Maturity of Key Technologies Provides More Options for Transit and Paratransit Planners

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Travel needs and patterns within metropolitan regions are becoming increasingly more complex. Community pressure to use limited operations budgets in the most effective and efficient manner is also increasing, even though these requirements often conflict. Ideally, in response, service planners should be able to explore a wide range of service design options, unencumbered by technological constraints. A service planning concept based on a spectrum of possible service designs ranging from pure fixed route to pure demand responsive, with many intermediate options, is described. Intelligent transportation system technologies and scheduling software have matured to the point that this concept is now realistic. How these technologies enable a highly integrated system in which numerous service designs can be operated simultaneously is explained. Likely benefits are presented from several perspectives: planning latitude given by time of day, by change of season, and for efficient vehicle use and adaptation to changes in service area character over the years. Some requirements for reorganization by typical transit agencies are discussed. Potential benefits from better coordination or the merger with outside agencies are outlined. Vendors have been cautious to date and are unlikely to complete the technological integration needed without firm commitments. Thus, a funded research project at an appropriate volunteer site would be required.

Historically, in all but the largest cities, transit planners typically committed to service plans that used large buses on fixed routes over large sections of an agency's service area. These buses operated with constant headways for the entire day and might have been supplemented by extra runs during peak commuting hours and student travel periods. Planners often coordinated routes in a timed-transfer network design in which vehicles met at regular intervals to facilitate transfers and thereby increased the number of origin–destination pairs that could be served. In parallel, a purely demand-responsive service typically accommodated people unable to use the fixed routes and served areas of exceptionally low demand. The real-time management and oversight of these two networks were separate, as was all data analysis for planning future operations.

Planners also recognized the shortcomings of this approach. Crowding could be excessive at peak times, and excess capacity would be large during other periods. With labor as the dominant cost of most bus operations, any operating cost savings from adjusting vehicle sizes were often seen as minimal unless the total number of service hours was significantly reduced. Furthermore, many parts of the overall service area would have excessive walking distances to the nearest fixed stop. At the same time, demand-responsive vehicles would pass through these areas but were not allowed to serve the general population.

The ineffectiveness (poor area coverage) and inefficiency (poor use of space) of such simple service plans have been accepted because, from the operating agency's perspective, cost and complexity are associated with managing too many different schedules, service designs, and vehicle types. Buttressing this defense of the status quo, passengers must keep abreast of schedules and service designs that change more frequently.

NEED FOR MORE OPTIONS

Travel needs and patterns within metropolitan regions are becoming increasingly more complex. Dispersal of employment locations, mismatches of housing and employment opportunities, chronic congestion, security concerns, an aging population, and other challenges call for more complex transit operations to meet a wider variety of needs. Although traditional service operations still work and need only relatively minor enhancements in large, high-density cities, the latent demand for transit service in small cities and modern auto-oriented suburbs is huge. At the same time, communities are pressured to use limited operations budgets in the most effective and efficient manner to meet these often-conflicting requirements.

Developing service solutions often entails providing service to those who are at once among the most in need and among the most expensive to serve (e.g., the reverse commuter who has an evening shift in a suburb far from home in the central city)—hence the conflict. In contrast, the most efficient service may be least expensive to serve but also the least socially urgent (e.g., the radial commuter to the central business district, where employees likely earn higher-than-average incomes and are well able to drive).

Because of cost, service historically has been planned with limited information that was collected and analyzed infrequently. It also was done with a keen eye to the limitations of scheduling software and the complexity of services that dispatchers could manage. Balancing conflicting requirements calls for the exploration of more complex transit service options than have been used in the past. Ideally, service planners should be given maximum latitude for such explorations, unencumbered by technological constraints. In other words, the tail (technology) should not be wagging the dog (service design).

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POTENTIAL SERVICE DESIGNS

Table 1 lists service designs, from pure fixed route to pure demand responsive. The pure forms are still the most ubiquitous, but all have been tried successfully; none are merely hypothetical concepts. The defining attributes for each service design type are given, along with a likely range of appropriate vehicle sizes. Some, of course, are much more common than others.

Koffman provides an overview of different types of flexible service designs in use in North America (*1*), where the term "flexible" describes the designs between the pure demand-responsive and pure fixed-route forms. The flexible-service route (listed in Table 1) was developed in Sweden and probably is unfamiliar to many readers. It involves fixed end points with numerous optional stops between; Westerlund has described it in detail (*2*). Westerlund et al. summarize research on the optimal domain of flexible-service routes versus fixed-service routes (*3*). Bihn systematically describes examples of various differentiated services operated in Germany (*4*). The European Union–sponsored Knowledge Portal provides links to research findings and descriptions of various innovative service designs (*5*).

