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Modelling of bus passenger collection strategies

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Abstract

This paper presents results obtained from modelling of bus passenger collection strategies with the view of providing a method for selection of the optimum bus service arrangement. Selection of optimum operating characteristics is a challenge faced by transit system operators. The range of passenger collection strategies investigated include pickup and drop off at fixed stop locations, anywhere along the route and door to door services. Australian case studies presented demonstrate the presence of these different operating strategies. From the point of view of passengers, the main difference among these methods is in the amount of access distance involved.

The model required to identify optimum operating strategy is developed using computer simulation techniques. Individual passengers and progress of each bus along the route are simulated. Key features of the simulation model and underlying formulations are described. The model allows estimation of journey time components and service reliability under specified operating strategies. Comparison of case studies with results from the simulation model reveals that the intensity of passenger demand is the primary determinant in the selection of passenger collection strategy. The method for selection of the optimum passenger collection strategy and implications of simulation results are explained in the paper.

Keywords: Bus operations; Simulation; Reliability

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Introduction

Optimisation of bus stop frequency and stop spacing has drawn much attention in the past from transit system modelling community investigating bus operations and passenger collection strategies. However, in the analysis presented here the domain of passenger service strategies is extended to include services that deviate from the traditional fixed route fixed stop concept. In some literature these non-traditional services are referred to as paratransit systems. It is important to operators and planners to be aware of conditions conducive to adoption of such collection and distribution strategies.

The model presented is based on computation of access, waiting and riding components of passenger journey. The analysis incorporates variables such as route length, catchment width, headway and passenger demand density. Formulations related to above components under three strategies for passenger collection are investigated. Passenger collection strategies have been classified here according to the level of flexibility available in arrangements of passenger pickup locations.

First strategy considered is the traditional fixed stop fixed route system that requires passengers to access specified stop locations. This type is referred to as the fixed stop strategy in this paper. The second method relaxes the fixed stop nature and adopts a stop anywhere along the route policy. This is referred to here as flexible stop strategy. In practice, even in such systems, the stopping activity necessary to pickup or set down passengers is performed only where it is safe to stop. However, for the analysis purposes it is assumed that safe stopping is feasible along the complete length of the bus route. These systems eliminate the passenger access distance along the route but increase the travel time and operating costs because of frequent stops and the reduction in the average number of passengers served per stop. The third type of operation further relaxes the routing and stopping constraints and allows the bus to deviate from the designated route to pick up passengers anywhere within a specified catchment. Here the passenger access distance is completely eliminated at the expense of extra travel time. This type is called flexible route strategy in this paper.

Previous research on bus service route design has focused on conventional service concept that provide fixed route, fixed schedule, and single size of vehicle on all routes. Number of researchers has relied on analytical formulation for such analysis. In pioneering work in this area, Newell (1979) focused on minimization of the sum of the costs incurred by passengers and operators for a transit corridor with uniform demand distribution. Theoretical concepts related to route spacing, stop location and station spacing of bus service in a grid pattern of network in terms of many to one of passenger demand have been documented by Szplett (1983). Also, Chang and Schonfeld (1993) have developed an analytical model to evaluate zone length, route spacing and headway for uniform demand pattern in a rectangular grid network. In contrast, Giannopoulos (1989) has presented an empirical model for bus operation planning. Nevertheless, there are some researchers who have adopted simulation in this field. For example, Santhakumar and Hariharan (1992) have presented a simulation model to analyse stop locations and operating speeds under many to many demand pattern.

Paratransit Market

Door to door services and stop anywhere operations are often referred to under paratransit category. In the USA, the concept of paratransit was first observed in Mansfield, Ohio in 1969. And some other large public transit operators soon followed in Haddenfield, New Jersey; Rochester, New York; and Ann Arbor, Michigan (Sutton, 1987). They became pioneers in the field by serving for niche markets. In Australia, Radbone et al. (1994) and D'Este et al. (1994) have described early research work carried out in this field.

In the USA, in 1998, an estimated 22,884 private paratransit companies operated more than 370,00 vehicle. Furthermore, Lave and Mathias (2000) reported that during six years (1990-1996) paratransit market in the USA had increased from 68 million to 95.4 million passenger trips. It was 1.2 percent of the 7.96 billion total transit passengers trip in 1996. It is predicted that paratransit demand will continue to grow as a result of expansion of urban sprawl that expands low density areas.

