AN INVESTIGATION OF INTEGRATED TRANSIT SERVICE

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16. Abstract

In the United States, many transit agencies are considering integrating their demand-responsive service with traditional fixed-route service. In some cases, it may be advantageous to the transit agency or to the passenger to coordinate traditional demand-responsive transit service with fixed-route service. The demand-responsive service connects passengers from their origin to the fixed route service and (or) from the fixed route service to their final destination. Such a service is expected to reduce the cost of transit service, but also will affect the level of service experienced by passengers. The integrated transit service problem is to schedule both passenger trips (or *itineraries*) and vehicle trips for this service. In considering the literature, this research proposes a scheduling method that explicitly incorporates both transit agency cost and passenger level of service. More specifically, the model assumes: (i) a fixed-route bus schedule; (ii) desired passenger pick-up and drop-off points; (iii) time window constraints for passenger pick-ups, drop-offs, and transfers; and (iv) passenger level of service constraints, including maximum travel times and number of transfers. Using this information, the proposed technique determines which trips are eligible for integrated service using the passenger level-of-service constraints. A schedule is then created for both the passenger trips and the vehicle trips, so that the total cost of service is minimized. The method is illustrated using a case study of transit service in Houston, Texas, showing the possible cost advantages and changes in passenger level of service with integrated service. The contributions of the research include: (i) a new heuristic for scheduling integrated transit trips that accommodates both passenger and vehicle scheduling objectives; and, (ii) an illustrated method for evaluating the operating cost and passenger level-of-service implications of integrated transit service.

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ABSTRACT

In the United States, many transit agencies are considering integrating their demand-responsive service with traditional fixed-route service. In some cases, it may be advantageous to the transit agency or to the passenger to coordinate traditional demand-responsive transit service with fixed-route service. The demand-responsive service connects passengers from their origin to the fixed route service and (or) from the fixed route service to their final destination. Such a service is expected to reduce the cost of transit service, but also will affect the level of service experienced by passengers. The integrated transit service problem is to schedule both passenger trips (or *itineraries*) and vehicle trips for this service. In considering the literature, this research proposes a scheduling method that explicitly incorporates both transit agency cost and passenger level of service. More specifically, the model assumes: (i) a fixed-route bus schedule; (ii) desired passenger pick-up and drop-off points; (iii) time window constraints for passenger pick-ups, drop-offs, and transfers; and (iv) passenger level of service constraints, including maximum travel times and number of transfers. Using this information, the proposed technique determines which trips are eligible for integrated service using the passenger level-of-service constraints. A schedule is then created for both the passenger trips and the vehicle trips, so that the total cost of service is minimized. The method is illustrated using a case study of transit service in Houston, Texas, showing the possible cost advantages and changes in passenger level of service with integrated service. The contributions of the research include: (i) a new heuristic for scheduling integrated transit trips that accommodates both passenger and vehicle scheduling objectives; and, (ii) an illustrated method for evaluating the operating cost and passenger level-of-service implications of integrated transit service.

Keywords: *public transit scheduling; integrated transit service; coordinated transit service; demand-responsive service*

AN INVESTIGATION OF INTEGRATED TRANSIT SERVICE

EXECUTIVE SUMMARY

In the United States, many transit agencies have been considering integrating their demand-responsive service with traditional fixed-route service. In this integration, the demand-responsive service connects passengers from their origin to the fixed route service and (or) from the fixed route service to their final destination. Using this concept, transit agencies can extend demand-responsive service into low-density markets or may substitute demand-responsive service for fixed-route service. In these cases, operating costs may be reduced, and the level of service to passengers may increase by providing door-to-door service.

In other situations, longer trip lengths and growing patronage for demand-responsive service may lead a transit agency to consider providing at least part of the trip on fixed-route service, thereby reducing operating costs. The Americans with Disabilities Act (ADA) of 1990 requires that complementary paratransit services be provided to eligible elderly and disabled riders. Demand-responsive service is well-suited to the provision of such complementary service, but it is expensive. Integrated transit services may reduce the costs of providing this service.

The research described in this report examines the current technical and operational feasibility of integrated transit service as a substitute for traditional paratransit service. The key challenges that this research addresses are: (i) the overall level of service experienced by the passenger, in terms of their travel time and transfers; and, (ii) the effects on service costs to the transportation service provider. To answer these questions, the research investigates how one might schedule integrated service in order to provide the highest possible level of service to the passenger, while also reducing the overall costs to the operator. The *integrated transit service problem* is to schedule transit trips that may be carried by some combination of demand-responsive and fixed-route transit service. Both passenger trips (or *itineraries*) and vehicle trips must be scheduled.

State of the Practice

There is considerable interest in the US for integrated transit service. In actual practice, the most advanced integrated transit services exist today in the US in the form of "feeder service" and "smart shuttle" programs that use computer-assisted scheduling routines in the integration of transit services. Information on such programs was collected through relevant literature, the Internet, and telephone interviews. The extent and organization of these programs vary widely, although most agencies are using either in–house software or commercially available programs to do the scheduling of the passenger itineraries and vehicle trips. However, the actual integration of these two scheduling tasks, while possible in existing commercial software, is not specifically oriented to the joint tasks of passenger itinerary and vehicle trip scheduling.

Moreover, there has been only limited investigation of methods to handle these types of trips; the work of Wilson et al. (1976) and Liaw et al. (1996). The method of Wilson et al. focuses on passenger trip scheduling for integrating paratransit service "zones" with a common fixed–route system. However, this method does not explicitly consider agency costs in trip scheduling. Conversely, the work of Liaw et al. focuses on the integrated service problem more directly. The method explicitly considers the costs incurred in passenger and vehicle trip scheduling, but without considering the level-of-service needs of passengers.

In contrast to these previous works, the proposed approach decomposes this problem into two parts. First, one must find a feasible passenger itinerary, connecting the passenger's origin with the passenger's destination with transit service that maximizes the passenger's level of service. If such a passenger itinerary can be found, the passenger's trip is scheduled. Second, the paratransit trip legs must be added to a vehicle's schedule. This is done through existing vehicle routing heuristics for paratransit service. Through this decomposition, it is believed that this technique improves upon that of Liaw et al. (1996) by explicitly considering the passenger's level of service. It also improves upon the technique of Wilson et al. (1976) by explicitly incorporating operating costs into the scheduling process.

Proposed Methodology

In the proposed methodology, the tasks of passenger (itinerary) scheduling and vehicle scheduling are performed sequentially. Typically, the passenger itinerary will be scheduled on-line, so that the itinerary can be relayed directly to the passenger when they are requesting a trip. The vehicle trip scheduling can be done off-line, once all passenger trips are scheduled.

Passenger Itinerary Development

In the first stage, the potential passenger trip from the origin to the fixed route, on the fixed route, and from the fixed route to the destination is scheduled. The itinerary development process is summarized in Figure ES–1. To develop an integrated itinerary, a passenger is selected and his/her requested times and locations are identified. With this information, the Euclidean distance between the origin and destination is calculated. This distance must exceed some specified minimum distance; this screening is done to eliminate an inconvenient pair of transfers for very short trips, particularly when the paratransit legs of the integrated trip together form a very high percentage of the total origin-to-destination (O-D) distance. An additional screening is made based on the passenger's disability; the ability of a transit agency to accommodate trips by persons with disabilities is an important determinant of the number of trips eligible for integrated service.

Then, possible transfer points to the fixed route network must be identified. These should be less than some maximum distance from the origin or destination; the transfer points should also be farther than some minimum distance. To minimize passenger inconvenience, no more than two transfers are allowed, and so only two transfer points need to be identified. The proposed method constructs circles geographically about both the rider's origin and destination and identifies transfer points within these circles along a common fixed route.

Figure ES–2 illustrates these "proximity circles" and the paratransit and fixed-route trips that might serve a single request. Possible paratransit connections are denoted with capital letters; these only connect the origin and destination to points within the proximity circle. One integrated transit trip might be *Origin → C → F → Destination*, via *Fixed Route 2*.

After potential transfer points have been identified, common routes that connect the origin and destination must be found. This is accomplished through an explicit matching of fixed routes associated with major time points near both the origin and destination. If the time points near the origin and destination are not connected by a common route, then the trip request is served entirely with paratransit.

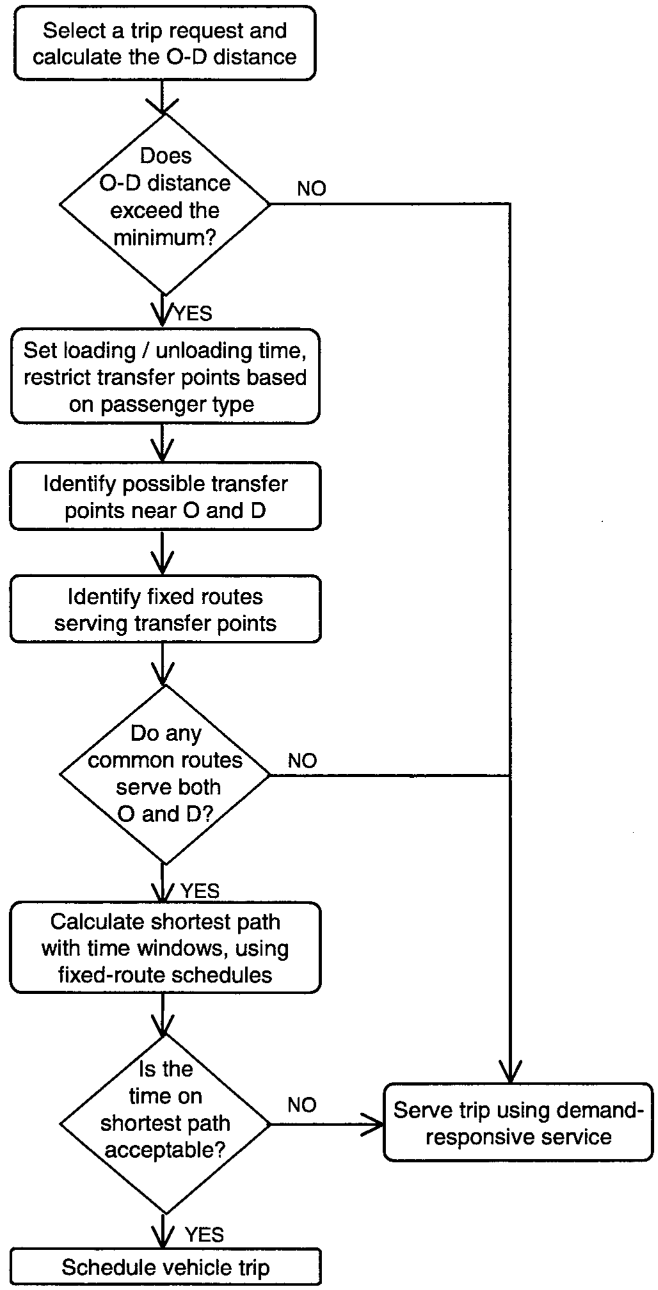

Figure ES–1. Passenger Itinerary Heuristic

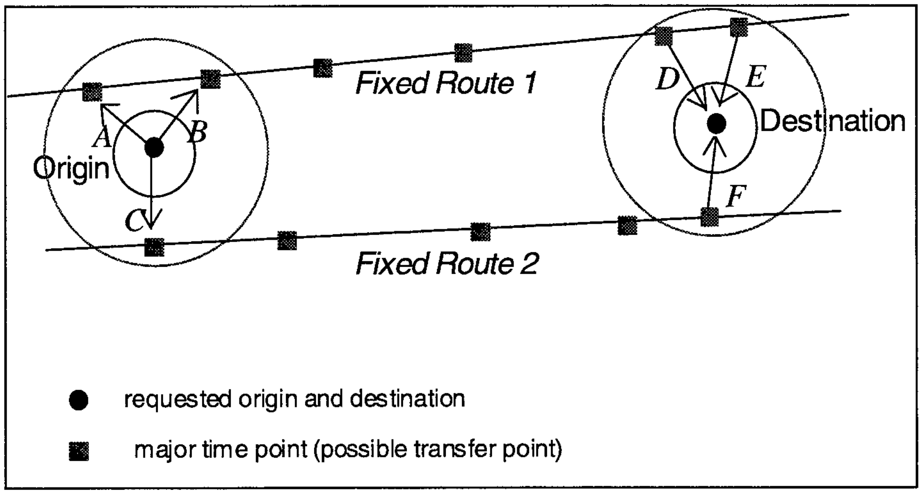

Figure ES–2. Possible Integrated Transit Itineraries for a Single Request

With the resulting sub-network of feasible paratransit legs and fixed-route services, feasible itineraries are constructed. Essentially, this involves solving a shortest path problem with time windows at the origin, destination, and transfer points. Also, the published fixed-route schedule is used to estimate available time windows at transfer points; passengers must be picked up or dropped off within the time windows. Currently, the shortest path is generated by full enumeration. If the passenger has specified an appointment time at the destination, a backwards pass through the network is performed. If, instead, a departure time from the origin is specified, a forward pass through the network is performed.