Unfortunately, industrywide consensus on the names of service designs does not yet exist. In this paper, no effort is made to match the terminology of U.S. or European authors or institutions, nor does space permit a detailed discussion of the subtleties of variations in concepts. Rather, a highly integrated service planning concept based on the existence of a spectrum of possible service designs is described. The information presented in Table 1 is not purported to be definitive or complete.

MATURITY OF REQUIRED ELEMENTS

The service planner should optimally be able to choose from a list of individual service designs and integrate them into a cohesive overall plan, unencumbered by software or hardware restrictions. Furthermore, it should be possible to oversee and manage them all from one control center. Possibilities to consider include using different service designs at different times of day, overlaying more than one design in the same area for all or parts of the day, and making capacity adjustments according to demand. The keys to enabling these possibilities are intelligent transportation system (ITS) technologies and scheduling software.

ITS Technologies

Starting in the early 1990s, pilot ITS projects received help from the U.S. Federal Transit Administration (FTA) in the form of ITS operational test grants. At the same time, several aerospace companies entered the transit market with ITS products in a bid for defense conversion. On the European front, the European Union (EU) sponsored Systems for Advanced Management of Public Transport Operations (SAMPO) from 1996 to 1997 and the Systems for the Advanced Management of Public Transport Operations (SAMPLUS) project from 1998 to 1999. These programs were not designed to fund ITS testing, per se, but innovative service concepts. Although many positive results were achieved, some projects failed to yield the expected benefits. However, taken in a long-term context, both the U.S. FTA grant program and its EU parallel must be viewed as successes because they financed projects that would have been too risky or too expensive to spread over a few pilot vehicles.

Unlike the for-profit sector, in which technological experimentation is proprietary, most of the transit sector in developed nations is in the public sector, and service planners speak freely among themselves. Through this process, ITS and software vendors refined their products and agencies learned more effective models of technology procurement. One important lesson that many agencies learned was to limit special requirements to those genuinely needed, allowing vendors to refine products rather than develop highly customized products for each agency. Another lesson learned by many agencies

TABLE 1 Spectrum of Service Designs

Service Type	Distinguishing Features	Usable Vehicle Types
Pure fixed route	Totally deterministic operations according to schedule.	Rail vehicles Articulated buses 12-m long buses Midibuses Small buses
Fixed-service route	Totally deterministic, but may leave arterials to enter access roads including driveways of institutions—emphasis on access instead of speed.	Midibuses Small buses
On-request fixed route	Deterministic operation, but only initiates if at least one person makes request before scheduled departure time.	Small buses Vans
Route deviation service	Mostly deterministic, but slack is added to schedule to allow moderate deviations upon request.	Midibuses Small buses
Quasi-routing	Partially deterministic with skeleton of a route based on locations and frequency of trips by subscription riders.	Midibuses Small buses
Flexible service route	One or two fixed endpoints with numerous optional stops. Route entirely determined by requests. Confined areas may overlap.	Small buses
Checkpoint	Confined to a limited area, but random movement within except for scheduled transfer times.	Small buses Vans Taxis
Zone	Confined to a limited area, but random movement within this area. Confined areas may overlap.	Small buses Vans Taxis
Pure demand-responsive	Totally random movement anywhere within entire operating area.	Small buses Vans Taxis

was to use turnkey approaches in which a prime contractor was responsible for system integration, thereby relieving agency staff of coordinating between vendors and settling vendor disputes over responsibility. Communications standards and regional ITS architectures also have evolved to simplify specification and improve interoperability with other ITS, both within and without the agency.

As a result of this evolution, ITS for transit applications is now mature in many respects. Numerous computer-aided dispatching–automatic vehicle location (CAD-AVL) installations are operating reliably across North America. Automatic passenger counters (APCs) also have proven performance and reliability, even in harsh environments. Real-time passenger information (RTPI) is used widely, in the form of annunciators that are compliant with the Americans with Disabilities Act (ADA) aboard buses and railcars and increasingly available at major stops, on the Internet, and on personal digital assistants (PDAs). Interactive voice recognition (IVR) is cutting wait times to make requests for demand-responsive service and to seek route itinerary and schedule information by telephone. Additional features (e.g., covert alarms, surveillance equipment, and vital sign monitoring sensors on vehicle subsystems) continually upgrade transit safety and reliability.

Scheduling Software

Scheduling software used by the transit industry also has matured. It traditionally has been of two basic types: fixed route and demand responsive. All medium-to-large transit agencies (and most moderately sized agencies) in industrialized nations use such software. The precise capabilities and features of scheduling software (including the call-taking and reservation functions for demand-responsive services) are important to service planning. The final service design must be statable in a format that the software can accommodate

Lave et al. suggest that a demand-responsive fleet of more than 30 vehicles should use software to assist in taking requests and assigning passenger requests to particular runs (*6*). The minimum fleet size to justify such software may be larger for fixed-route applications. It is easier to schedule deterministic services for smaller fleets because they recur in a cyclic fashion and because a few vehicles at most are assigned to any one route. However, as fleet size increases, the possibilities multiply, and manual scheduling cannot possibly be as efficient as an advanced algorithm that can study interlining, operator fallback to another vehicle during rest periods, reassignment of vehicles between depots, and other complications. Efficiency gains become too important to ignore because even small percentage gains can represent large absolute savings.