In Australia the paratransit concept has a short history of about 25 years. Wonthaggy Community Bus launched a demand responsive service in 1974, sponsored by the shire of Wonthaggy, Victoria (BTE, 1980). Soon after, Invicta, another bus company in Victoria, introduced a demand responsive system in selected number of suburbs. Now, Invicta operates 12 minibuses in 5 suburbs (Transit Australia, 1994).

In Sydney, in February 1993, Westbus introduced a 'hail almost anywhere' service with high frequency midibuses. This service was known as the Nepean Nipper. Here, the driver follows a fixed route but picks up and drops off passengers anywhere along the route and is not constrained by predetermined stop locations. In the first year of operation the passenger number of the service have increased by almost 25 percent. This service operates at a minimum frequency of 15 minutes throughout the day until midnight, carrying around 140,000 passengers per month (Transit Australia, 1994). Witherby (1993) has described a flexible route arrangement attempted in Wollongong.

In February 1994, Brisbane City Council introduced a hail and ride cross-suburb service to enable residents with better public transport around their own local areas. Buses pick up or set down passengers at any point along the route where the kerb is marked by color. In other words, this is flexible stop service. Passenger are served anywhere along the route except adjacent to busy intersections, no standing zones, metered parking zones and loading zones. It marked the start of intra-suburb neighborhood transport in Brisbane. These services feature distinctive 25 seat midibuses. It is claimed that the introduction of midibuses has not changed other bus operations in the area (Transit Australia, 1994).

In 1997, paratransit services called DoorStopper and ShopperStopper were launched in Hobart, Tasmania.

In May 2000, TransAdelaide launched a flexible stop system. This is only a night service. This flexible stop service has been introduced due to safety concerns of night time passengers.

Table 1 shows the distribution of flexible stopping and flexible routing operations in Australian cities. About half the States have attempted introduction of flexible stop and flexible route operations in a limited context. However, fixed stop operations are the dominant system in metropolitan areas.

Application areas

General predictions of performance under different stop strategies are shown in table 2. The performance here is considered from the passenger point of view. Although flexible route strategy shows better results on average, the applicability of that strategy is limited to low levels of demand and route length as shown later in from the simulation analysis.

Fixed stop arrangement of public transport will continue to be an important method in large urban areas, which have a high usage level of public transport. However, in Australian cities that have a relatively low density of development, and dispersed trip origins and destinations, a reasonable proportion of trips may not be suitable for the conventional fixed stop strategy.

TABLE 1 Metropolitan Transit Operation Configurations

State	Routes	Operators	Fixed stops	Flexible stops	Flexible routes
New South Wales	559	38	549	10	-
Victoria	252	41	243	9	-
Queensland	213	4	204	5	4
South Australia	128	5	128	-	-
Western Australia	298	4	298	-	-
Tasmania	63	1	46	9	8
Northern Territory	23	1	23	-	-
ACT	85	1	85	-	-

Compiled from: Bureau of Transport Economics (1985), Australian Bureau of Statistics (1998) and Department of Transport NSW (1998)

TABLE 2 Performance Under the Three Operating Strategies

Performance Measure	**Fixed stop**	**Flexible stop**	**Flexible route**
Access distance	High	Moderate	Zero
Waiting	Need shelters	Lacks shelters	Convenient (home)
In vehicle travel time	Low	Moderate	High
Service flexibility	Little	Moderate	High
On time reliability	High	Moderate	Low
Night time safety	Low to moderate	Moderate	High

Passenger collection strategies

Consider the catchment area shown in Figure 1. The shaded area in the figure shows the catchment area of bus services, with length of route *L* and width of corridor *w.* Solid dots in the diagram represent passenger origin locations.

Fixed Stop Strategy

Arrow lines in Figures 1a and 1b are access paths to the nearest bus stop. It is shown in Figure 1a that a passenger access has two components, one in lateral and the other in longitudinal direction to the route. In this operation, routes and stops are fixed. Drivers are required to follow the specified route under all circumstances.