For each such itinerary, a passenger's level-of-service measure must be evaluated; a "generalized time" is used, which calculates the sum of waiting, travel, and transfer time along each path. The path with the minimum generalized time is then compared to the generalized time of a direct paratransit trip (the baseline in the case study). If the overall level-of-service is acceptable, the itinerary is given to the passenger, and the paratransit trip legs are sent to be included in a vehicle trip.

Vehicle Trip Scheduling

In the Houston case study, it was not necessary to develop a full vehicle schedule. However, an outline of the approach for the vehicle trip scheduling task is given. Once an integrated trip has been accepted, the vehicle trips from the origin to the fixed route and from the fixed route to the destination are added to a traditional paratransit vehicle routing and scheduling problem.

Two more recent techniques are now being investigated for use in this research. The first is a vehicle trip insertion heuristic (Jaw et al., 1986). This method assigns an incremental "cost" to each vehicle itinerary to accept a new trip. The vehicle with the lowest such "cost" receives the new passenger trip, as long as vehicle capacity constraints are not violated.

Given the large number of potential trips (over 3500 per day in the Houston case study), and the existence of a reasonably good paratransit vehicle schedule, a mini-clustering and column generation technique (Ioachim et al., 1995) is also possible. In this technique, the trips are grouped into clusters. Once so clustered, the algorithm uses a modified shortest path technique to re-optimize the allocation of clusters to individual vans. The goal in this re-assignment is to minimize the total number of vehicles, the total pieces of work required (i.e., the vehicle trips), and the total travel time.

Houston Case Study

The proposed scheduling heuristic is illustrated using the existing transit service in Houston, Texas. The transit agency in Houston (METRO) operates 94 fixed routes and a demand-responsive service for over 1750 passenger round trips per day, or about 3500 one-way trips per day. About 53% of METRO's demand-responsive passengers are ambulatory-impaired, and hence are really not eligible for integrated transit service as a result of METRO's own level-of-service requirements. However, with the requirements of the ADA, METRO is experiencing rapid growth in demand for the demand-responsive service, and is considering integrated service. Yet, METRO experiences greater costs for demand-responsive service than for fixed-route service. As a result, there is reason to believe that the substitution of fixed-route service for part of the demand-responsive service may result in cost savings to the agency.

The primary questions to explore included:

- What number and percentage of trips could be served by integrated service?
- What impacts might be expected for passenger level of service, for eligible passengers?
- What potential cost savings might be realized?

As a case study, the passenger scheduling heuristic was applied to a representative day of service at Houston METRO. The input to the heuristic was the existing schedule of trips, as output from the METROLift scheduling software. On the given day, a total of 3588 one-way passenger trips were taken on METROLift. Of those trips, 924, or about 26%, could be accommodated using the integrated service. Of the trips that were not covered, 1925 (53%) were not covered due to passenger disability (e.g., a wheelchair prohibited the trip), 217 trips were too short for our heuristic (under 4.8 km or 3 mi total length), 312 trips could not be served by a single fixed route, and 211 could not meet the maximum travel time constraint. It is interesting that the trip length and total travel time constraints, while important, had a more modest effect in reducing the number of trips served.

As for the overall passenger level of service, 39% of the trips on the integrated service actually provided a *shorter* travel time than that produced by METRO's scheduling software. Yet, 61% will be slightly worse off. This comparison includes a 10-minute total transfer penalty (5 minutes per each transfer). Interestingly, there are a number of passengers who would realize slight increases in travel time with the integrated service. However, there are also many passengers would realize substantial savings. Time savings appears to be more substantial for shorter trips where ride sharing occurs. In these cases, the integrated trip results in a less circuitous trip, and the passenger experiences a net time savings. Longer trips, on the other hand, are less likely to have time advantages for the integrated trip, due to the low speeds of the fixed–route service for long trips.

The potential cost advantages for METRO are stated in terms of the potential reduction in passenger-km of travel. When compared with the Euclidean distance, the integrated service reduces the total passenger-km of travel by 7380 km (4584 mi). This amounts to approximately 15% of the total passenger-km of travel at METROLift. At an average cost of $0.77 per passenger-km, the total cost savings has an upper bound of approximately $5682. This equates to about 15% of the daily operating cost of $36,000 at METROLift.

At the same time, this over-states the potential cost savings, since vehicle costs are likely to be highly non-linear with the costs per passenger-km. That is to say, the percentage reduction in passenger-km, particularly for trips where rides are shared, likely overstates the proportional reduction in vehicle-km. It is necessary to input the new integrated service trip legs through the vehicle scheduling heuristic to get a more accurate estimate of the vehicle operating cost savings.

A sensitivity analysis to various assumed parameters in the passenger scheduling heuristic was performed. Summarizing:

- If all (not just ambulatory) passengers were permitted to use the integrated service, a similar percentage (about 50%) could be accommodated. However, the level-of-service measures of travel time, average trip length, and length of the paratransit trip legs, are comparable between the full set of passengers and the restricted set mentioned above.
- The number of trips with the integrated service is very sensitive to the assumed radius of the proximity circles for fixed-route bus stops about the origin and the destination. As the radius increases from 10% to 50% of the Euclidean distance from the origin to the destination, the number of trips accommodated grows markedly.
- With respect to the minimum allowable trip length, the total trips accommodated does not vary substantially as the minimum trip length increases. As might be expected, the total trip length, average length of the paratransit trip legs, and travel time savings versus the original trip time, all increase as the minimum trip length increases. This is caused by the combination of longer trips more generally, with corresponding higher speeds, as well as higher speeds for paratransit service versus fixed-route service.
- The percentage of trips with improved service drops rather sharply as the assumed transfer penalty increases. With a higher penalty, the percentage of trips that are accommodated drops rapidly. A 10-min penalty per transfer (20 min total) reduces the number of possible trips accommodated to about 36%, and a 15-min penalty reduces this to only about 11%.

Finally, the analysis in this report is clearly limited by the fact that it focuses on the passenger scheduling task. This task is useful and important in generating some preliminary figures about the cost and level-of-service. Nonetheless, a full analysis using a vehicle scheduling heuristic is required to obtain more definitive cost implications for the operator.

Of course, cost and passenger travel time are not the only factors one might consider in deciding to implement such an integrated service, but the proposed method does allow evaluation of the cost and level-of-service implications. At the same time, potential increases in travel times, the effects of the requirement to transfer, and the resulting comfort and safety of passengers, must also be considered before such an integrated service is offered.

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AN INVESTIGATION OF INTEGRATED TRANSIT SERVICE

1. INTRODUCTION

In the United States, many transit agencies have been considering integrating their demand-responsive service[1] with traditional fixed-route service. In some cases, it may be advantageous to the transit agency or to the passenger to coordinate traditional demand-responsive transit service with fixed-route service. The demand-responsive service connects passengers from their origin to the fixed route service and (or) from the fixed route service to their final destination. Using this concept, transit agencies can extend demand-responsive service into low-density markets or may substitute demand-responsive service for fixed-route service. In these cases, operating costs may be reduced, and the level of service to passengers may increase by providing door-to-door service.

In other situations, longer trip lengths and growing patronage for demand-responsive service may lead a transit agency to consider providing at least part of the trip on fixed-route service, thereby reducing operating costs. Operating costs of demand-responsive service have increased resulting from the difficulties encountered by the elderly and the disabled in utilizing traditional transit services, which culminated in the Americans with Disabilities Act (ADA) of 1990. The ADA requires that complementary paratransit services be provided to eligible elderly and disabled riders. Demand-responsive service is well suited to the provision of such complementary service, but it is very expensive. Integrated transit services have the potential to reduce the costs of providing this service.

Interestingly, integrated transit service projects were planned, implemented, and analyzed in the 1970s. However, one key criticism of integrated transit service during the 1970s was poor coordination and timing of transfers between different routes and services. Passenger inconvenience and low levels of service resulted in the abandonment of the research and demonstration projects.

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[1] Demand-responsive transit service is defined by Kirby et al. (1974) as transportation that "provides door-to-door service on demand to a number of travelers with different origins and destinations." Demand-responsive transit services provided by a public agency providing same-day service, have historically been referred to by a number of terms in the literature, including "dial-a-ride." More commonly, demand-responsive service as now practiced in the US involves making reservations 24 hours in advance.

The research described in this report examines the current technical and operational feasibility of integrated transit service as a substitute for traditional door-to-door or curb-to-curb paratransit service. The key challenges that this research addresses, in evaluating service feasibility, are: (i) the overall level of service experienced by the passenger, in terms of their travel time and transfers; and, (ii) the effects on service costs to the transportation service provider. To answer these questions, the research investigates how one might plan and schedule integrated service in order to provide the highest possible level of service to the passenger, while also reducing the overall costs to the operator. The *integrated transit service problem* is to schedule transit trips that may be carried by some combination of demand-responsive and fixed-route transit service. Both passenger trips (or *itineraries*) and vehicle trips must be scheduled.

From a scheduling perspective, the integrated transit service problem is to schedule transit trips that may be carried by some combination of demand-responsive and fixed-route transit service. Both passenger trips (or *itineraries*) and vehicle trips must be scheduled. Past research on this specific problem includes the work of Wilson et al. (1976) and Liaw et al. (1996). The work of Wilson et al. examines scheduling of integrated service where several demand-responsive services operate in different geographic zones that are connected by a fixed-route service. The problem is formulated with a passenger utility function as its objective, subject to various level-of-service constraints. Operator costs are not included directly in the model. To schedule passenger and vehicle trips, a trip insertion heuristic is used. Somewhat in contrast, the work of Liaw et al. (1996) examines scheduling of integrated service using operating cost as the objective function. The problem is formulated using hard time window constraints, but no other passenger level-of-service measures are included in the model. An on-line heuristic is used to generate passenger itineraries, and the passenger and vehicle trips are further refined using simulated annealing.

A more general approach to multi-modal and flexible transit scheduling is discussed in several other references, including Gerland (1991), Crainic et al. (1998), Horn (1999), and Malucelli et al. (2000). These works have made important contributions in scheduling and routing integrated transit service. These approaches are more general than the methodology described here, and they have great advantage in modeling new transit service options. In contrast, the model described in this paper is specific to the integration of fixed-route and demand-responsive systems, constrained to the context of current transit service options in the US.

What is still lacking in this context is a scheduling method for integrated service that includes both the passenger and operator objectives. To this end, this research explicitly incorporates both transit agency cost and passenger level of service directly in the model. From the transit agency's perspective, the goal in scheduling vehicle trips is to minimize the total cost of service. On the other hand, passengers desire a high level of service; e.g., minimizing travel time, transfer time, and the number of transfers. To balance agency and passenger objectives, this research introduces a heuristic to schedule integrated trips that minimizes transit agency cost, subject to passenger level-of-service constraints. In the model formulation, the following elements are given: (i) a fixed-route bus schedule; (ii) desired passenger pick-up and drop-off points; (iii) time window constraints for passenger pick-ups, drop-offs, and transfers; and (iv) passenger level of service constraints, including maximum travel times and number of transfers. Using this information, the proposed technique determines which trips are eligible for integrated service using the passenger level-of-service constraints. A schedule is then created for both the passenger trips and the vehicle trips in the integrated service, so that the total cost of service is minimized.