Scheduling software is intimately tied to geographic information system (GIS) maps, which provide coordinates for street locations within the service area and store information about travel times by time of day along route segments (fixed route) and travel speeds along arterials (demand responsive). These data are important inputs into the mathematical optimization algorithms that then create vehicle and crew schedules subject to certain constraints about operator break times, recovery time for delay, road use restrictions, and so on.

Scheduling software is also intimately tied to CAD-AVL systems. AVL time and location readings for each vehicle are compared with the scheduled times to determine schedule adherence. Algorithms also make predictions about future estimated arrival times. These current adherence and future arrival estimates, in turn, form the basis for CAD displays used by dispatchers for real-time control, inform vehicle operators via mobile data terminals (MDTs), and provide RTPI to the public.

Because all time and information can be archived by a CAD-AVL system, the actual operating results also can be statistically summarized to assist in the identification of patterns and causes of delays on particular fixed routes. At least one stand-alone package developed as part of a university research project is available for studying and refining schedules on an individual route (*7*). These data sets also can be fed back into postprocessing modules available with major fixed-route scheduling packages. These modules can perform what-if scenarios to generate tentative new schedules for an entire network by using optimization algorithms within the scheduling software. Statistical indicators that both single-route and network analysis tools might use include the 85th percentile of run times between time points and from end to end, values commonly used in the Netherlands (*8*).

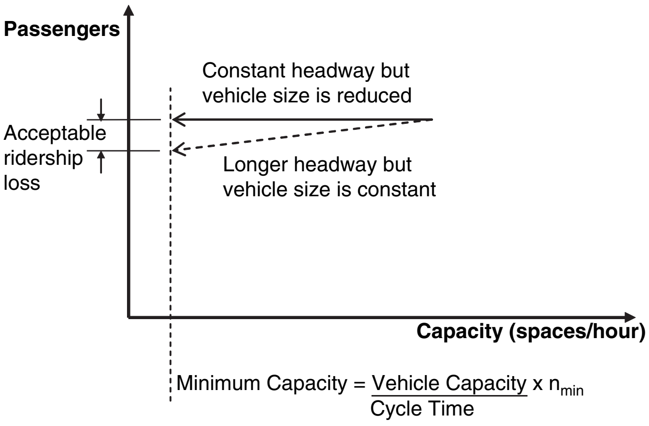
To the extent possible, statistical indicators should be extracted and loaded for an entire network. The larger the number of vehicles and routes included and the fewer the restraints that are set, the greater the opportunity for efficiency gains from the optimization algorithms. Examples of restrictions that can readily be lifted include the following:

- Only a certain bus size can operate on a given route,
- Only certain depot(s) can store a certain bus size, and
- Certain vehicles must stay on the same route or service type for the entire daily work block.

Transit signal priority (TSP) is closely tied to schedule refinement as well, because it affects both average operating speed and reliability of travel times. Thus, TSP can be designed or refined at the same time. Muller and Furth report more details (*8*).

Passenger count data also can be archived. Passenger count data should be postprocessed to identify where crowding exceeds acceptable standards and, conversely, where space (capacity) is excessive. Using postprocessing modules, statistical descriptors of passenger demand (e.g., average value and average plus 1 standard deviation at a particular stop over a certain part of the day) can be used in what-if scenarios to generate tentative new schedules that better allocate capacity to demand.

The optimization algorithm can consider two alternative possibilities for any particular fixed route: the headway is kept constant and a different sized vehicle is used, or the headway is changed on a route and vehicle size is kept constant. In Figure 1, the top curve indicates



$$\text{Minimum Capacity} = \frac{\text{Vehicle Capacity}}{\text{Cycle Time}} \times n_{\min}$$

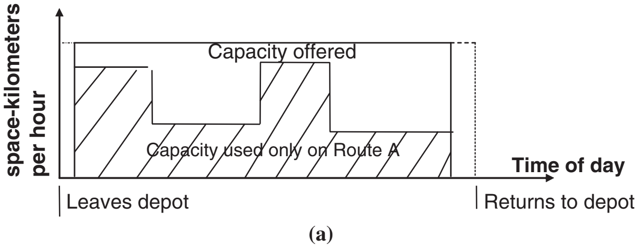
FIGURE 1 Setting a minimum fleet size for a route if headway is lengthened rather than vehicle size reduced.

that passengers should not decrease if only vehicle size is decreased to better match supply with demand. With the second possibility, demand is affected adversely by an increase in headway that might come with a decrease in fleet size. The passenger loss is shown by the bottom curve and can be estimated by using a headway elasticity of demand. The acceptable loss from using the same-sized vehicle but increasing headway thus can be introduced with a mathematical constraint for each vehicle size that says that the fleet cannot be less than $n_{\min}$ on a particular route. This number can change with the time of day, if desired.