An analytical model was first established as a validation tool for the simulation. It is attempted to briefly describe the analytical model before explaining simulation components. In general, public transport travel consists of access trips to (and from) a route or bus stop, waiting time for a vehicle and on-vehicle travel time. Averages of time required for these components are function of number of operating characteristics. For example, the location and spacing of stops affect the *average access time.* Headway of buses affects the *average waiting time*. Passenger demand level, vehicle characteristics and stop spacing affect the *on -vehicle travel time.*

Hence the average journey time with fixed stop strategy is given by:

$$T_{fixed\,stop} = \frac{\overline{d_a}}{v_a} + \left(\frac{L}{v_b} + t_{oc}\, n_s + t_{ab}.p_s \right) + \frac{h}{2} \qquad (1)$$

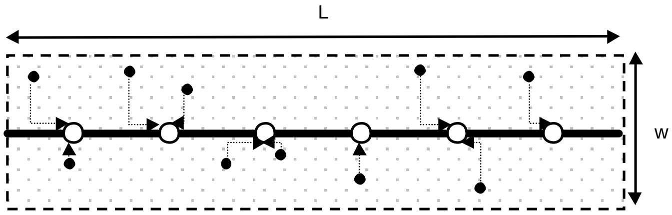
where,

L = route length,
v_b = average vehicle speed,
t_{oc} = average time required for door opening and closing,
n_s = number of stops along the route,
t_{ab} = average time allocated for boarding and alighting per passenger,
p_s = number of passengers along the route per bus and
h = average headway of buses.

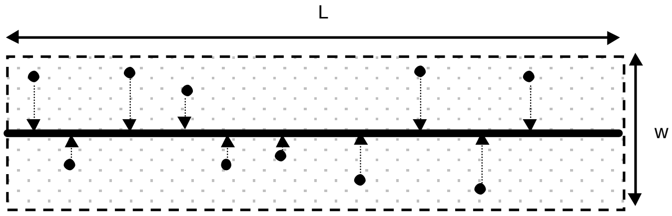
Flexible Stop Strategy

In this strategy buses can pick up and drop off passengers anywhere along the route and is not constrained by fixed stop locations. Figure 1b shows the schematic explanation of a flexible stop service and access paths of passengers. From the passenger point of view, the advantage of this system compared to the fixed routing is the reduction of access distance along the route. The access distance is reduced on average by quarter of stop spacing of the fixed stop strategy with a grid network of access roads.

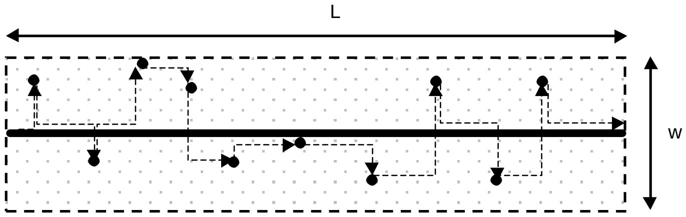
Figure 1 Passenger Collection Strategies



(a) Fixed stop strategy



(b) Flexible stop strategy



(c) Flexible route strategy

Therefore, for flexible stop strategies, the number of stops is equal to the number of passengers along the route. Thus, the journey time is:

$$T_{flexible\ stop} = \frac{\overline{d_{ay}}}{v_a} + \left(\frac{L}{v_b} + (t_{oc} + t_{ab})p_s \right) + \frac{h}{2} \quad \text{...(2)}$$

Where; $\bar{d}_{ay}$ is average of the lateral components of access distance.

Flexible Route Strategy

The operating space of a flexible route system is spread out compared to conventional transit systems. In flexible route systems, buses deviate from a spine route to provide a door to door service for passengers within the service corridor. Figure 1c shows the flexible route strategy applied to same passengers covered in Figure 1a. The vehicle travels from one passenger to the next as shown by the dotted lines.

Typical operations characterized by flexible route strategy may consist of relatively small vehicles to provide door-to-door, curb-to-curb, or point-to-point transportation at the user's demand. These systems are also known as demand responsive or dial-a-ride services.