This report begins with a brief review of the state of the practice in Section 2. The remainder of the report describes and illustrates a proposed two-stage technique to schedule the integrated service. In Section 3, existing methods are reviewed, and the proposed two-stage method is described. In the Section 4, the proposed technique is used to illustrate the possible advantages and impacts of integrated service in Houston, Texas. The case study is used to identify the potential cost and level of service implications for a transit agency considering shifting a fraction of the existing demand-responsive trips to an integrated service that leverages a considerable fixed-route transit network. The fifth section (Section 5) presents conclusions on the value of integrated service, and on the benefits of the proposed scheduling method.

2. REVIEW OF THE STATE OF THE PRACTICE

This section reports on the state of the practice for integrated transit service.[2] The most advanced integrated transit services exist today in the US in the form of "feeder service" and "smart shuttle" programs that use computer-assisted scheduling routines in the integration of transit services. Information on such programs was collected through relevant literature, the Internet, and telephone interviews. The collection process began by contacting the agencies listed in the recent report by the Transit Cooperative Research Program (TCRP), *Transit Operations for Individuals with Disabilities* (1995). Of particular interest were agencies that were listed as providing "feeder service." These agencies were contacted to determine the role that computer-assisted scheduling tools play in the provision of their services. Client agencies named by transit scheduling software companies or in research papers were also studied. Searches were conducted across the Internet, using the World Wide Web and mailing lists, to discover more agencies. Referrals by the interviewed agencies and other transportation professionals identified additional agencies.

The full set of agencies, and a brief summary of their current practice in integrated service, is shown in Table 1. The following sections provide additional detail from each agency. As the reader may note, the extent and organization of these programs vary widely.

[2] The material in this section was primarily collected during 1998. We have not re-contacted these agencies again before submission of this report. As a result, the material may be somewhat dated. We suggest the motivated reader re-contact the agencies listed in this section to find out the latest details.

Table 1. Current Integrated Transit Service Projects

Agency	Location	Type of Feeder Service	Software Used	Other Information
Ann Arbor Transit Authority	Ann Arbor, MI	Demand-responsive paratransit feeder	In-house	Based on research of Liaw et al. (1996)
Blacksburg Transit	Blacksburg, VA	Demand-responsive paratransit feeder	CTPS by COMSIS	
Burbank Local Transit	Burbank, CA	Demand-responsive feeder to downtown and airport	Trapeze	Operates during peak hours only; contracted to private operator
Cape Cod Regional Transit Authority	Cape Cod, MA	Fixed-route feeder and demand-responsive paratransit feeder	MIDAS by Multisystems	Ongoing demonstration project
Cobb Community Transit	Cobb County, GA	Demand-responsive paratransit feeder	In-house	
Corpus Christi Regional Transportation Authority	Corpus Christi, TX	Demand-responsive paratransit feeder	Unknown	Based on research of Dial (1995)
Greater Cleveland Regional Transit Authority	Cleveland, OH	Demand-responsive paratransit feeder	MIDAS by Multisystems	Unsuccessful experiment
Greater Lafayette Public Transportation Corporation	Lafayette, IN	Demand-responsive paratransit feeder	Trapeze	Currently studying expansion of timed-transfer network
Island Transit	Coupeville, WA	Demand-responsive paratransit route deviation	PASS by Trapeze	Paratransit vehicles deviate within cities, but not between them
Metropolitan Tulsa Transit Authority	Tulsa, OK	Demand-responsive zone routing	Unknown	Zone routing
Potomac and Rappahannock Transportation Commission	Virginia	Fixed feeder routes	Unknown	OmniLink; regular bus service is a flex-route service
SAMPO	Keski-Uusimaa and Seinäjoki, Finland	Demand-responsive paratransit feeder and route deviation	MobiRouter by Mobisoft	Demonstration projects
The T	Fort Worth, TX	Demand-responsive paratransit feeder	In-house	Separate ADA and non-ADA feeder services
VIA	San Antonio, TX	Demand-responsive paratransit feeder	Unknown	Unsuccessful experiment

Ann Arbor Transportation Authority

The Ann Arbor Transportation Authority (AATA) in Ann Arbor, Michigan, oversees a network of fixed-route and paratransit vehicles that serves more than four million passengers per year (FTA, 1996). Fixed-route and paratransit vehicles are coordinated using the decision support system developed in the bimodal dial-a-ride research of Liaw et al. (1996). Data collected in Ann Arbor after the implementation of the bimodal decision support system showed an average increase of 10 percent in service capacity and an average decrease of 10 percent in the number of paratransit vehicles necessary to meet all passenger requests (Texas A&M, 1998).

AATA's focus has since shifted away from the bimodal decision support system. It was found that Ann Arbor is not large enough and there are not enough paratransit trips to fully show the impacts of the decision support system on the whole of AATA's transit operations. AATA has shown interest in providing suburban feeder service into Detroit, which is 40 miles away, but institutional barriers hinder the development of such a service (White, 1998).

Blacksburg Transit

Blacksburg Transit uses Intellitrans' CTPS program for real-time paratransit scheduling in Blacksburg, Virginia. Paratransit patrons can schedule a transfer to any fixed-route line, including a trolley that serves Blacksburg and the neighboring town of Christiansburg. These transfers are scheduled to occur at time points on the fixed route. Passengers must schedule the transfer at least one day in advance, and paratransit drivers will wait at the stop with the passenger if possible (Danker, 1998).

Burbank Local Transit

Burbank Local Transit (BLT) in Burbank, California, operates two feeder shuttles through private contractors. The Downtown Burbank shuttle connects the downtown Metrolink train station at the Regional Intermodal Transportation Center (RITC) to areas not served by fixed-route lines. The Golden State/Airport Area shuttle connects the RITC to Burbank Airport. These shuttles operate only during the peak hours. Reservations are required by 2:00 p.m. for afternoon trips and by 6:00 p.m. on the previous day for morning trips, unless a rider is meeting the shuttle at the RITC, where a stop is always scheduled. Kiosks at the RITC display schedule information, and the shuttle will wait up to five minutes for a late train (Aguilar, 1998).

Cape Cod Regional Transit Authority

In October of 1997, the Cape Cod Regional Transit Authority (CCRTA) in Massachusetts received an Advanced Public Transportation Systems (APTS) grant for a demonstration project showing how ITS technologies can be used to improve transit service and efficiency. Components of the project will include advanced computers and telecommunications, traveler information systems, automatic vehicle location (AVL), enhanced management strategies, and improvements in passenger safety (Cape Cod, 1998).

As of March of 1998, CCRTA has upgraded its computer systems, introduced monthly billing, and developed a web page on which real-time transit information can be displayed (Cape Cod, 1998). CCRTA fixed-route trolleys currently provide connections to a number of intercity, fixed-line routes, but implementing demand-responsive feeder service is a "major objective" of the project because CCRTA would like to reduce the high costs associated with its b-bus paratransit service. Trips on the b-bus service require reservations and are scheduled using Multisystems' MIDAS package. B-bus is available to both the public and ADA-eligible riders. CCRTA expects that the availability of real-time information and improved telecommunications will result in easier transfers and fewer missed connections between fixed routes and between fixed routes and paratransit (Harman, 1998).

Cobb Community Transit

Cobb Community Transit (CCT) of Cobb County, Georgia, developed scheduling software in-house to facilitate its paratransit operations, which include feeder service to MARTA transit lines. Transfers are arranged at transfer centers, and drivers will wait to make sure that the transfer is completed. CCT requires at least one day's notice, and only the elderly and disabled are eligible to use the paratransit service (Cobb County, 1998).

Corpus Christi Regional Transportation Authority

The Corpus Christi Regional Transportation Authority is developing an Autonomous Dial-a-Ride Transit (ADART) system, based on the work of Robert Dial (1995). Corpus Christi, Texas, is a low-density urban area, and some areas of the city do not generate sufficient ridership to make fixed-route transit service economically viable (Smith, 1998). ADART provides an alternative to fixed-route service in these areas. ADART also makes the provision of early morning and late evening service more feasible (Smith, 1998).

Phase 1 was a review of available hardware and software, and it was concluded that the ADART project is technologically feasible. Phase 2 is the development and testing of the software and algorithms using simulation. Phase 3 is a field test of the ADART system in one area of the city, using three vehicles that will be tied in to the fixed-route network at predetermined transfer points. Phase 4 is a more extensive test involving up to 20 vehicles and the provision of late evening service as well as daily service (Smith, 1998). As of March of 1998, the project was in Phase 2. Evaluation is expected to begin as Phase 3 approaches (Smith, 1998).

Greater Cleveland Regional Transit Authority

Prior to 1996, the Greater Cleveland Regional Transit Authority (GCRTA) in Ohio experimented with feeder services to improve transit system efficiency. The project was the first large test of Multisystems' MIDAS package. The computer program, the TransCAD GIS platform, and the scheduling and dispatching elements worked well, but the project failed because the GCRTA service area is large and urban and the "interfaces" between sidewalks and streets are both wide and numerous. Making all buses accessible and constructing curb cuts at each stop was so prohibitively expensive that paratransit vehicles would have been necessary for most trips anyway (Kelly, 1998).

Greater Lafayette Public Transportation Corporation

The Greater Lafayette Public Transportation Corporation (GLPTC) in Lafayette, Indiana, operates two paratransit services. Both services require reservations at least one day in advance. Schedules are created using a package from On-Line Data Products, a company that is now part of Trapeze (Kuzmet, 1998).

The first service, TeleRide, is sponsored by the state's Department of Families and Children, and is available to welfare recipients who need to reach jobs outside the regular service area. Ridership averages one to two riders per day. In a very small number of cases, TeleRide will operate as a feeder service. Riders who wish to transfer are given a transfer ticket at a downtown timed-transfer station. The TeleRide vehicles currently do not wait to assure that the transfer is successfully completed. The second service, Access, is exclusively for ADA-eligible riders. Access is not used as a feeder service (Kuzmet, 1998).

Future GLPTC plans include a route network plan that will add new timed-transfer stations throughout the service area. These timed-transfer centers will "function as bases for small demand-response vehicles that increase the service area and reduce operating mileage for line-haul buses. This arrangement . . . supports more flexible demand-responsive service" (Wilbur Smith and Associates, 2001).

Island Transit

Island Transit is centered in Coupeville, Washington, on an island in Puget Sound. It is a rural system that connects with ferries to the mainland. One town on the island has hospitals -- a major destination -- while the other contains most of the island's population. Other residents are scattered around the area. There is fixed-route transit service as well as a paratransit service exclusively for ADA-eligible riders. Paratransit trips are scheduling using an older version of Trapeze's PASS software (Alldridge, 1998).

The feeder service is a route deviation service. Fixed-route bus operators are notified that they will be met at both ends of a passenger's trip by a paratransit vehicle. The paratransit vehicles spend 20 minutes in each of the two towns to collect and/or distribute paratransit passengers before meeting the fixed-route buses. The fixed-route buses are allowed to deviate on some occasions (Alldridge, 1998).

Most paratransit trips are subscription trips, but Island Transit is trying to reduce the number of subscription trips to 50 percent. About 1000 riders are registered for the service, and approximately 150 trips are made per day. To get a guaranteed ride, passengers must call before 4:00 p.m. on the previous day. If a call is made on the same day for which service is requested, Island Transit requires at least two hours notice, although fitting the request into the schedule still may not be possible (Alldridge, 1998).