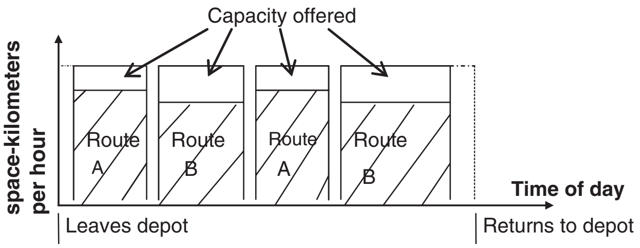
However, the situation is not this simple. If a different-sized vehicle is shifted to better match supply with demand, then deadhead movements between routes may introduce offsetting losses. Figure 2*b* shows poor use of space during two parts of the day, but deadhead losses occur only during the trip from the depot to the route at the beginning of the day and the trip back from the depot at the end of the day. Figure 2*a* shows much better use of space when swapping between Routes A and B but introduces deadhead movements midday as well. The optimization algorithm would look at multiple routes simultaneously. It would both reallocate vehicles to high-demand routes and swap different-sized vehicles between routes. It could take into account the trade-offs between possible ridership losses from headway increases and productivity losses from deadhead movements.

Hybrid services need hybrid software, with elements of both fixed-route and demand-responsive scheduling. Such scheduling software has been developed and is readily obtainable. Bruun and Marx discuss the software features for an operational ITS-assisted route-deviation service (*9*); Westerlund discusses software features to support an operational flexible-service route (*2*).

Hybrid services having mostly but not purely a fixed-route component (e.g., route-deviation services) can be included in the what-if scenarios of the fixed-route network, but doing so may require some ingenuity. Route deviation modeling might require that only a limited number of time point stops be included, because intermediate stops are supposed to have some latitude for arrival times. Other service types with a mostly demand-responsive component (e.g., flexible-service route or checkpoint service) probably could be included in the fixed-route network optimization, to the extent that they form timed-transfer constraints within the network. Thus, two parallel optimizations likely would be needed: one for service types that have mostly a fixed-route component and another for those that have a more significant demand-responsive element. The networks would be physically connected at timed-transfer points.



(a)



(b)

FIGURE 2 Increase in space-averaged load factor with route swapping: (*a*) vehicle swaps between Routes A and B and (*b*) vehicle stays on Route A.

Services with a significant demand-responsive element also can be optimized on a network basis, although not with the same mathematical algorithms as for fixed routes. The two networks need not be entirely separate, because they can be interconnected by timed-transfer points, as shown in Figure 3.

Analysis of demand-responsive service requires more attention to the individual passenger. Plotting rider addresses on a GIS map using various search criteria (e.g., frequency of similar requests, time of day, popular destinations, incidences of pickup or drop-off outside of promised windows, and so on) also lends insight. The analyst might identify quasi routes based on subscription riders and logical zone boundaries for zone service or checkpoint service. Furthermore, an analyst might determine needed changes to software parameters and to trip assignment techniques used by call takers. Over time, analysts can learn to identify problematic types of individual trip requests for one service design and perhaps shift them to other service designs that deliver results within a satisfactory range.

The output from one network optimization would influence the inputs to the other in an iterative fashion. For example, the demand-responsive analyst might identify promising service routes, which could then be added to the other network for further study. The consequences to cost and service quality of adding some demand-responsive capability to the mostly fixed-route network would have to be weighed against the monetary savings within the mostly demand-responsive network and service quality improvements to numerous individuals who are mainstreamed into the mostly fixed-route network.

Other software developments are important. Enterprise resource programs (ERPs) are increasingly being installed at transit agencies. They have the potential to unify data collected from all departments within an agency. Used effectively, the common database can eliminate duplicate efforts in various departments and automate many processes, including the analysis and dissemination of information collected by ITS. However, the details of ERP are beyond the scope of this paper.

