Simulation Modelling of Paratransit Services

Yossyafra[a] **and U. Vandebona**[b]

[a] *School of Civil and Environmental Engineering, The University of New South Wales, Sydney NSW 2052, Australia (yossy@civeng.unsw.edu.au)*

[b] *School of Civil and Environmental Engineering, The University of New South Wales, Sydney NSW 2052, Australia, (U.Vandebona@unsw.edu.au)*

Abstract: This paper presents a modelling framework suitable for performance analysis of paratransit services. The proposed model provides a methodology for the selection of operating strategies to suit the level of demand. The proposed model is based on simulation techniques and takes into account access, waiting and travelling components of the public transport journey. The focus of the analysis presented relates to reliability aspects of the simulated paratransit operations. A review of operating strategies adopted by public transport operators in Australian capital cities and other urban centres is included. Usage levels of such systems are also discussed. Comparison of these case studies and results of the proposed model reveals that the passenger demand is a significant determinant in selection of paratransit schemes.

Keywords: Paratransit; Simulation; Reliability

1. INTRODUCTION

Paratransit systems have a mixture of characteristics found in both public and private transportation systems. In other words paratransit systems attempt to provide personalised transport service to generally unrelated groups of passengers. Paratransit systems include demand responsive systems and shared ride modes.

In this paper, the term of paratransit is adopted to mean demand responsive services, which provide door-to-door service by deviating from the main route to serve passengers. In different countries these systems are known as dial-a-ride, dial-a-bus, ring-a-ride, ring-a-bus or call-a-bus systems.

Table 1. Characteristics of conventional and paratransit systems.

Characteristic	Conventional	Paratransit
Route	Linear between two terminals	Non linear, between many small generators
Population density	Dense	Thin
Access distance	About 400m	Short or non-existent
Vehicle size	Large or articulated	Range of size
Dispatching	Timetable bases	Timetable based or demand responsive
Journey type	Mainly for journey to work	Range of activities
Trip distribution	Many to one or one to many	Many to one or many to many

Source: Modified from Sutton [1987].

The concept of demand responsive is considered to be able to provide transit service for users in areas of low-density and low-demand areas that are not cost effective to serve by conventional transit operations. It is also argued that communication technology would make paratransit efficient [Lave and Mathias, 2000].

The original objective of paratransit systems has been to provide a service not covered by conventional transit systems. The main difference between paratransit and conventional bus services has been discussed by Sutton [1987] as described in the Table 1. The simulation model presented in this paper enable comparison of conventional and paratransit systems in a quantitative manner.

2. PARATRANSIT MARKET

In the USA, the concept of demand responsive (paratransit) was first launched 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 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 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]. Another bus company in Victoria, Invicta later introduced a demand responsive system in selected number of suburbs. Now, Invicta operates 12 minibuses in 5 suburbs.

In February 1994, Brisbane City Council introduced a demand responsive cross-suburb service to enable residents with better public transport around their own local areas. These services feature distinctive 25 seat midibuses [Transit Australia, 1994]. In 1997, paratransit services called DoorStopper and ShopperStopper were launched in Hobart, Tasmania.

Table 2 shows that about half of Australian States have attempted introduction of paratransit systems at least in a limited context. However, conventional transit systems are the dominant variety in metropolitan areas.

3. PERFORMANCE MEASURES

Research on evaluation of the performance of transit operations has generally focused on two main aspects. First is the performance of public transport system and its efficiency. This relates to the relationship between cost of operation and output of the transport system. Second is the ability of the transit system to meet basic objectives [OECD, 1980]. This covers the ability to serve passengers to travel to their destinations.

Table 2. Number of paratransit services in Australia.

State	Number of urban routes	
	Conventional transit	Demand responsive
New South Wales	553	-
Victoria	243	5
Queensland	204	6
South Australia	128	-
Western Australia	298	-
Tasmania	46	8
Northern Territory	23	-
Australian Capital Territory	85	-

Compiled from: ABS [1998], Bus Australia [2001], DoT NSW [1998]

In general, there are number of key elements considered by a person who travel by public transport. These element consist of access trips to and from a route or bus stop, waiting time, in-vehicle travel time, flexibility and on-time reliability.

Some contrasting features related to performance measures of the two operating strategies are shown in Table 3. The performance here is considered from the passenger point of view. Paratransit systems are able to provide minimal access distance and pleasant waiting environments. However, paratransit concept may not be an effective method of improving public transport reliability.

Table 3. Selected Performance of Measures.

Performance Measures	Conventional transit	Demand responsive
Access Distance	High	Zero or low
Waiting	May need shelters	Convenient
In-vehicle time	Low	High
Service flexibility	Little	High
On time reliability	High	Low

Measure of service reliability accounts for the importance of providing reliable and predictable service. Reliability affects the amount of time passengers must wait at a transit stop for a transit vehicle to arrive, as well as the consistency of a passenger arrival time at a destination on a daily basis. Reliability encompasses both on-time performance and the regularity of headways between successive transit vehicles.

The importance of reliability of bus services to both passengers and bus operators has been discussed in previous studies. For example, Newell and Potts [1964] have investigated bus schedule by considering a mathematical model of maintaining a bus schedule. Turnquist [1981] has identified potential strategies for improving reliability of bus transit service. Nicholson and Du [1994] have described a framework for analysis of transportation system reliability. Those studies have been limited to conventional service concepts that provide fixed stop, fixed schedule bus systems.