The journey time of a passenger who travels the full length of a flexible route can be formulated by the following equation:

$$T_{flexible\ \ route} = \frac{d_t}{v_b} + (t_{ab} + t_{oc})p_s + \frac{h}{2} \quad \text{..(3)}$$

Simulation Model

The simulation model has been developed using Fortran language to follow the progress of buses along the route, serving passengers as specified under the particular operating strategy. The simulation allows experimentation with different levels of passenger demand, corridor width and route length. The model also incorporates variables related to area coverage, frequency of buses, and duration of operation. Bus characteristics related to operation speed, time spent on door opening and closing activities and service time per boarding and alighting passengers are also included.

There are five main components considered in the model. They are:

Service corridor: The simulation program requires the area coverage, stop locations and route length to be specified. The simulation considers a rectangular grid street network as the default setting. In the simulation of a conventional transit system, buses stop only at designated stop locations. It is assumed that passengers access stops nearest to their origin (home) locations.

Passenger distribution in space and time: The simulation model allows varying the passenger demand level along the corridor. The transit demand can be constant or varying over time. Spatial and temporal distributions of public transport demand (passenger origins) are generated from the input demand distributions. Random *x* and *y* coordinates within the designated area are generated according to the specified demand levels to signify passenger origins. In this paper, only uniformly distributed demand pattern is applied. All passengers are assumed to alight at the final stop in the present simulation. In other words a many to one demand pattern has been implemented.

Transmission of passenger requests: Flexible route passengers request transit service by contacting a central dispatch facility. Time required to transfer requests from a passenger to control centre to bus driver is set as a constant in the simulations. Thus the first bus with empty seats that pass the passenger origin location since the receipt of the request serves the passenger.

Vehicle and passenger characteristics: The simulation requires vehicle characteristics related to bus operating speed for computation of travel times and time consumed in opening and closing of doors to compute dwell times at passenger service locations. Also, passenger characteristics related to boarding and alighting times are required by the simulation. There is no limit to the fleet size. The size of vehicle can be specified. Anyhow, vehicles are assumed to operate at a constant speed throughout the route.

Scheduling: Start time, headway and hours of operation in a day can be specified by the user of the simulation model.

Example

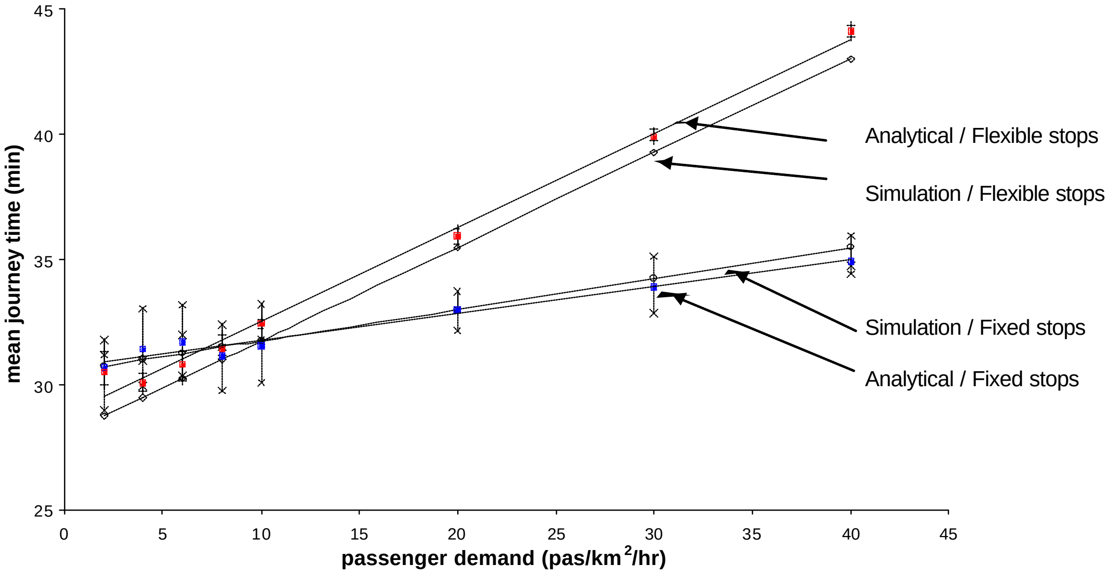
An example of a simple urban scenario has been selected to illustrate the effect of passenger demand density and route length on passenger travel time and reliability of service. It is assumed that the width of route corridor is 1 km. The route length selected is 10 km. The access speed of 5 km/hr is derived from the average walking speed of 1.35m/s mentioned earlier. The average vehicle operating speed is considered to be 30 km/hr and the sum of boarding and alighting time allocated for a passenger is 6 seconds. The passenger capacity of buses is set at 20% higher than the average occupancy predicted. For conventional fixed stop operation, it is assumed that the stop spacing is 0.5 km. Headway of bus service is selected as 30 minutes (minimum urban and suburban bus frequencies as suggested by Giannopoulos, 1989). In this example, a 16 hour day of operation is assumed. For statistical accuracy purposes, the simulation has been repeated 25 times to obtain each data point shown in the following graphs.