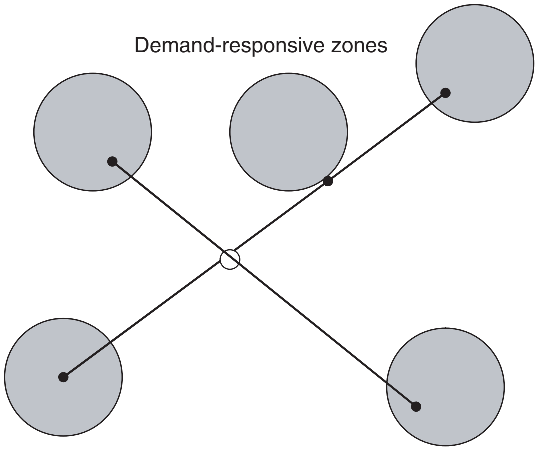


FIGURE 3 Checkpoint services interconnected to fixed-route network using timed transfers.

In summary, ITS, fixed-route and demand-responsive scheduling software with postprocessing capability, hybrid scheduling software, and ERP are already available. It would not take an inordinate amount of effort to integrate them fully. Suggestions as to how this level of technological maturity can be applied to better balance often conflicting service objectives is the subject of the remainder of this paper.

COMMON INFRASTRUCTURE

Latitude to operate a complex array of service designs that could vary by time of day and by district—perhaps with the same vehicle operating under more than one service design over the course of the day—also implies a high level of operational flexibility and control capability. To support this approach, a full array of vehicle types may all need similar communications and control equipment connected to the same network.

Software will have to have some common features. Scheduling and CAD software will have to integrate all modes and service designs. Otherwise, it will not be possible to arrange for timed transfers between them. Furthermore, the ability to shop between more than one possible demand-responsive trip assignment solution will require that the same rider database be used with all scheduling subpackages that investigate passenger accommodation possibilities. For example, a route-deviation service and a zone service might well overlap, and both might be capable of servicing the same ride request.

Hardware also will have to have some common features. Real-time monitoring and the archiving of time and location data for all vehicles will require a location-tracking AVL subsystem (most likely using the Global Positioning System). All vehicles, regardless of the service design under which they may be operating, also should be seen (or at least have the potential to be seen) on the CAD display.

All vehicles should have MDTs for two-way communication with the dispatcher and to store and transmit data for the CAD system and archives. Most routine communications can be handled with digital messages that require the use of only a predefined button. The particular display screen visible on the MDT would vary depending on the service design being operated. A display screen for pure fixed-route service might have each stop scroll off the screen after it is served or merely display time estimates of how early or late the vehicle will arrive at the next time point to help the vehicle operate maintain schedule reliability. Purely demand-responsive or zone service vehicles must have a manifest of upcoming pickup and drop-off addresses. Route-deviation and checkpoint service vehicles will need fixed time points as well as pickup and drop-off addresses.

All vehicle types should have some sort of passenger-counting device. Larger vehicles can have APCs designed for large and even multiple-channel doorways that operate continuously. Only a subset of the fleet must have them, but care must be taken to distribute these particular vehicles across routes. Smaller vehicles cannot accommodate APCs designed for large doorways, but they can have popup displays on their MDTs where drivers enter boarding and alighting counts on selected days as well as information about mobility devices, special fares, and so on.

Public confidence in connection reliability is important in any network that uses timed transfers. It will be especially true given the more dynamic nature of a highly integrated system in which services will make transitions and headway changes throughout the day. Thus, RTPI should be installed at all major connecting points. Passengers must have several means to check service status. Not all people will have PDAs or access to the Internet, so an IVR feature also should be available for telephone users.

In reality, not every type of vehicle will be a candidate for every type of service design. An articulated bus will never be used for route deviations, and a small bus or van will never be used on a busy trunk route. But it probably is not worth the effort to invent different specifications for each part of the fleet. To the contrary, using a minimum of equipment types has advantages: the cost of holding inventory is lower, and training in operations and maintenance is reduced. If the proper standards are cited and performance specifications are used, then newer replacement equipment might continue to be readily installable on older vehicles for many years.

BENEFITS OF INTEGRATING ALL SERVICES

It is convenient to describe the benefits as seen from several perspectives. It is not implied in this section that these benefits do not overlap.

Planning Options by Time of Day

If demand-responsive services traditionally structured as an entirely separate service organization are instead perceived to be part of a spectrum of service designs under one operating budget, then it might be acceptable to somewhat degrade the performance of one service if it is offset by improvement in another. For example, if demand along some fixed routes is below a certain threshold at midday or in the evening, then switching to route-deviation service may relieve the cost of pure demand-responsive service while simultaneously mainstreaming some ADA-eligible riders. Experience at the Potomac and Rappahannock Transportation Commission suggests that with fewer than 20 passengers per hour, adding 10 min of slack time will accommodate one or two deviations per hour for routes that take approximately 35 min to drive without deviations (*9*).

Service designs with a more significant demand-responsive element sometimes could entirely replace fixed-route and even route-deviation services. For example, during early-morning or late-evening hours, the unproductive tail of a fixed route might be replaced by checkpoint service. It could have the added benefit of increasing area coverage, because walking to the nearest fixed stop is not required. Not only might the overall operating cost be reduced, but the revised service could address unmet needs of potential new riders by improving access or increasing their sense of security.