Metropolitan Tulsa Transit Authority

In 1995, Community Resource Group, Inc., developed the "zone routing" concept for Ozark Regional Transit (which does not provide feeder service) in an attempt to make more efficient use of transit resources in the face of insufficient transit funding. Zone routing is based on traditional demand-responsive service but tries to minimize operating costs and increase the freedom and spontaneity with which potential customers can make transit trips (Kopke and Associates, 1998).

In a zone routing system, customers call the dispatcher and relay their destination and the time at which they would like to be delivered. The zones a transit vehicle will be traveling through are predetermined by origin and destination studies, so the dispatcher is able to identify which of the vehicles passing through the customer's origin zone will later pass through the destination zone before the specified delivery time. The transit vehicles operate on circular routes and will pass through a given zone multiple times according to a predetermined schedule, and so there are many opportunities to find a schedule that suits the customer. Pickups and deliveries are door-to-door, but some fixed stops at popular locations can be set up (Kopke and Associates, 1998).

Zone routing is currently being used by the Metropolitan Tulsa Transit Authority (MTTA) in suburban Tulsa, Oklahoma, and the nearby city of Jenks, where some low ridership bus routes have been replaced with zone routes that serve as feeders to the Tulsa fixed-route lines. Zone routing is also used as a cross-town service for southern Tulsa (Kopke, 1998).

Potomac and Rappahannock Transportation Commission

The Potomac and Rappahannock Transportation Commission (PRTC) in Virginia sponsors OmniLink, which offers flexibly routed local service and flag-stop feeder service to commuter rail. ITS technologies such as AVL, real-time scheduling, and computerized scheduling and dispatching have been a part of the OmniLink project since 1997. Funding for the project came from ISTEA (Farwell and Marx, 1996; OmniRide, 1997).

Feeder services began in December of 1994. Today, five routes are connected to three commuter rail stations. These five routes are fixed routes—it is the local bus service that operates as a flex-route service—but patrons can flag down the feeder buses anywhere on their routes. PRTC oversees both services, but they are operated separately. The feeder routes arrive at the rail station 10 minutes before each train departs to allow time for walking and purchasing tickets. There is no subscription service because of the train schedule and the fact that some people do not always want to take the same train or bus. The system was originally designed so that a single vehicle could cover the route every 30 minutes and meet the train on time. A survey found that the weight placed on making the train was very heavy because the trains operate at 30-minute headways. This survey, in fact, was the origin-destination survey used to design the feeder system. Questions such as, "How much ride time or fare would you accept in making the decision to use transit?" allowed respondents to "design their own transit service," and only respondents who indicated that they would use transit at least three days a week were included in the GIS match-up to determine the routes the feeder service would travel (Marx, 1997).

At first, ridership was more than 10 people per trip. More than 400 trips were made per day, and the feeder had a 30 percent market share of trips to the rail station. Riders were very happy with the service, according to new surveys. The feeder service allowed them to avoid parking lot charges at the rail station, and they were able to avoid roadway congestion. Riding the feeder was free with a rail ticket. The extension of a parallel HOV lane along I-95 from Washington, D.C., to the PRTC service area, however, recently hurt rail ridership considerably. To attract ridership, the Virginia Railway Express (VRE) stopped charging for parking at the rail station. However, the number of feeder trips made per day dropped to 200, and, with the ridership decline, service was reduced in July of 1997 (Marx, 1997).

The decline in ridership meant that the planned multimodal tracking of vehicles and trains using ITS technologies did not happen, and the extensions and new feeder routes planned were not implemented either. It is probable that the feeder service will be modified to feed the park-and-ride lots for commuter bus operations, which is the only other fixed-route service in the area and operates at 15- to 20-minute headways. These park-and-ride lots are currently at capacity and experience congestion when the commuter buses arrive in the evening and the riders try to leave the lot. The feeder service may relieve some of this congestion (Marx, 1997).

As of December of 1997, 20 percent of riders call in advance to schedule deviations, the other 80 percent use it without deviations, and same-day reservations are feasible, according to the PRTC web site. Due to budget constraints, the flex-route local service operates only from 7:30 a.m. to 6:00 p.m., with some overlap of the peak hours when the feeder operates. There are 22 feeder buses, and 17 operate on the five feeder routes, five to ten vehicles at a time. ADA requirements are met by both feeder and flex-route service because buses are lift-equipped (Marx, 1997).

SAMPO

The System for Advanced Management of Transportation Operations (SAMPO) is a series of demonstration projects sponsored by the Transport Telematics Programme of the European Union Fourth Framework research program. SAMPO originated in response to increased interest in demand-responsive transit services, and it aimed to develop demand-responsive transit services (DRTSs) in a variety of regions across Europe and for a range of passenger types and modes, using optimized routes and real-time data (Telematics Application Programme, 1997; SAMPO, 1998).

One SAMPO demonstration project was in Finland. It involved integrated DRTSs operating out a Travel Dispatch Centre (TDC) covering the rural municipalities of Keski-Uusimaa and Seinäjoki. The Finnish project included many modes: taxi, bus, paratransit for the disabled, and rail (Westerlund, 1997). Some vehicles were equipped with mobile data terminals, GPS systems, and "smart card" readers (SAMPO, 1998). Although feeder service was not a formal part of the project, intermodal connections were scheduled. The potential for a more developed integrated service exists, and the technology and integration logic is applicable to integrated transit service projects elsewhere.

The demonstration officially began in February of 1997 and ended in July of 1997, but service continued afterwards. Evaluations showed no improvements in cost-effectiveness, but it was believed that a future demonstration project with fewer technical difficulties, better publicity, and a longer demonstration period would show more promising results (Westerlund, 1997).

The scheduling software for the project was MobiRouter, developed by Mobisoft Ltd., which also provided technological support (SAMPO, 1998). SAMPO vehicles stopped at predetermined locations except in the case of disabled riders, where pickups and dropoffs occurred at the door. SAMPO stops were most often the same as area trunk line stops, and trunk line schedules were integrated into the scheduling software so that riders requesting trips could be placed on fixed routes whenever possible. Where no trunk line stops existed in Uusimaa, new stops were created so that 98 percent of all residents were within 400 meters of a stop (Westerlund, 1997).

The T

Three-and-a-half years ago, transit ridership in Fort Worth, Texas, was either stagnant or decreasing in the areas served by The T. A full evaluation of the state of the organization was conducted using focus groups, community meetings, on-board surveys, passenger counts, and a service analysis review by a consulting firm. Riders indicated that the problems with the transit service were related to frequency of service, consistency, and convenience. These problems were reflected in the underutilization of many routes (Anderson, 1998).

The T's administrators decided to overhaul the transit network to stop the decline in ridership, and they looked at the different technologies and types of service used at other agencies to identify possible improvements. Originally, 50 routes ran radially from a single transfer center in the CBD. Buses would meet there within 15 minutes of the hour so that riders could transfer between buses. Riders did not find this convenient, so administrators cut the number of routes from 50 to 20, changed some fixed radial routes to cross-town routes, and built four new transfer centers at different points in Fort Worth (Anderson, 1998). A curb-to-curb demand-responsive service called Rider Request was then created to serve all Fort Worth residents. The T's Mobility Impaired Transportation Service (MITS) for ADA-eligible riders is a separate service

(The T, 1998).

For trips originating within a given Rider Request zone, customers can call 24 hours in advance to schedule curb-to-curb service for peak period trips or call same-day to schedule off-peak trips. Subscription service is available, and "open" rides are scheduled manually between 2:00 and 10:00 p.m. after subscription rides have been scheduled. Rider Request trips also serve as feeders to the "spine" and cross-town routes. Spine routes 1 and 2 run north-south and east-west, respectively, every 15 minutes, and connect to cross-town routes at transfer stations (Anderson, 1998).

The T is currently investigating scheduling and dispatching software packages. Initially, the agency modified the MITS scheduling software for Rider Request, but hopes that new scheduling software can address the limitations of the modified software (Anderson, 1998).

The T expected a decline in ridership immediately after the implementation of the new service configuration, but that never happened. Transfers showed a clear increase, partly because of feeder service to the spine routes and partly because of a new transfer policy that allows riders to use transfer tickets within a two-hour window instead of a one-hour window, even to the same bus. In some regions of the service area, feeder trips made up the largest percentage of transfers (Anderson, 1998).

As of March 1998, the first item on The T's action plan was to look into combining Rider Request with MITS. This was Phase 2 of the service improvement plan. Currently, Rider Request will "lighten the load" on MITS where pickups and deliveries are in the same area, the effort is made to coordinate such an event, and the age or disability of the customer does not specifically require door-to-door service. When Rider Request and MITS are combined, passengers will be able to select the service they wish to use, or, ideally, will not even be able to tell the difference between them (Anderson, 1998).

VIA

VIA, in San Antonio, Texas, attempted to set up a non-ADA feeder service in the late 1980s, but the project was unsuccessful in the face of little strong support from within the agency, little time spent on making improvements to the project, and great expense. (The cost of providing service to one rider on the feeder service was two to three times that of the fixed-route service). The service was designed to collect and drop off riders at fixed-route stops in sparsely populated areas of San Antonio so that a transit market might develop in these areas and ultimately justify the creation of new fixed routes (Perkinson, 1997).

Capabilities of Existing Software and Technology

A recent Federal Transit Administration report (FTA, 1998), describes the roles and successes of advanced technologies such as geographic information systems, communications systems, AVL systems, and operations software at North American transit agencies. The appendix describes the capabilities of specific software packages in the scheduling of integrated transit services. Some packages can fully support integrated transit services, while others can support various aspects of the integration.

3. EXISTING RESEARCH AND PROPOSED METHOD

3.1 Overview

Development of an integrated transit service schedule comprises two main tasks: scheduling passenger trips and scheduling vehicle trips. In the scheduling of passenger trips, an itinerary is developed for each integrated service request in which:

1. A paratransit vehicle may pick up the passenger from his/her origin and "feed" him/her to an appropriate fixed-route stop.
2. A fixed-route vehicle will then pick the passenger up and transport him/her to another fixed-route stop.
3. A second paratransit vehicle may carry the passenger from the second fixed-route stop to the door of his/her destination.

One or more of the paratransit "legs" may be excluded, and multiple itineraries are possible for a single request. Figure 1 conceptually illustrates the scheduling of a single passenger's request where two transfers must be made.

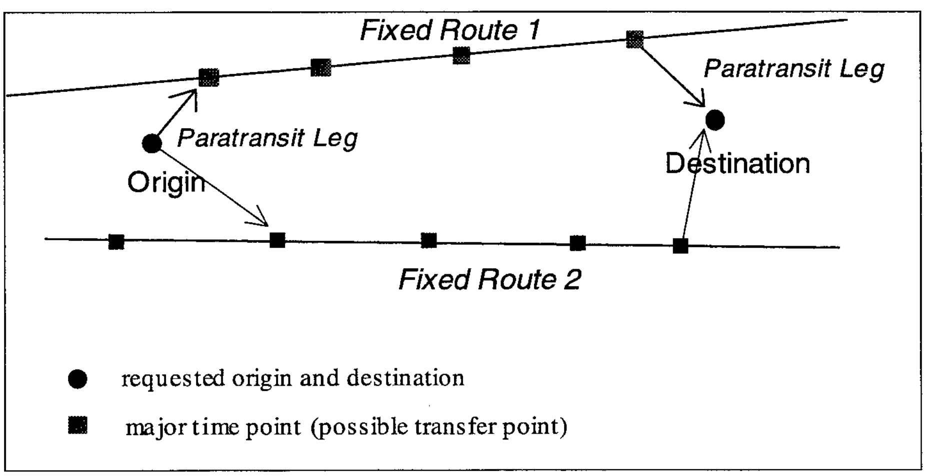

Figure 1. An Integrated Transit Trip

An initial foray into this problem was proposed by Wilson et al. (1976), in the context of same-day dial-a-ride services. A "coordinated system" algorithm was proposed to handle explicitly the integrated transit services problem. However, the algorithm was designed for a fairly specific instance of the integrated services problem: separate paratransit (or "dial-a-ride") organizations operate "autonomous" zones within the area, and a single fixed-route transit system connects these zones. The coordinated system algorithm is composed of modules for the following tasks (Wilson 1976):

- assigning trip requests to paratransit zones;
- choosing the fixed route and transfer points to serve the trip;
- permanently assigning the origin stop and first transfer point for the trip;
- initially assigning the second transfer point and destination stop;
- monitoring service in real time for late arrivals; and,
- permanently assigning the second transfer point and destination stop.