Effect of Demand Density

A set of simulations has been conducted to examine the effect of different levels of passenger demand on the mean journey time. The effect of passenger demand on the average journey time of passengers under different passenger collection strategies is shown in Figure 2. Eight levels of demand density have been considered for each operational strategy. Demand density is varied from 2 to 40 pass/km^2/hr.

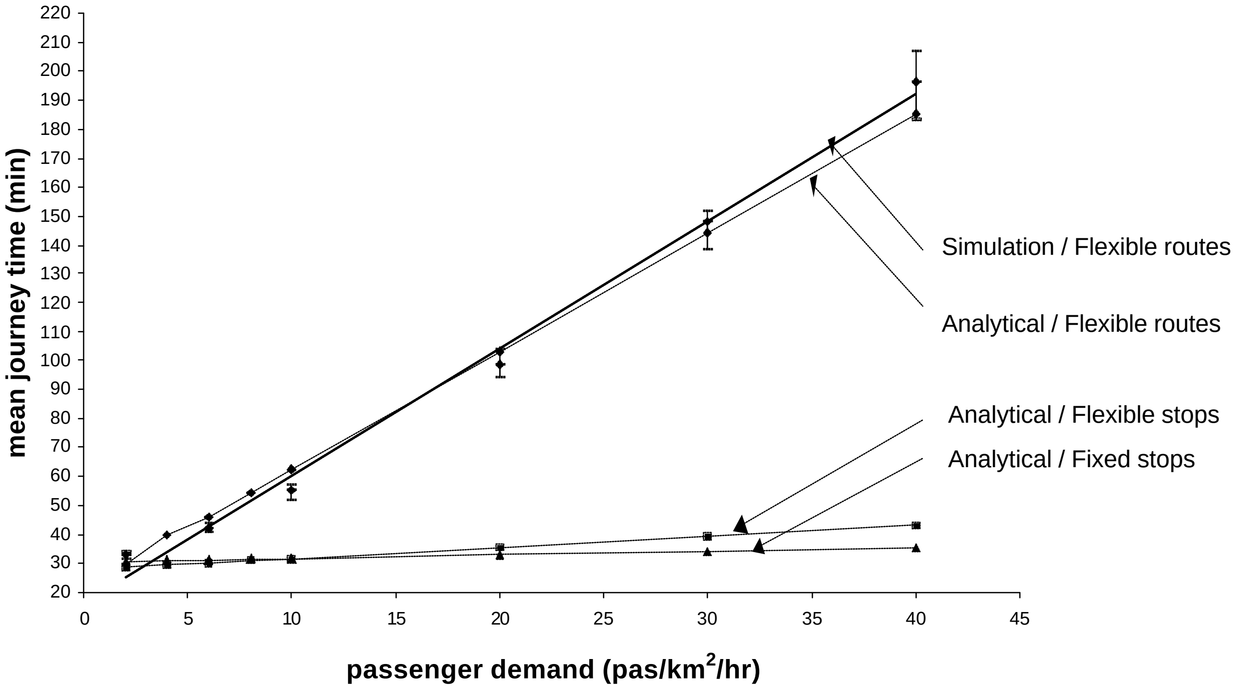
Figure 2 shows the comparison of fixed stop and flexible stop strategies. Solid lines in Figure 2 indicate the analytical model results. Dashed lines represent mean values obtained from simulations. The mean, upper 85% and lower 15% values of simulation results are also shown in the graph to show the spread of results available from simulation. Figure 2 shows that analytical and simulation results compare well for both operating strategies. It is also shown that the flexible stop strategy is better for conditions of less than 7 pas/km^2/hr demand. The exact point of intersection may be worth further investigation by comparison of large number of scenarios. However, it is evident that the flexible stop strategy is suitable for thin passenger demand densities.