Planning Options for Efficient Vehicle Use

Activity during certain times of the day on different routes or in different districts might vary synergistically. Some routes or route segments might have peak-hour commuters, others might have many midday travelers; school students might travel in the shoulder period between midday and the peak hour; and so on. It might be advantageous to swap vehicles of different sizes between routes to readjust space supply to space demand when their peaks do not coincide. More than one vehicle swap might occur. For example, in the early evening in a fringe area, a midibus might be replaced by an even smaller bus or van, which in turn might be replaced by accessible taxis later into the night. (The possibilities of changing headway and vehicle size and how the scheduling software can investigate were discussed in the section on scheduling software.)

With the ability to oversee all services operating in real time by using CAD and to efficiently schedule the transition movements between different services, swapping might be practical where it was not before. Vehicles meet periodically anyway when timed-transfer networks are used, and swapping between routes is exceptionally easy. Moreover, with RTPI, buses may not even need to physically relocate to another berth, because the information about berth change for any particular route can be made available to waiting passengers in advance.

Planning Options by Changes of Season

Although seasonal services in resort areas commonly have dramatic schedule changes, such major differences are much less frequent for urban networks. The traditional difficulty was obtaining planning information detailed enough to avoid major mistakes in capacity provision during service changes. However, once a data archive has been built up, recurring seasonal variations become predictable, and service can be adjusted accordingly. For example, during the summer, larger vehicles can be assigned to routes going to recreational destinations and smaller ones to routes serving colleges. In the fall, these assignments would be reversed.

In fact, changes could be investigated that are far more profound than adjustments to vehicle size and service headways. Nasty winter weather conditions, hot or humid summer weather, variation in the length of daylight by season, idle students during the summer, and so on could influence the travel mode chosen—or the choice to travel at all. By using regression analysis and other statistical techniques on the archived data, the advanced analyst might be able to identify most of the significant factors that influence seasonal demand and adjust service dramatically. For example, hybrid services might be substituted on a specific fixed route only during parts of the year when there are deterrents to waiting outside or walking to the nearest fixed stop, and separate routes aimed at the special needs of high school or college students would be operated while school is in session but merged with other routes during the off-season.

Latitude for Change over the Years

In general, the continual archiving of performance data by a CAD-AVL system and trending of key statistics will help identify subareas within the overall operating areas that exhibit rapid change. When travel patterns change sufficiently, entirely new approaches to serving areas can be studied. For example, areas that previously were served by peak-hour, peak-direction buses that meandered through neighborhoods before operating express to a CBD might increasingly exhibit all-day demand and more requests for services to newer, closer employment centers. Conversion to routes that operate all day for closer trips but are timed to make connections to express bus and rail services for longer trips might then be a more effective solution.

Fast-growing suburbs require particular attention. They exhibit increasing demand levels with infill, and rider concentrations become evident. The pattern might begin as a few houses in a field until entire tracts are filled. In typical zoning based on separate uses, office and commercial areas may start to appear nearby. Even where zoning changes to allow neotraditional development, the eventual density may be higher, but these designs take time to build out.

Under a fully integrated system, supply can be matched with demand over the course of infill. For example, rather than extend the tail of an existing fixed route to a brand-new development, a fully accessible van or low-floor small bus can be assigned for local checkpoint service such that onward trips are connected to the existing terminus of a fixed route by timed transfer. As demand builds, the fixed route can be extended, with route deviation permitted only along the new extension. As demand further reveals itself through the pattern of deviation requests, fixed stops may revert to optional stops, and vice versa. If demand continues to build, then a larger bus in pure fixed-route service can operate during peak periods. The trips that cannot be accommodated by the fixed route would again require supplementary accessible vans or small buses. This evolutionary growth process is illustrated in Figure 4.

Even existing areas experience changing demographics, and service consequently may need adjustment as well. An aging population also requires particular attention. Many residential tracts have large numbers of people who retire in place. As the neighborhood ages, the number of advanced elderly and disabled (in the United States, those eligible for ADA-complementary paratransit) increases. As ridership on service designs with a significant demand-responsive service increases, the addition of route-deviation capability to fixed-route buses during the nonpeak hours may be efficient to attract some