Consistent with Wilson's other dial-a-ride work, the algorithm for assignment of trip requests is based on passenger utility, including waiting time, riding time, and deviations from the passengers' desired pickup and dropoff times.

In an autonomous dial-a-ride system, the dial-a-ride service zones do not overlap and each operates its own control system to construct itineraries. Zone size has a considerable effect on service quality. There is no awareness of the operating status or schedules of other zones, and passengers are automatically directed to the system in their origin zone when they call. When passengers request trips that will take them to another zone, a centralized control system will receive a tentative schedule from the origin zone's control system, choose a fixed-route line to connect the origin and destination zones, and then notify the destination zone's control system of the trip. The fixed-route line chosen is the one that will minimize travel time to the destination zone. If the fixed-route vehicle is behind schedule, expected arrival time in the destination zone is recalculated by the central control system and passed to the destination zone's control system. Within each zone, a dial-a-ride heuristic is used to assign passenger trips to paratransit vehicles (Wilson et al, 1976).

The integrated service problem was also attacked more recently in the work of Liaw et al. (1996). These researchers developed a decision support system to support integrated advance-request paratransit and fixed-route transit services. The problem was termed the Bimodal Dial-A-Ride Problem, or BDARP, to reflect the coordination of fixed-route and dial-a-ride vehicles. The goals of the research were to "reduce total system cost and improve total system accessibility for the prospective rider without significant reduction in individual rider convenience." The decision support system was tested using data from Ann Arbor, Michigan, and showed a 10 percent improvement in the number of paratransit requests that could be accommodated by the agency (Liaw et al., 1996).

In the approach of Liaw et al., a solution to the BDARP is composed of routes and schedules that minimize the number of paratransit vehicles in service, the distance they travel, and the total time they are in use, while meeting all of the time constraints that result from rider requests. These time constraints take the form of time windows. Time windows for a given trip are calculated from the estimated travel time between two points and the maximum allowable deviation from requested arrival and departure times.

The decision support system in Liaw et al. (1996) consists of on-line and off-line systems. The on-line system generates an initial feasible solution (a passenger itinerary) through three main tasks:

1. Select an appropriate fixed-route bus to serve a given request, and then choose the stops along that route at which paratransit vehicles will meet the fixed-route bus. To minimize rider inconvenience, there will be no more than two transfers along the rider's entire trip, and these transfers will be made between paratransit and fixed-route vehicles only. Paratransit trips should be as short as possible, and fixed-route vehicles are assumed to have sufficient capacity.
2. Construct time windows for the endpoints of the paratransit trips, subject to the maximum allowable wait time.
3. Schedule the paratransit trips.

The off-line decision support system improves upon the initial feasible solution using simulated annealing and data "strings" – one for each trip request – that define the service configuration. It also schedules trips that were rejected in the on-line system. The procedure used in the off-line system comprises three steps:

1. Calculate the total service cost of the initial solution. This involves optimizing the route and schedule of each vehicle for each shift and adding up the costs associated with every schedule.
2. Find more efficient solutions using simulated annealing and recalculate the total service cost to find the service configuration with the lowest total service cost.
3. Schedule stand-by requests, if possible, using the methods of the on-line decision support system.

In contrast to these previous works by Wilson et al. (1976) and Liaw et al. (1996), the proposed approach decomposes this problem into two parts. First, one must find a feasible passenger itinerary, connecting the passenger's origin with the passenger's destination with transit service that maximizes the passenger's level of service. If such a passenger itinerary can be found that meets these level-of-service requirements, the passenger's trip is scheduled. Second, the paratransit trip legs must be added to a vehicle's schedule. This is done through existing vehicle routing heuristics for paratransit service. Through this decomposition, it is believed that this technique improves upon that of Liaw et al. (1996) by explicitly considering the passenger's level of service. It also improves upon the technique of Wilson et al. (1976) by explicitly incorporating operating costs into the scheduling process.

The following (typical) inputs for these two scheduling tasks are assumed:

- the location of the passengers' pickup and dropoff points;
- the passenger's requested times, and associated time windows, in which pickups and dropoffs must occur;
- the location of fixed-route stops;
- the schedules of all fixed-route vehicles;
- the accessibility level of all fixed-route vehicles and transfer points;
- the time windows in which paratransit vehicles are permitted to meet fixed-route vehicles at transfer points;
- vehicle capacities;
- passenger loading and unloading times;
- the distance between stops; and,
- minimum passenger level of service standards.

The time windows for connecting between paratransit and fixed-route service may be based on local policy. In this case one must balance the need for flexibility and slack to accommodate variation in vehicle travel times with the need for short waiting periods at the transfer station. At the same time, the dwell time at the transfer point must be sufficiently long to load and unload passengers from the fixed-route service. Recent research has suggested that the elderly and disabled may require significantly longer time to board and alight, on the order of 1-3 minutes (Kittelson and Associates, 1999).

The tasks of passenger scheduling and vehicle scheduling are then performed sequentially. Typically, the passenger itinerary will be scheduled on-line, so that the itinerary can be relayed directly to the passenger when they are requesting a trip. The vehicle trip scheduling can be done off-line, once all passenger trips are scheduled. The following sections describe the passenger and vehicle scheduling methods, respectively.

3.2 Passenger Itinerary Development

In the first stage, the potential passenger trip from the origin to the fixed route, on the fixed route, and from the fixed route to the destination is scheduled. The itinerary development process is summarized in Figure 2. The method proposed below is a variant of more traditional public transit itinerary methods, such as Bovy and Stern (1990), Bander and White (1991), Han and Hwang (1992), and Koncz et al. (1996). The interested reader is referred to these other works for more detail on these methods.

To develop an integrated itinerary, a passenger is selected and his/her requested times and locations are identified. Consistent with most existing paratransit scheduling software, the Euclidean distance between the origin and destination is calculated. The Euclidean distance allows a computationally fast estimate of the total travel time, although at a loss of precision when compared with the computationally burdensome but accurate shortest path techniques. The method here also uses a single vehicle speed, although one might have this value vary in peak periods versus off-peak periods in order to account for congestion.

The Euclidean distance must exceed some specified minimum distance; this screening is done to eliminate an inconvenient pair of transfers for very short trips, particularly when the paratransit legs of the integrated trip together form a very high percentage of the total origin-to-destination (O-D) distance. The distance between the origin and destination can also be used to estimate the passenger's expected travel time for a direct paratransit trip. Also, the maximum allowable ride time for each passenger can be calculated as an incremental percentage above the expected travel time (e.g., 50% higher).

An additional screening is made based on the passenger's disability. The integrated service is intended to accommodate passengers traveling under provisions of the Americans with Disabilities Act (ADA) of 1990. This means that one could consider all types of passengers for integrated service. However, this requires that the stops, routes and vehicles on the fixed-route system are all able to accommodate ADA passengers (e.g., with wheelchair lifts, accessible shelters, appropriate curb treatments, etc.). As will be noted later, the ability of a transit agency to accommodate these ADA trips is an important determinant of the number of trips eligible for integrated service.

Based on the passenger's origin and destination, and any accessibility requirements, possible transfer points to the fixed route network must be identified. These should be less than some maximum distance from the origin or destination; in this way one may screen out trips where the fixed-route segment accounts for only a small percentage of the trip. The transfer points should also be farther than some minimum distance because, for the agency and for other passengers, it would be impractical to schedule a paratransit vehicle for a trip that is too short. Rather, such a request would be served directly by paratransit or by a single-transfer trip. To minimize passenger inconvenience, no more than two transfers are allowed, and so only two transfer points need to be identified.

The proposed method is a variation of that proposed by Liaw et al. (1996). One may construct circles geographically about both the rider's origin and destination and identify transfer points within these circles along a common fixed route. This technique can be used to identify any fixed routes that serve the origin or destination directly (i.e., within a very small walking distance), hence requiring only one or no paratransit legs.

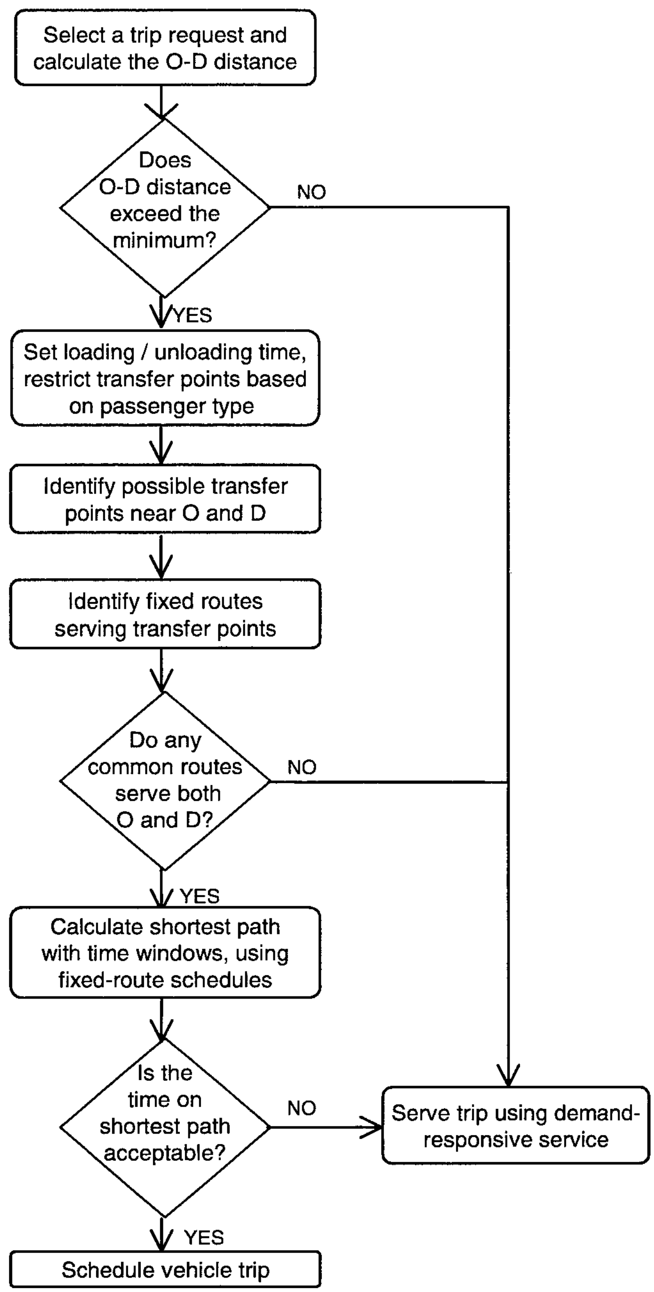

Figure 2. Passenger Itinerary Heuristic

In contrast to Liaw's method, however, it seems that integrated trips with two paratransit legs have a minimum, as well as a maximum, radius (i.e., a ring). The distance between a passenger's origin and destination, for example, may be long enough that the passenger cannot make the trip without assistance but short enough that a single paratransit trip would be less expensive for the agency than a combination of paratransit and fixed-route trips. If served with a single paratransit vehicle and no fixed-route transfers, the passenger would not experience the onerous-ness of transfers or waiting at a fixed-route stop, and other passengers would not be unduly penalized by the need to schedule an additional integrated trip. Specifying a practical minimum distance between the origin and destination therefore improves passenger level of service for short trips and mitigates overall system scheduling inflexibility.