Figure 2 **Average Journey Time With Fixed Stop and Flexible Stop Strategies**



Results of flexible route operations are not shown in Figure 2 because of incompatibility of the vertical scale. Vertical scale in Figure 3 is selected to include flexible route strategy as well. For purpose of clarity only analytical results of fixed stop and flexible stop system (previously shown in Figure 2) are reproduced in this figure. Both analytical and simulation results are shown for the flexible route strategy. The average journey time with flexible route strategy increases rapidly with increasing passenger demand. This feature is due to the additional bus travel distance to pickup passengers. Nevertheless, it is clear that for very low passenger demand densities, the flexible route option provides the least mean journey time.

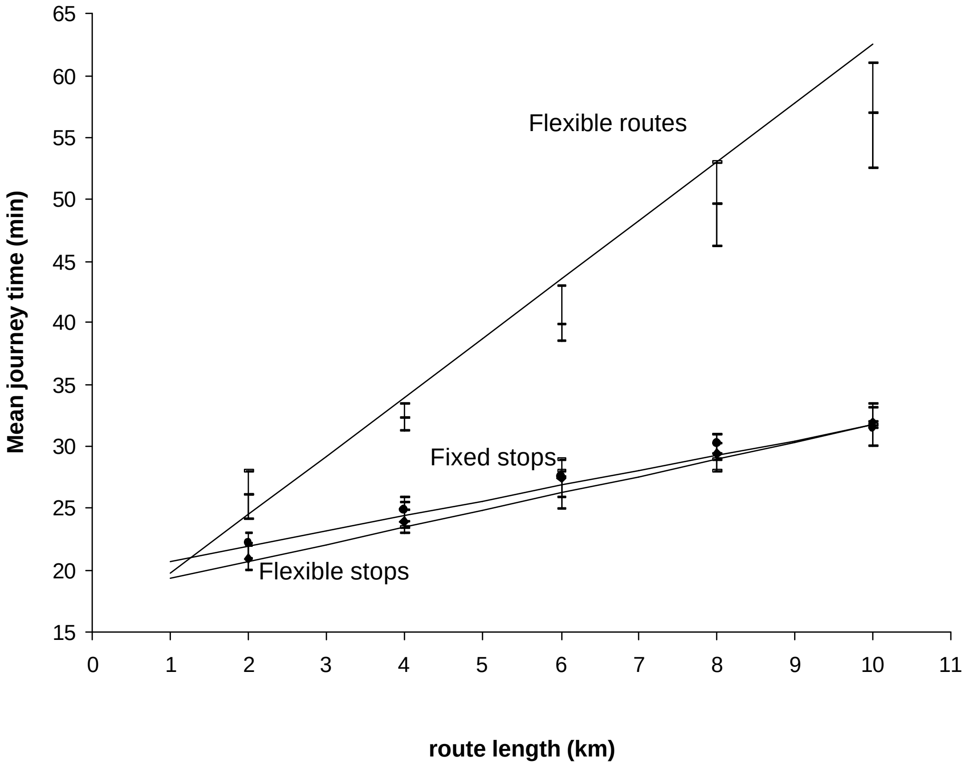
Figure 3 Journey Time Comparison Under the Three Strategies



Effect of Route Length

Figure 4 shows the effect of route length on mean travel time. Here, the analysis has been repeated for different route lengths (2 to 10 km). The demand level for these conditions has been selected as 10 pas/km^2/hr. The spread of simulation results are also shown. The graphs shown are developed from the analytical formulations. The simulation assists in verification of the trends shown by the analytical model. The high level of variability of travel time under flexible route strategy is also revealed. The figure also shows that the flexible stop strategy may be suitable for operations with less than about 9 km of route length under the selected operating parameters.