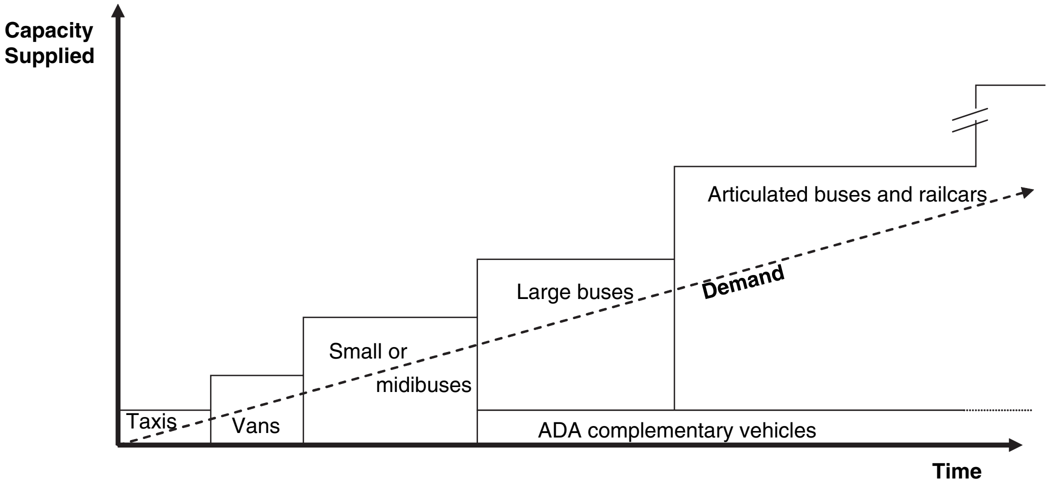


FIGURE 4 Effect of demand increase over time on vehicle types and capacity, first within a zone and later along a route.

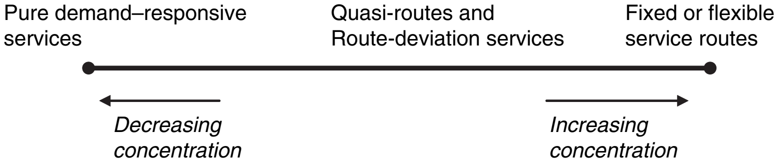


FIGURE 5 Effect of concentration of origins and destinations on selected demand-responsive service designs.

of these riders from the more expensive service alternative(s). If many people request trips from the same few locations or to a few popular destinations (e.g., shopping malls, senior centers, and medical complexes), then a flexible- or a fixed-service route might be an effective solution to meet part of the demand. This evolutionary selection process is illustrated in Figure 5.

INSTITUTIONAL REQUIREMENTS FOR INTEGRATION

Technological capability is a necessary but insufficient condition for providing planners the ability to design and implement an array of fully integrated service design options. After the required technological investments have been procured and their functionality has been tested, little or no organizational distinction between demand-responsive and fixed-route operations would be required to proceed. However, the vast majority of transit agencies currently are not organized to plan, manage, or operate such an array.

Labor issues also would require negotiation and resolution. For example, pay differences between operators and dispatchers of different services (e.g., demand-responsive versus fixed-route services) could create an insurmountable obstacle to the cooperation needed for the envisioned vehicle and service substitutions likely to evolve in a highly integrated system.

A wider array of vehicle types would need to be procured. Historically, smaller and midsize vehicles that are heavy duty, attractive, and fully accessible have been lacking. Because of low production levels and limited procurement budgets, most designs are based on a passenger van or light truck chassis. Consequently, vehicles tend to have operational shortcomings and a poor public image. As the demand for such vehicles increases and funding is pooled with larger vehicles, this problem might solve itself.

In general, higher levels of both operational management and planning skills would be required. The skills nurturing and increased training and education needed would be just as important as the technical investments. Dispatcher and supervisory oversight would be more complicated and would require skillful resolution in case of service delays and cancellations. Because of more complex operating plans, the disposition of vehicles, operators, and mechanics among depots also would be more complex. Service planners would have to review archived data and passenger feedback much more often.

Employees associated with select service designs would have to become accustomed to continual adaptation and adjustment. Many vehicle operators would need to know how to operate more than one service design. This dynamic environment would be in sharp contrast to the stasis that most agencies have traditionally cultivated to provide reliable and consistent service.

More frequent community outreach also would be required as a result of more frequent schedule changes and a more complex variety of service types. Some of these developments would require explanation to and training of potential riders. The expenditures required should not be viewed only as passenger education but also as marketing that increases the transit profile in the community. Most other sectors of society are undergoing an information revolution; demonstrating the use of advanced technology to improve responsiveness to public needs can only improve transit's public image.

INSTITUTIONAL OPPORTUNITIES FROM INTEGRATION

In addition to reorganizing existing operations within one agency, the same ITS and scheduling improvements open possibilities to improve coordination with or even absorb other transportation providers.