Figure 3 illustrates the proximity circles and the paratransit and fixed-route trips that might serve a single request. Possible paratransit connections are denoted with capital letters; these only connect the origin and destination to points within the proximity circle. One integrated transit trip might be *Origin* → *C* → *F* → *Destination*, via *Fixed Route 2*.

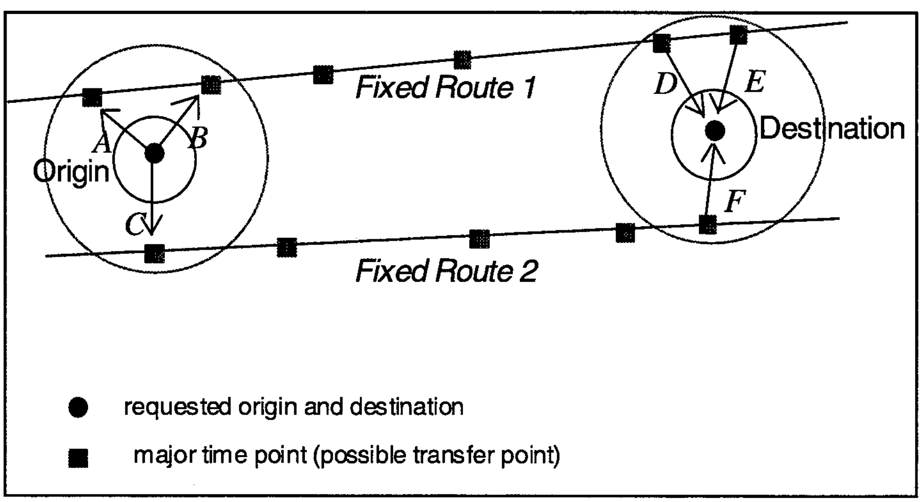

Figure 3. Possible Integrated Transit Itineraries for a Single Request

It is reasonable to expect that circles of different sizes will have different effects on the capabilities and cost-effectiveness of the integrated transit system. For example, large circles will include more fixed routes but may also require longer paratransit trips. At the same time, the more distant an origin and destination, the longer the paratransit trip legs can be without seeming an inefficient connection. Setting circle size at a percentage of the distance between a given origin and destination is one method for taking total travel distance into consideration. This percentage can be set at different levels for a given transit system and a sensitivity analysis performed to determine what radius provides a reasonable screening of itineraries.

After potential transfer points have been identified, common routes that connect the origin and destination must be found. This is accomplished through an explicit matching of fixed routes associated with major time points near both the origin and destination. If the time points near the origin and destination are not connected by a common route, then the trip request is served entirely with paratransit.

With the resulting sub-network of feasible paratransit legs and fixed-route services, feasible itineraries are constructed. Essentially, this involves solving a shortest path problem with time windows (Desrochers and Soumis, 1988) on this sub-network. For this, time windows at the origin, destination, and transfer points are used. Also, the published fixed-route schedule is used to estimate available time windows at transfer points; passengers must be picked up or dropped off within the time windows during which the transit vehicle is expected. Currently, the shortest path is generated by full enumeration (the size of the sub-networks are generally not too large). If the passenger has specified an appointment time at the destination, a backwards pass through the network is performed. If, instead, a departure time from the origin is specified, a forward pass through the network is performed.

For each such itinerary, a passenger's level-of-service measure must be evaluated; a "generalized time" calculates the sum of waiting, travel, and transfer time along each path. The waiting and transfer times can be estimated from the associated time windows; the fixed-route schedules give an estimate of travel times on the fixed-route service; and, a straight-line distance divided by an average vehicle speed is used to estimate in-vehicle travel times for the paratransit trips. It is also possible that different weights can be applied to these different components of travel time (e.g., if transfer time is more onerous than other types of time). In the example, a transfer "penalty" equivalent to 5 minutes of travel time is added. In total, a generalized time or disutility function Z can be described as follows:

$$\text{Minimize } Z = \beta_1 * WT + \beta_2 * IVT + \beta_3 * XT + \beta_4 * NX$$

where Z = generalized time or disutility, WT = total waiting time, IVT = in-vehicle travel time, XT = transfer time, NX = number of transfers, and β_1, β_2, β_3, β_4 = weights (coefficients) on each variable.

The path with the minimum generalized time is then compared to the generalized time of a direct paratransit trip (the baseline). The approach in the case study assumes that the *existing paratransit service* is the "default" or "baseline" service, should it prove infeasible or not cost-effective to serve the trip with the integrated service. In this case, the cost-effectiveness of full paratransit service is compared with the integrated transit trip. [One could just as easily define the default as fixed-route service, in order to examine the cost-effectiveness of paratransit "feeder" service. While not described in this paper, such a technique involves only minor modification of the proposed method.] The passenger trip is accepted if the generalized time (Z) is not more than the maximum allowable trip time. As one might expect, however, varying the maximum allowable trip time may have considerable impact on the likely number of passengers served with the integrated service.

An additional term could be added to the objective (passenger generalized time, Z) to include the disutility, or delay, to passengers on the fixed route service when waiting for, loading and (or) unloading integrated service passengers. Since many of these passengers may require considerable time to load and unload, the effect of this term may also be important. For the ease of analysis, this is not included here, but could easily be added.

3.3 Vehicle Trip Scheduling

In the Houston case study to be described later, it was not necessary to go to the detail of a full vehicle schedule. Rather, the results of the passenger trip scheduling technique were sufficient to evaluate the feasibility and potential advantages of the integrated service scheme. Below, an outline of the approach to completing the vehicle trip scheduling task is given; this is an area of ongoing research.

Once an integrated trip has been accepted, the vehicle trips from the origin to the fixed route and from the fixed route to the destination are added to a traditional paratransit vehicle routing and scheduling problem. There are now a large number of heuristics that can be used for paratransit vehicle routing and scheduling; see, for example, the excellent review by Bodin et al. (1983). However, two more recent techniques are now being investigated for use in this research. The first is a vehicle trip insertion heuristic (Jaw et al., 1986); this method is an updated technique that naturally follows the original work by Wilson et al. (1976). This method essentially assigns an incremental "cost" to each vehicle itinerary to accept a new trip. The algorithm begins by sorting each request according to pickup time or delivery time. Then it finds, for each dial-a-ride vehicle, all the ways in which a new request can be feasibly inserted into a vehicle's schedule. The insertion that minimizes the incremental disutility experienced by the passenger whose request is under consideration, by all other passengers in the system, and by the system as a whole is identified. The vehicle with the lowest such "cost" receives the new passenger trip, as long as vehicle capacity constraints are not violated.

Given the large number of potential trips (over 3500 per day), and the existence of a reasonably good paratransit vehicle schedule, a mini-clustering and column generation technique (Ioachim et al., 1995) is also possible. In this technique, the trips are grouped into clusters. Once so clustered, the algorithm uses a modified shortest path technique to re-optimize the allocation of clusters to individual vans. The initial method of clustering can be done in any number of ways (Bodin et al. 1983). However, the possible re-assignment of these mini-clusters to different vehicle trips is carried out with a modified shortest path technique, which generates a new "column" consisting of a new vehicle trip. The goal in this re-assignment is to minimize the total number of vehicles, the total pieces of work required (i.e., the vehicle trips), and the total travel time.

For the case study, Houston METRO has provided an existing vehicle schedule that was created by their paratransit trip scheduling software. This provided a set of trip requests, locations, and time windows for these trips. It also provided "baseline" vehicle assignments of all the passenger trips.

Rather than re-scheduling all 3500 trips, the existing passenger trips were separated into two groups: those that could use the integrated service and those that could not. The potential integrated service trips may be removed from the existing vehicle schedules. This creates a subset of all passenger trips that are eligible for re-scheduling. Using the technique of Jaw et al. (1986), the re-scheduled trips may be re-inserted into the vehicle trip schedules based on a minimum cost insertion.

In some cases, however, this re-insertion is not desirable because of the ensuing geographic dispersion of vehicle trip segments. Rather, the remaining trips (those not eligible for integrated service) may be left as "clusters" of consecutive passenger trips served by a given vehicle, in the spirit of the "mini-clusters" described by Ioachim et al. (1995). These existing clusters can then be combined with the new integrated trip legs; i.e., there will be new trip "clusters" defined as the union of: (1) the individual integrated service trip "legs" (zero to two per integrated passenger trip); and, (2) the remaining "clusters" of consecutive trips served completely by door-to-door paratransit service. At this point, these mini-clusters can be optimized using the column generation technique of Ioachim et al. (1995).

4. HOUSTON CASE STUDY

4.1 Background

The proposed scheduling heuristic is illustrated using the existing transit service in Houston, Texas. The transit agency in Houston (METRO) operates 94 fixed routes and a demand-responsive service for over 1750 passenger round trips per day, or about 3500 one-way trips per day. Much of the demand-responsive service is oriented to passengers qualifying under the Americans with Disabilities Act (ADA) of 1990, which specifies particular paratransit service requirements for these patrons. In this regard, 53% of METRO's demand-responsive passengers are ambulatory-impaired, and hence are really not eligible for integrated transit service as a result of METRO's own level-of-service requirements. This is because there are still fixed-route stops and vehicles that are not fully equipped for ADA service.

Because of a large service area (1400 sq km), trip lengths for the paratransit service average 13.3 km. Trip lengths over 40 km are not uncommon. With the requirements of the ADA, METRO is experiencing rapid growth in demand for the demand-responsive service, and is considering integrated service. Yet, METRO experiences greater costs for demand-responsive service ($10.28 per passenger trip, or $0.77 per passenger-km) than for fixed-route service ($2.24 per passenger trip, or $0.27 per passenger-km). As a result, there is reason to believe that the substitution of fixed-route service for part of the demand-responsive service may result in cost savings to the agency.

The primary questions to explore included:

- What number and percentage of trips could be served by integrated service?
- What impacts might be expected for passenger level of service, for eligible passengers?
- What potential cost savings might be realized?

For the purposes of this feasibility study, only the proposed passenger scheduling heuristic is applied. The passenger scheduling heuristic gives an initial estimate of the potential number of passengers served, the passenger level of service, and an upper bound on the potential reductions in paratransit vehicle kilometers and hours that might be possible under the integrated service strategy. The cost savings to the agency could be estimated based on the potential reduction in vehicle-km or vehicle-hours traveled. Assuming a constant utilization rate of vehicles, an upper bound on the cost savings is estimated as the total paratransit vehicle distance saved in the passenger itinerary, multiplied by the average paratransit cost per passenger-km. That is, the estimate of the cost savings is equal to the cost per passenger-km, multiplied by the difference in distance of the direct trip versus the sum of the new paratransit "legs."

4.2 Application

This case study explores the possible cost advantages and changes in passenger level of service with integrated service. Using the proposed scheduling method, the integrated service is compared with the existing fully demand-responsive service, using performance measures of the total number and percentage of trips served, the passenger level of service (travel time and transfers), and the potential agency cost savings.

Global parameters and assumptions for this case study included the following:

Eligible passengers. Only those passengers with no ambulatory impairments were considered eligible for an integrated trip. This corresponds to METRO's desire to serve these trips with the highest level of service, giving these passengers additional attention.

Minimum integrated trip length. The passenger's origin and destination must be at least 3 mi (4.8 km) apart in order to be considered for an integrated trip. Shorter trips are likely more easily served simply through a direct paratransit trip. Longer minimums may also be considered; this is an area for further sensitivity analysis. The 3 mi restriction eliminates another 6% of the trips from consideration, with slightly under half of the trips (about 1700 of 3500) being eligible on the basis of having an ambulatory passenger with a sufficient trip length.

Average paratransit vehicle speed. This was set based on the distance between the passenger's origin and destination, and the value does not include intermediate stops. Distance-based values were provided by Houston METRO and ranged from 24 km/h for trips under 2 mi (3.2 km) to 66 km/h for trip lengths exceeding 20 mi (32 km).

Origin and destination time windows. 15-minute time windows were used for the pick-up at the origin and the drop-off at the passenger's destination.

