups and the current lack of knowledge concerning patrons' evaluation of different trip attributes.
4. More effective dispatching processes provide an opportunity to increase the average volume and quality of service, decrease the size of the vehicle fleet necessary to achieve a given level of service, or a combination of both. Because the improvements in the quality of service and the reductions in the fleet size are valued differently and accrue to different groups, the range of possible effects of more effective dispatching should be identified. The cost reduction that will result from reducing the size of the vehicle fleet may be more desirable than an increase in the average quality of service.
5. Dispatching systems should be compared on the basis of their performance within good system designs. For example, structured or zonal dial-a-ride service with manual dispatching may be more effective than an areawide dial-a-ride service above a certain patronage level.

Effectiveness of Automated Dispatching

The available evidence concerning the relative effectiveness of real-time computerized and manual dispatching systems is at present limited to several before-and-after comparisons in the Irondequoit district of the RGRTA system. Unfortunately, these data are limited and several exogenous changes (including fewer hours of operation, lower demand, and fewer vehicles) that tended to have offsetting effects on the quality of service provided occurred between the comparison periods. However, the following conclusions may be drawn.

1. Automated dispatching is a possible method for routing and scheduling dial-a-ride or shared-ride taxi systems. The computer-based system in Rochester has proven practical, although manual dispatching is required 10 percent of the time due to various system malfunctions.

2. Automated dispatching appears to have improved the level of service in the Irondequoit district compared with the manual dispatching system previously in use. In particular, waiting time and service reliability were significantly improved with computerized dispatching.

3. Automated dispatching has proved to be more expensive than manual dispatching in the RGRTA system.

Considering the large extra costs associated with the computer system, the limited area and patronage volume served, and the minor extent of the improvements in the level of service, the existing computerized dispatching system in Rochester does not appear to be economically preferable to manual dispatching. However, the use of less-expensive computerized dispatching systems in larger systems may be economical and desirable.

Potential of Automated Dispatching

Previous assessments of the potential of automated dispatching have emphasized that it is a necessity for large-scale paratransit systems that have real-time control (21, 22). Effective automated dispatching may be required for the control of an affordable, high-volume, areawide dial-a-ride service in which vehicles circulate throughout a metropolitan area. However, it appears to be quite feasible to operate a large, structured paratransit system by using manual control methods. Moreover, in taxi systems that have a substantial proportion of street hails, shared-ride taxi service is possible without automated control (as in Washington, D.C.). The potential of automated dispatching depends on the relative benefits and costs of alternative dispatching and record-keeping processes within various system designs, not on some necessity for automated dispatching.

Unfortunately, the volumes that may be attracted by large-scale systems and the penalties associated with different structural designs are largely unknown. Experience has shown that the initial estimates of the volume that might be attracted by a dial-a-ride service were overly optimistic (8). Moreover, it is possible that the inherent reliability and efficiency in serving unsymmetric or skewed demand patterns (as in many-to-one service) make highly structured paratransit systems desirable in high-volume cases.

An important trend in considering automated dispatching is that of the cost, capability, and flexibility of new computers. Considering the remarkable decrease in the cost of computers in the last 20 years, further reductions are probable and will improve the relative position of the automated-dispatching alternative. The costs of manual record keeping will probably increase, which means that computer information processing will become increasingly advantageous. Unfortunately, the costs of constructing an adequate data base for dispatching purposes are unlikely to decline (but they might be shared with other agencies or firms). Given the existing cost structure and experience, it is likely that fully automated dispatching should be only considered for paratransit services in which computerized record keeping is desirable (or nearly so) and that have high volumes, large fleets, and a fairly complex dispatching process.