Brown et al. surveyed 35 college and university programs that grant unlimited access to all campus-affiliated transit riders (*10*). This approach requires an annual fee from students or a payment from the college to the transit system. The reported results exhibit few if any downsides. The students have lowered transportation costs, the university and city benefit from lower parking requirements, and the transit agency can afford to provide more service to the remainder of the public. Miller surveyed 30 campus transit systems and found successful examples of the campus and surrounding cities pooling their services, sometimes even without the fare incentives created by an unlimited access program (*11*).

When merging the campuses' and the remainder of the city's needs, the synergies and schedule reoptimization possibilities can be expected to be exceptionally strong. Student demand peaks at different times than that of regular shift workers. The combined total demand justifies shorter headways and induces yet more demand. Furthermore, many students want to travel late in the evening, thus improving the level of service justified for the rest of the community.

Human service providers often run transportation services in parallel to that provided by transit agencies. Evidence indicates that the United States receives substantial economic benefits from coordinating the two, stemming from the increased mobility options and reduced duplication when ridership is pooled (*12*). Historically, coordination was limited, partly because of restrictions on the commingling of funds and also because of the difficulties of joint scheduling and communication between vehicles run by unrelated entities. Even short of a merger, provision of ITS to the human service transportation providers still could facilitate the merging of human service agency trips and vehicles into the transit agency operation, to the benefit of both taxpayers and users of the coordinated services.

FUTURE RESEARCH

The suggestions presented in this paper need to be refined in an actual setting. Unlike the consumer electronics sector and despite their technological maturity, transit command- and control-related ITS have experienced little technology push in recent years. Impeding the aggressive promotion of advanced solutions has been the financial difficulty—and even offers for sale—of parent companies of several of the major CAD-AVL vendors. To minimize financial risk, their responses to proposal requests give only what is requested, using proven solutions to the maximum degree. In other words, vendors are not likely to provide a polished and fully integrated set of CAD-AVL and software with the features described here without a firm set of specifications and a commitment to purchase the finished product.

Funding mechanisms similar to the FTA Operational Test Grant or SAMPO/SAMPLUS programs could remove the financial risk to both a transit agency and vendors willing to make the commitment. The grant awards could be based on the competitive merit of the particular location. However, the geographic distribution of grants is also required to examine the impacts of climate, urban form, and existing proclivity to use transit.

An agency that would be ideal for testing the concepts could not be so small that possibilities are limited for network optimization but not so large that the reorganizational changes required would be unwieldy.

REFERENCES

1. Koffman, D. *TCRP Synthesis 53: Operational Experience with Flexible Transit Services.* Transportation Research Board of the National Academies, Washington, D.C., 2004.
2. Westerlund, Y. DRT in Goteborg: FlexLine as a Social Tool. Presented at the International Conference on Mobility and Transport of Elderly and Disabled People (TRANED), Florence, Italy, Dec. 4–5, 2003.
3. Westerlund, Y., G. Carlsson, A. Ståhl, J. Tornberg, and B. Stålner. *Servicelinjer Eller Flextrafik: När, Var, Hur? Erfarenheter—Jämförelser—Planeringsprinciper* [with summary in English]. LogistikCentrum, Gothenburg, Sweden, 2006.
4. Bihn, F. (ed.). *Differenzierte Bedienungsweisen: Nahverkers-Bedienung Zwischen Grossen Verhersaufkommen und Geringer Nachfrage.* Verbund Deutscher Verhkersunternehman, Cologne, Germany, 1994.
5. European Union. CONNECT website. srvweb01.softeco.it/connect. Accessed July 12, 2006.
6. Lave, R., R. Teal, and P. Piras. *TCRP Report 18: A Handbook for Acquiring Demand-Responsive Transit Software.* TRB, National Research Council, Washington, D.C., 1996.
7. Muller, T. H. J., and P. Knoppers. *TRITAPT: TRip TIme Analysis in Public Transport.* Delft University of Technology, Faculty of Civil Engineering, Transportation & Planning Section, Delft, Netherlands, 2005. tritapt.nl. Accessed July 12, 2006.
8. Muller, T. H. J., and P. Furth. Integrating Service Planning with Analysis, Operational Control, and Performance Monitoring. Presented at the ITS America Annual Meeting, Boston, Mass., May 1–4, 2000.
9. Bruun, E. C., and E. Marx. OmniLink: Case Study of Successful Flex Route–Capable Intelligent Transportation System Implementation. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1971,* Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 91–98.
10. Brown, J., D. B. Hess, and D. Shoup. Unlimited Access. *Transportation,* Vol. 28, 2001, pp. 233–267.
11. Miller, J. H. *TCRP Synthesis 39: Transportation on College and University Campuses.* TRB, National Research Council, Washington, D.C., 2001.
12. Burkhardt, J. E., D. Koffman, and G. Murray. *TCRP Report 91: Economic Benefits of Coordinating Human Service Transportation and Transit Services.* Transportation Research Board of the National Academies, Washington, D.C., 2003.

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