Maximum waiting time at a fixed-route stop. Ideally, the paratransit vehicle would arrive at the transfer point at the same time as the fixed-route bus. However, to allow some flexibility in scheduling, a maximum waiting time for the paratransit passenger was set to five minutes. In other words, when dropping off a passenger, a paratransit vehicle could arrive to a fixed-route time point up to five minutes before the scheduled arrival of the fixed-route vehicle. Also, when picking up a passenger, a paratransit vehicle could arrive up to five minutes after the scheduled arrival time of the fixed-route vehicle.

Maximum ride time. METROLift limits the amount of time that a rider spends on a vehicle to values that vary with the distance between the origin and destination. These values range from 30 minutes to 120 minutes for trips up to and exceeding 48 km.

Radius of proximity circles about origin and destination. A preliminary value of 30 percent of the distance between the origin and destination was selected. This was used to identify potential transfer points to the fixed-route system. Also, a minimum radius of 0.25 miles (0.4 km) was specified as the minimum distance eligible for a paratransit trip. Increasing this value would have the effect of reducing the number of integrated trips. Finally, for a direct connection to a fixed-route bus stop, a maximum walking distance of 0.1 mi (160 m) was used to restrict eligible fixed-route stops.

Penalty factors. It was also assumed that a penalty of 5 minutes of travel time would be applied for each transfer. With two transfers, a total of 10 minutes is added.

4.3 Example

Consider the following example trip for scheduling under the passenger itinerary heuristic. A fully ambulatory customer wishes to travel from their origin (home) to their destination (a doctor's office), a total (Euclidean) distance of 14.2 km. The passenger requests to leave home at 8:20 a.m., with 15-minute time windows on either side.

To begin, an initial screening of potential fixed-route stops indicated that none were within 0.1 miles (0.16 km) of the origin or destination. Second, "rings" around the origin and destination were generated from a radius of 0.4 km to 30% of the total O-D distance (4.25 km). From these rings, there were 6 timepoints near the origin and 365 timepoints near the destination (the destination is in a dense downtown area). These points have 5 routes in common.

With the current METRO operating parameters, the 14.2 km trip has a maximum allowable ride time of 59 minutes. Because a pick-up time is specified, the shortest path with time windows is determined using a forward pass in the network, from the origin to the destination. For this trip, the shortest travel time on the integrated service is 32 minutes (excluding the transfer penalties), comprised of two paratransit legs and a fixed-route leg:

- 3 min paratransit trip from the origin to a local transit center 0.6 miles away, traveling at an average of 15 mph (1.0 km at 24 km/h);
- 5 min total waiting time (one-half of the 5-minute time window at each fixed-route stop);
- 20 min on the fixed-route bus; and,
- 4 min paratransit trip from the second stop to the destination 0.8 miles away, averaging 15 mph (1.3 km at 24 km/h).

The pick-up at the origin is scheduled for 8:08 a.m. with a fixed-route segment from 8:13 to 8:33. The final drop-off at the destination is scheduled for 8:40. Finally, for the level-of-service comparison, an additional 10 minutes is added as a transfer penalty (2 transfers at 5 min/transfer) to obtain a total time of 42 min. Note that this assumes that the demand-responsive legs of the integrated trip provide direct service from the origin to the fixed route, and from the fixed route to the destination. In this sense, the values from the passenger trip scheduling algorithm are lower bounds on the actual travel time once vehicle trips are scheduled.

As for the passenger level of service, the integrated trip described above can be compared with the "baseline" paratransit schedule. Interestingly, in this case, the scheduling software at METRO scheduled this passenger's trip for 43 minutes, which is longer than the direct trip on the integrated service. This occurs because the paratransit van also had an additional, intermediate stop between the passenger's origin and destination. As a result, even with the 10 minute transfer penalty, this particular integrated trip (if served directly) provides the passenger with a slightly better level of service. From the operator's viewpoint, the trip is also beneficial, in that the total paratransit trip distance has been cut from 14.2 km (direct) to 2.3 km (for two legs), or a savings of 11.9 km.

4.4 Full Results

As a case study, the passenger scheduling heuristic was applied to a representative day of service at Houston METRO. The input to the heuristic was the existing schedule of trips, as output from the METROLift scheduling software. On the given day, a total of 3588 one-way passenger trips were taken on METROLift. Of those trips, 924, or about 26%, could be accommodated using the integrated service. This was a much higher percentage than originally anticipated. Of the trips that were not covered, 1925 (53%) were not covered due to passenger disability (e.g., a wheelchair prohibited the trip), 217 trips were too short for our heuristic (under 4.8 km or 3 mi total length), 312 trips could not be served by a single fixed route, and 211 could not meet the maximum travel time constraint. It is interesting that the trip length and total travel time constraints, while important, had a more modest effect in reducing the number of trips served.

As for the overall passenger level of service, 39% of the trips on the integrated service actually provided a *shorter* travel time than that produced by METRO's scheduling software. Yet, 61% will be slightly worse off. This comparison includes a 10-minute total transfer penalty (5 minutes per each transfer). Graphically, this result is illustrated in Figure 4, using a histogram of the time savings comparing the integrated trip versus the existing scheduled trip. The skew of this histogram to the left indicates that there are a number of passengers who would realize slight increases in travel time with the integrated service. However, the long tail to the right indicates that many passengers would realize substantial savings. The effect of this long tail is evidenced in the mean of the distribution, which is -3 minutes (i.e., an average 3-min disadvantage for the integrated trip versus the existing schedule).

Time savings appears to be more substantial for shorter trips where ride sharing occurs. In these cases, the integrated trip results in a less circuitous trip, and the passenger experiences a net time savings. Longer trips, on the other hand, are less likely to have time advantages for the integrated trip. With an extensive freeway network, the assumed demand-responsive vehicle speeds are much higher than the fixed-route service for these long trips.

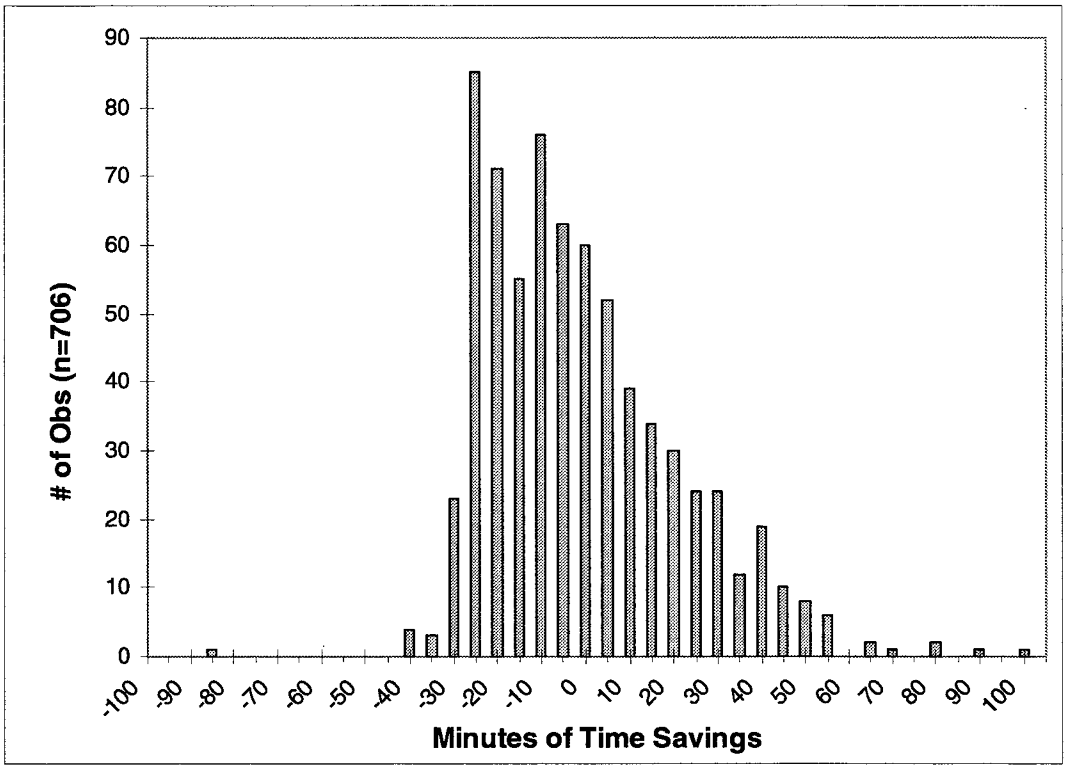

Figure 4: Histogram of Travel Time Difference, Existing – Integrated Service

The potential cost advantages for METRO are stated in terms of the potential reduction in passenger-km of travel. When compared with the Euclidean distance, the integrated service reduces the total passenger-km of travel by 7380 km (4584 mi). This amounts to approximately 15% of the total passenger-km of travel at METROLift. At an average cost of $0.77 per passenger-km, the total cost savings has an upper bound of approximately $5682. This equates to about 15% of the daily operating cost of $36,000 at METROLift.

At the same time, one notes that this over-states the potential cost savings, since vehicle costs are likely to be highly non-linear with the costs per passenger-km. That is to say, the percentage reduction in passenger-km, particularly for trips where rides are shared, likely overstates the proportional reduction in vehicle-km. It is necessary to input the new integrated service trip legs through the vehicle scheduling heuristic to get a more accurate estimate of the vehicle operating cost savings.

4.5 Sensitivity Analysis

A sensitivity analysis to various assumed parameters in the passenger scheduling heuristic is appropriate. First, one might examine the effect of restricting the integrated service to persons that are ambulatory. As noted before, about 53% of the total passenger trips in the METRO case study involve ambulatory-impaired passengers. To examine this restriction, the passenger scheduling heuristic was also run with all 3588 trips. Fixed-route boarding and alighting times for the ambulatory-impaired passengers were set to 3 min each (Kittelson and Associates, 1999). The results are presented in Table 2.

Measure	All Trips	Ambulatory Trips
Trips accommodated with integrated service	1805	924
Total trips	3588	1664
Avg paratransit (Euclidean) distance per trip (mi)	3.41	3.37
Avg (Euclidean) O-D distance per trip (mi)	8.40	8.34
Avg time difference, Original - integrated service (min)	-4.5	-2.7
Percent of trips, Original time > integrated time	35.5%	39.2%

Table 2: Sensitivity Analysis on Allowable Passenger Trips

Of the 3588 trips, 1805 (50.3%) could be accommodated using the integrated transit service. This is just slightly lower than for ambulatory passengers, with 924 (55.5%) of 1664 total trips accommodated. The average trip length, and length of the paratransit trip legs, are comparable. Between the two trip categories, there is a slight difference in the travel time when comparing the original demand-responsive service with the integrated service. This is reflected in the greater time savings with ambulatory trips (average -2.7 min savings versus -4.5 min for all trips) and a larger percentage of trips that are better off with integrated service with ambulatory trips (39.2% versus 35.5%). In summary, while the set of available passengers may change dramatically, the net passenger level-of-service is not noticeably different. The operator cost savings, while likely to be proportional to the number of potential trips served, is somewhat uncertain without a more detailed vehicle schedule.

Secondly, from Table 3, it appears that the number of trips with the integrated service is very sensitive to the assumed radius of the proximity circles for fixed-route bus stops about the origin and the destination. As the radius increases from 10% to 50% of the Euclidean distance from the origin to the destination, the number of trips accommodated grows markedly from only 63 (3.7%) with a radius of 10% to 1415 (85.0%) with a radius of 50%. As might be expected, the length of the paratransit trip legs increases with the radius, while the average O-D distance drops as the radius increases. Curiously, the percentage of trips that do better with the integrated service (versus the original service) increases with the value of the radius. This occurs because the operating speed of the demand-responsive service is much higher than that for the fixed-route service at longer distances. This implies that higher values of the radius will likely lead to more passengers being accommodated, and to greater average time savings for those passengers, assuming they receive a direct trip. However, the effect on the agency operating cost is uncertain; the large number of trips and the considerable length of paratransit trips raise questions about the net effect on operating costs.