Figure 4 Effects of Route Length



Optimum Strategy

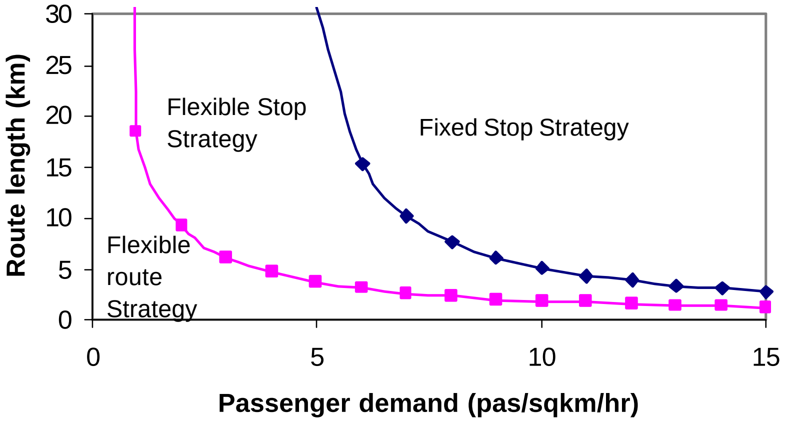
The locus of the intersection points identified in above diagrams can explain the boundaries of suitable application areas for each passenger collection strategy. This can be achieved by equating travel times found from pairs of equations (1) and (2) and equations (2) and (3). Thus, figure 5 shows the strategies that yield the least travel time on a many to one operations with characteristics of passengers and vehicles as mentioned before.

It can be shown that this diagram is sensitive to the bus headway. Therefore, Figure 5 is applicable only for bus headway of 30 minutes. It can be also shown that this analysis is not much sensitive to the values of time requirements for door opening and closing nor the average time requirement for passenger boarding and alighting.

Effect of Demand Level on Reliability

The simulation keeps a detailed record of the progress of each bus along the route (Yossyafra and Vandebona, 2001). Therefore, the progress of buses can be plotted as a set of trajectories. The level of reliability of the bus operations is computed from the comparison of the simulated operation with the trajectory diagram of the scheduled operation. The performance measures considered are maximum and average of lateness and earliness and average passenger occupancy. The variation of passenger occupancy is not dealt with here to conserve space.

Figure 5 Optimum Passenger Collection Strategy



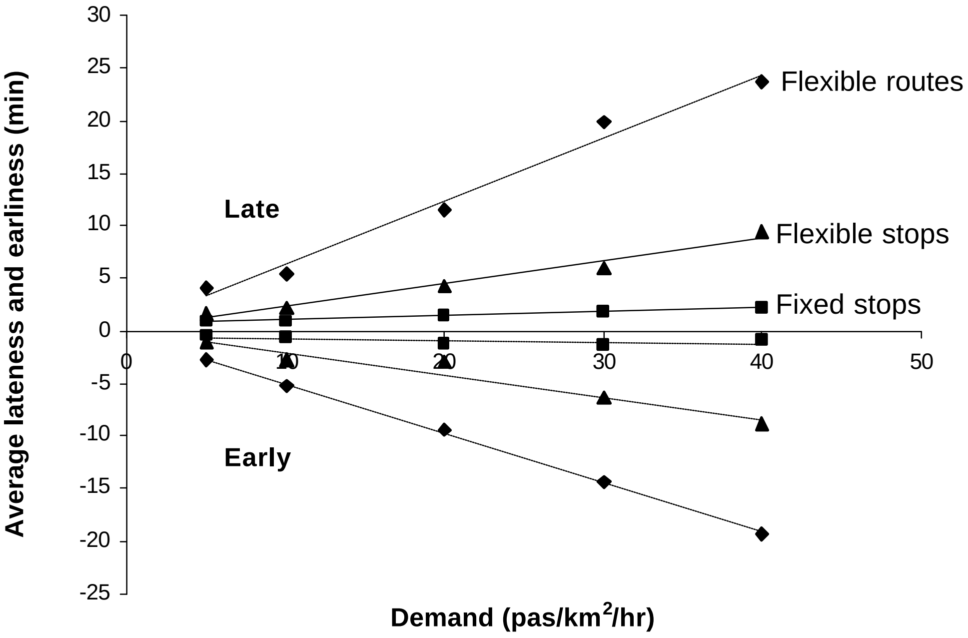
A set of simulations has been conducted to examine the effect of different passenger demand levels on reliability. Five levels of demand density (from 4 to 40 pass/km^2/hr) have been considered for each operational strategy. Each level of demand density is simulated 25 times. The catchment area and operational parameters are as mentioned in a previous section.