REFERENCES

1. G. J. Fielding, P. Freeman, B. E. Potter, and A. U. Simpson; DAVE Systems, Inc. Shared-Ride Taxi Computer Control System Requirements Study. Transportation Systems Center, Cambridge, MA, and Urban Mass Transportation Agency, Rept. DOT-TSC-UMTA-77-39, Aug. 1977. NTIS: PB 275 335/8SL.
2. S. Lerman, M. Flusberg, W. M. Pecknold, R. E. Nestle, and N. H. M. Wilson. Method for Estimating Patronage of Demand-Responsive Transportation Systems. Transportation Systems Center, Cambridge, MA, and Urban Mass Transportation Administration, Rept. DOT-TSC-UMTA-77-52, 1977.
3. H. N. Psaraftis. Dynamic Programming Algorithms for Specially Structured Sequencing and Routing Problems in Transportation. Department of Ocean Engineering, Massachusetts Institute of Technology, Cambridge, Ph.D. dissertation, 1978.
4. T. Sexton and L. D. Bodin. The Subscribed Dial-a-Ride Problem. Paper presented at 24th International Meeting, Institute of Management Sciences, Honolulu, June 1979.
5. G. Haines, R. Wolff, P. Bunt, and G. Steward. Demand Responsive Dispatching Systems: A Study of Task Complexity. Univ. of Toronto-York Univ. Joint Program in Transportation, Univ. of Toronto, Toronto, Ont., Working Paper, 1978.
6. C. T. Hendrickson. Approximate, Analytic Performance Models of Integrated Transit System Components. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Ph.D. dissertation, 1978.
7. D. M. Stein. Scheduling Dial-a-Ride Transportation Systems. Harvard Univ., Cambridge, MA, Ph.D. dissertation, 1977.
8. N. M. H. Wilson and C. T. Hendrickson. Performance Models of Flexibly-Routed Transportation Systems. Transportation Research, to be published.
9. J. H. Batchelder, L. S. Englisher, B. C. Kullman, and K. L. Sobel. Operational Implications of a Major Modal Diversion to Transit: A Macroanalysis. U.S. Department of Transportation, Rept. DOT-TST-76-72, 1976. NTIS: PB 255 921/9SL.
10. J. W. Billheimer, R. Bullemer, and M. Holoszyc. Macroanalysis of the Implications of Major Modal Shifts in Integrated Regional Transportation Networks: Phase I—Appendices. U.S. Department of Transportation, Rept. DOT-TST-76-66, 1976. NTIS: PB 256 137/1SL.
11. A. U. Simpson and T. F. Carberry. Estimating Demand of Shared-Ride Taxi. Paper presented at Conference on Taxis as Public Transport, Univ. of California, Irvine, 1977.
12. M. Abkowitz, H. Slavin, R. Waksman, L. Englisher, and N. M. H. Wilson. Transit Service Reliability. Transportation Systems Center, Cambridge, MA, Staff Study, 1978.
13. N. M. H. Wilson, and N. Colvin. Computer Control of the Rochester Dial-a-Ride System. Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, Rept. 77-22, July 1977.
14. SYSTAN, Inc. The Rochester, New York, Integrated Transit Demonstration Suburb of Irondequoit. U.S. Department of Transportation, Draft Final Rept., 1978.
15. C. T. Hendrickson. Evaluation of Computer Dispatching. Transportation Systems Center, Cambridge, MA, Staff Study, 1978.
16. N. M. H. Wilson and E. Miller. Advanced Dial-a-Ride Algorithms Research Project: Phase 2—Interim Report. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Rept. R77-31, 1977.
17. P. Concannon, P. Connolly, and R. Favout. Evaluation of Current DAR Software and Expandability of AWDRT System. Transportation Systems Center, Cambridge, MA, Staff Study, 1977.

18. C. Orloff. Routing a Fleet of M Vehicles to/from a Central Facility. Networks, Vol. 4, No. 2, 1974, pp. 147-162.
19. P. D. Krolak and M. R. Williams. Computerized School Bus Routing. School of Engineering, Vanderbilt Univ., Nashville, TN, Technical Rept. 78-1, 1978.
20. B. T. Bennett and D. C. Gazis. School Bus Routing by Computer. Transportation Research, Vol. 6, 1972, pp. 317-325.
21. N. M. H. Wilson. Coordination and Control of Paratransit Systems. In Paratransit, TRB, Special Rept. 164, 1975, pp. 174-182.
22. G. J. Fielding. Demand-Responsive Transit: An Overview of Integrated Systems. In Paratransit, TRB, Special Rept. 164, 1975, pp. 45-54.