	Value of Radius				
Measure	10%	20%	30%	40%	50%
Trips accommodated	63	424	924	1284	1415
Total trips	1664	1664	1664	1664	1664
Avg paratransit (Euclidean) distance per trip (mi)	1.43	2.23	3.37	4.58	5.83
Avg (Euclidean) O-D distance per trip (mi)	9.73	8.49	8.34	8.22	8.13
Avg time difference, Original - integrated service (min)	-0.6	-3.6	-2.7	-0.7	+3.0
Percent of trips, Original time > integrated time	38.2%	37.4%	39.2%	43.0%	49.4%

Table 3: Sensitivity Analysis on Radius of Proximity Circles

Table 4 presents the results of a sensitivity analysis of the minimum allowable trip length, using a range from 1 mi (1.6 km) to 7 mi (11.3 km). Interestingly, the total trips accommodated do not vary substantially as the minimum trip length increases, particularly up to a minimum trip length of 4 mi (6.4 km). The number of trips then drops off more precipitously for a minimum trip length of 5 to 7 mi. As might be expected, the total trip length and the average length of the paratransit trip legs also increase as the minimum trip length increases. Note also that the passenger level of service, as measured by travel time savings versus the original trip time, increases as the minimum trip length increases. This is caused by the combination of longer trips more generally, with corresponding higher speeds, as well as higher speeds for paratransit service versus fixed-route service. Overall, there appears to be slightly better passenger level of service, but for fewer passengers, as the minimum trip length increases. Again, the effect on agency costs is indeterminate from this analysis.

Measure	Minimum Trip Distance (mi)						
	1	2	3	4	5	6	7
Trips accommodated	940	933	924	851	781	681	602
Total trips	1664	1664	1664	1664	1664	1664	1664
Avg paratransit (Euclidean) distance per trip (mi)	3.33	3.35	3.37	3.54	3.69	3.89	4.05
Avg (Euclidean) O-D distance per trip (mi)	8.23	8.28	8.34	8.74	9.12	9.65	10.07
Avg time difference (min), Original - integrated service	-2.9	-2.9	-2.7	-1.4	-0.3	+2.2	+3.5
Percent of trips, Original time > integrated time	38.8%	38.8%	39.2%	41.8%	44.4%	49.5%	53.1%

Table 4: Sensitivity Analysis on Minimum Trip Distance

Lastly, from Table 5, the percentage of trips with improved service drops rather sharply as the assumed transfer penalty increases. With a higher penalty, the percentage of trips that are accommodated drops rapidly. A 10-min penalty per transfer (20 min total) reduces the number of possible trips accommodated to 597 of 1664 (35.8%), and a 15-min penalty reduces this to only 177 trips (10.6%). Most of the other results are clearly mixed, due to the dramatic change in the number of trips that are accommodated under the different transfer penalties. It is curious, nonetheless, that the percentage of trips that are better off with integrated service (versus the original baseline) does not drop off. Rather, the longer trips that remain with the 15-min transfer penalty (assumed to be served directly) still have advantages over the original trips with intermediate stops. Clearly, the potential number of trips and passenger level-of-service are very sensitive to the assumed transfer penalty.

Measure	Transfer penalty (min per transfer) 0	5	10	15
Trips accommodated	1045	924	597	177
Total trips	1664	1664	1664	1664
Avg paratransit (Euclidean) distance per trip (mi)	3.48	3.37	3.35	3.64
Avg (Euclidean) O-D distance per trip (mi)	8.42	8.34	8.79	10.88
Avg time difference (min), Original - integrated service	+4.7	-2.7	-5.6	-2.9
Percent of trips, Original time > integrated time	52.8%	39.2%	36.0%	40.9%

Table 5: Sensitivity Analysis on Transfer Penalty

5. CONCLUSIONS

This report has described and illustrated a method for scheduling passenger and vehicle trips in an integrated transit service. It is suggested that the proposed two-stage heuristic for scheduling these trips allows more direct consideration of both passenger level-of-service characteristics and transit agency operating costs. Further sensitivity analysis is warranted on the proposed method. It appears that the potential cost savings and passenger level of service are sensitive to the parameters of (1) standards of passenger eligibility for the service; (2) the minimum and maximum passenger trip lengths for paratransit trip "legs"; and, (3) the assumed penalty for passenger transfers. Also, a full implementation with a vehicle scheduling heuristic is also warranted to obtain more detailed estimates of vehicle costs.

From the Houston case study, the number of eligible trips where fixed-route substitution is possible appears to be substantial. About 26% of the trips served by the existing demand-responsive service are eligible for the integrated service, upon consideration of the passenger disability, minimum trip lengths, maximum travel times, and the need for a single fixed route. Interestingly, a substantial minority (39%) of passengers will achieve travel time savings with the integrated service, when compared with the existing service. However, this result is heavily dependent on the assumed penalty to passengers for making transfers to and from the fixed-route service. Finally, preliminary indications are that the cost savings for integrated service can be bounded at about 15% of the total operating cost. However, the actual cost savings are likely to be lower.

Obviously, the next step in this evaluation is to compare these reductions in costs against the potential for degradation of the passenger level of service. Interestingly, some passengers will be made better off with the integrated service, because the existing baseline service has circuitous vehicle trips. However, the majority of passengers experience some degradation in the level of service, with longer total travel time (although still within stated maximum travel times). These increases in passenger travel times must then be balanced against the potential cost savings.

The analysis in this report is clearly limited by the fact that it focuses on the passenger scheduling task. This task is useful and important in generating some preliminary figures about the cost and level-of-service of integrating service. Nonetheless, a full analysis using a vehicle scheduling heuristic is required to obtain more definitive cost implications for the operator.

Of course, cost and passenger travel time are not the only factors one might consider in deciding to implement such an integrated service, but the proposed method does allow evaluation of the cost and level-of-service implications. At the same time, potential increases in travel times, the effects of the requirement to transfer, and the resulting comfort and safety of passengers, must also be considered before such an integrated service is offered (Balog et al., 1996 and 1997). Also, the degradation of fixed-route service caused by waiting for, loading and unloading these transferring passengers also deserves further study.

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APPENDIX

The following text briefly describes existing software for integrated paratransit and fixed-route service scheduling.

Advanced Transit Solutions

SCHEDULE PRO was developed by Easy Lift, a paratransit agency in Santa Barbara, California. It was reviewed in *Community Transportation Reporter* in December of 1997. The program is based in Microsoft Access, can be installed on PCs, and offers automated and manual trip-request features. Routes and schedules are determined from travel times, not travel distances, and the package is most appropriate for small- to medium-size transit agencies. There is currently no method for incorporating AVL technologies.

Automated Business Solutions

Automated Business Solutions, Inc., developed the Paratransit Management and Scheduling (PtMS) package to schedule paratransit trips, organize customer information, and generate reports. The Fully Automated Scheduler (FAS) can calculate a schedule for up to 1000 trips and 30 vehicles in less than five minutes. The Automated Trip Request System (ATRIP) allows outside agencies to request transit trips by fax or modem so that they can be directly imported into the PtMS system. A demonstration of PtMS is available through the company's web site.

Caliper

Caliper developed a customer information system based on their TransCAD GIS platform that can generate routes based on customer preferences and real-time transit data. These routes result from the use of clustering algorithms and "innovative" shortest-path scheduling heuristics. TransCAD itself is capable of a variety of transportation planning, network analysis, and routing functions. The latest version incorporates time windows and can handle mixed fleet routing and scheduling.

Cobb Community Transit

Cobb Community Transit of Cobb County, Georgia, provides feeder service using scheduling software developed in-house.

COMSIS

COMSIS has developed the COMSIS Routing and Scheduling System (CRSS) for paratransit scheduling. Schedules are optimized based on a highway network model rather than straight-line distances between stops. Subscription trips or same-day trips can be accommodated.

GIRO

HASTUS, by GIRO, is used internationally to schedule transit vehicles and crews for a variety of agency sizes and types. HASTUS makes use of interactive optimization algorithms and can be integrated with geographic databases and other software modules, such as customer information and operational analyses. GIRO's research on optimization and computerization has been done in collaboration with the University of Montreal's Center for Research on Transportation. The program is not specifically marketed for integrated services.

ACCES is designed specifically for paratransit operations and can be integrated with taxi operations, but it is not marketed for feeder services. ACCES optimizes schedules to maximize productivity, generates reports, and interacts with customer information and geographic databases. For same-day service, customer trip times can be confirmed while the customer is still on the phone, and off-line scheduling allows reoptimization as new trips are added or trips already scheduled are canceled or changed.

Intellitran

Intellitran's Mobility Master provides real-time and batch scheduling capabilities for paratransit services using historical travel time information in a Windows environment. The package can be integrated with GIS databases and client information databases to verify ADA eligibility, generate reports, and provide automated billing. The Mobility Master also supports two-way mobile data communications for quick re-routing and data collection. Using the Mobility Master with fixed-route monitoring would make the coordination of integrated transit services possible, but no agency is currently doing so.

The CTPS package is an older, DOS-based paratransit scheduling software package that is still used by some agencies. Intellitran has upgraded it and incorporated it into the Mobility Master.

IRD Teleride

TelerideSage was acquired by International Road Dynamics, Inc., (IRD) in October of 1996, and its transit software line was merged with IRD's TransView system to create the IRD Teleride division. IRD Teleride now provides integrated software and technologies for transit vehicle scheduling and dispatching, using real-time information and mobile communications. One component of IRD Teleride's Automated Dispatch System is its TeleDriver system, which automates the managing of transit vehicle operations.

Mobisoft

The MobiRouter scheduling package, by Mobisoft OY of Finland, was developed and used at the Finnish test site in the SAMPO project. MobiRouter is "a travel combining and dispatching system for [demand-responsive transit service]. . . . MobiRouter also supports regular traffic lines so that the orders can be first directed to existing traffic lines."

Multisystems

With MIDAS-PT and MIDAS-CIS, it is possible to schedule both fixed-route and paratransit services and provide same-day service as well as advanced reservation trips. Cancellations and last-minute add-ons can be incorporated, and customers can receive confirmed trip times when they first call to request a trip. Geographic databases are available for all modes through Caliper's TransCAD platform, and customer information for both fixed-route and paratransit services is integrated into the MIDAS packages. Scheduling solutions are based on user-defined objective functions and are calculated with interactive and/or batch scheduling algorithms. Mobile data terminals and AVL can also be incorporated. When MIDAS-PT and MIDAS-CIS are installed together, feeder service can be scheduled in conjunction with route planning utilities.

RouteLogic

RouteLogic offers three products: ParaRoute, ParaLogic, and RouteMap.

- ParaRoute is a package that specifically allows paratransit operations to be integrated with fixed-route operations using real-time order-taking, scheduling, and dispatching. It requires MapInfo, which can be purchased through RouteLogic, and works with GIS data.
- ParaLogic is the basic paratransit scheduling package for same-day service and subscription trips. Passengers can get pickup and dropoff times when they call, and scheduled trips can be locked to prevent subsequent trip additions from affecting them.
- RouteMap is for fixed-route customer service and operational information.

Schedule Masters

Schedule Masters is currently developing paratransit software to complement existing fixed-route scheduling software. The existing software is capable of optimizing routes and making use of timepoint data geocoded in MapInfo for Windows.

Trapeze

Trapeze-QV is an older package that has been used by a number of transit agencies for scheduling operations. With the Travel Planning System route finder module and the AVI module, Trapeze-CI is capable of integrating feeder and fixed-route services. The Windows version of the software is in development at this time. Trapeze-PASS uses real-time information in managing paratransit route and schedule changes for same-day or advanced trip requests. Schedules can be created through on-line or off-line processes. Solutions can be reoptimized interactively as cancellations occur or new requests are added to the system. PASS also manages customer service features, analyzes service policies, and works with two-way mobile communications technologies.