Figure 6 shows average lateness and average earliness of bus arrival time at terminus. It shows that as the demand density increases the average lateness and average earliness of bus arrival time increases. The average lateness and average earliness under flexible route strategy is higher than those under fixed stop and flexible stop strategies. Thus, Figure 6 indicates that the fixed stop strategy provides the best on-time performance within the range of demand densities considered. Figure 6 also indicates that the increase of demand density results in deterioration of reliability under all three passenger collection strategies considered.

Conclusions

This research work provides a framework for selection of operating options to assist the transport planning community particularly for low demand density applications. Different passenger collection strategies have been analysed in this paper. It is shown that under the flexible stop strategy the access distance of passengers may be reduced to nearly half of a fixed stop scenario. Access distance of passengers is completely eliminated under flexible route operation.

Figure 6 Average lateness and earliness of transit arrival time



Some contrasting observations related to performance measures of the three operating strategies have been pointed out previously with Table 2. The performance here is primarily considered from the passenger point of view. Flexible route strategies are able to provide minimal access distance and pleasant waiting environments. However, flexible route concept may not be an effective method of sustaining public transport reliability.

A review of operating strategies adopted by public transport operators in Australian capital cities and other urban centres has been performed. The simulation has been useful to identify that a key variable in selection of the appropriate stopping strategy is the passenger demand density. Other variables that contribute to the selection of operating strategy are operating speed, catchment width, bus headway as well as passenger boarding and alighting time requirements.

It is shown that the fixed stop placement strategy is generally suitable for urban conditions with high level of public transport usage. With relatively low levels of public transport demand, stop anywhere along the route and even route deviations to serve passengers become favourable strategies.

References

Australian Bureau of Statistics (1984) *ACT in Focus- Report 1307.8* Belconnen ACT: Australian Bureau of Statistics

BTE - Bureau of Transport Economics (1980) *Paratransit: Changing Perceptions of Public Transport* Canberra: Australian Government Publishing Service,

Bureau of Transport Economics (1985) *Benefit of Urban Public Transport Subsidies in Australia - Occasional Paper 71* Canberra: Australian Government Publishing Service

Chang S K and Schonfeld P M (1993) Optimal Dimensions of Bus Service Zone *ASCE-Journal of Transportation Engineering,* 119 (4) 567-585.

D'Este, G Radbone, I G and Taylor, M A P (1994) Demand Responsive Public Transport for Australia: 1. The Trade-offs, *Australasian Transport Research Forum 19*, 207-222

Department of Transport New South Wales (1998), *Sydney Public Transport Director* Sydney: NSW Government

Giannopoulos, G A (1989) *Bus Planning and Operation in Urban Area: A practical Guide*, England: Avebury

Lave, R and Mathias, R (2000) State of the Art of Paratransit, In: *Transportation in the New Millenium Document ID: 00784240* Washington D C: Transportation Research Board

Newell, G F (1979) Some Issues Relating to the Optimal Design of Bus Routes, *Transportation Science 13* (1) 20-35

Radbone, I G Taylor, M A P and D'Este, G (1994) Demand Responsive Public Transport for Australia: 2. Meeting the Needs, *Australasian Transport Research Forum 19*, 429-446

Santhakumar, S M and Hariharan, P (1992) Transportation Systems Management Options to Improve Urban Bus Route Performance Using Computer Simulation *Transportation Research Record 1338,* 22-27

Sutton, J C (1987) Transport innovation and passenger need - changing perspectives on the role of Dial-a-Ride systems *Transport Reviews* 7 (2) 167-182

Szplett, D V (1983) Approximate Procedure for Planning Public Transport Transit Systems: A Reviews and Some Examples *Journal of Advances Transportation 18* (3) 245-257

Transit Australia (1994) Minibuses making their mark *Transit Australia 49* (6) 127-129

Witherby, A (1993) Towards Area Wide Local Transport Management, *Australasian Transport Research Forum 18* (2) 751-781

Yossyafra and Vandebona, U (2001) Passenger Collection Strategies of Bus Operations *Proceedings of International Congress on Modelling and Simulation - MODSIM 2001* (4) 2069-2074.