Transit operators have adopted an on-time measure based on an allowable range of time, usually from three to five minutes after the scheduled arrival or departure time. According to Bates [1986], on-time performance of bus service is measured as a bus arriving, passing or leaving a predetermined point along its route within a time periods that is no more than *e* minutes early and no more than *l* minutes late compared to a published schedule time. The values of *e* and *l* vary among transit operators. However, a definition of no more than 1 minute early and no more than 5 minutes late is the most commonly used. On the other hand, National Research Council of the USA [NRC, 1995] adopts on-time performance as being within 5 minutes of the scheduled time for conventional transit systems. For paratransit trips a window of 15 minutes is allowed.

4. SIMULATION MODEL

This section explains the simulation model developed to determine the performance measures of transit operations. There are five main components considered in the model. They are;

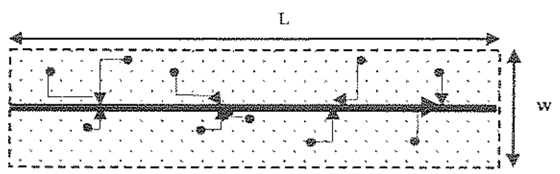
- *Service corridor*: The simulation program requires the area coverage, terminal locations, stop location and route location (for conventional transit) to be specified. The simulation considers a rectangular grid street network as the default setting. In the simulation of a conventional transit system, buses stop only at the designated stop locations. It is assumed that passengers access stops nearest to their respective origin (home) locations. Stop locations are equally spaced along the route.
- *Passenger distribution in space and time*: The simulation model allows varying the passenger demand level along the corridor. The transit demand can be uniform or non-uniform along the corridor over time. 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*: Paratransit passengers request transit service by contacting a central control center. Instantaneous transfer of requests from passenger to control center to bus driver is assumed. Thus the first bus that passes the passenger waiting location guarantees service. This aspect will be explained in the next section.
- *Vehicle and passenger characteristics*: The simulation requires vehicle characteristics related to bus operating speed for computation of travel times and door open and close times 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 and size of vehicles. Vehicles are assumed to operate at a constant speed.
- *Scheduling*: Start time, headway and hours of operation in a day can be specified by the user of the simulation model.

Spatial and temporal distributions of public transport demand (passenger origin) are generated from the input demand distributions. Random x and y coordinates within the specified area are generated according to the specified demand levels to signify passenger origins.

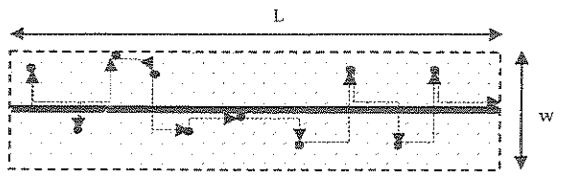
4.1 Conventional Transit Systems

The simulation of conventional transit operation computes the access distance for each passenger to the nearest bus stop. Then, access time is computed by division of walking distance to the nearest bus stop and walking speed. Walking is the only access mode considered in this analysis.

Consider the catchment shown in Figure 1a. The shaded area in the figure shows the catchment area of service, with length of route *L* and width of corridor *w*. The black dots are the passenger origins, and the arrow lines are walking tracks from origins to nearest bus stop locations. It is shown that each passenger has to walk in two directions, both in lateral and longitudinal direction to the route alignment. As mentioned before, the access network is assumed to be a grid pattern.



(a) Conventional transit



(a) Paratransit

Figure 1. Operational strategies.

The passenger waiting time at a bus stop is calculated from the time of passenger arrival at the bus stop and time of pickup by a bus. The passenger boards the first available bus. The waiting time includes the time taken for a queue of passengers to board a bus.

The in-vehicle time for each passenger is determined by the time from boarding to alighting at destination.

4.2 Paratransit Systems

Paratransit systems provide door-to-door service by deviating from the main route to serve passengers. In this model vehicles operate on a corridor rather then fixed a route. Figure 1b shows the paratransit route strategy applied to same passengers covered in Figure 1a. The vehicle collects passengers from origin locations and continues to subsequent passenger origin locations as shown by the dotted lines.

Each passenger request is identified by location and time. The simulation of paratransit operation computes the waiting time at passenger origin locations by the time of request and time of pickup by a bus. The passenger is served by the first possible bus.

The simulation computes the passenger travel time by adding access time, waiting time and in-vehicle time. The simulation keeps a detail record of the progress of each bus along the route between two termini. Therefore, the progress of buses as a set of trajectories can be plotted from the distance along the route on horizontal axis and time on the vertical axis as shown later.

5. COMMUNICATION INTERFACE

An important aspect of paratransit operations is how passengers make requests. This relies on the communication system. Paratransit systems require a special process for bus drivers to know passenger locations in advance. A mechanism is needed to process information from passenger to a controller and to the bus driver. The communication system may consist of telephone, mobile phone or internet facilities.

According to McDonald and Lyons [1996], there are three suitable in-vehicle communication systems. They are autonomous navigation aids, one-way devices and two-way communication systems. The one-way and two-way communication systems are sufficient for the present day paratransit systems. In one-way communication systems, information is sent from the control center to the vehicle without the ability for a response or a query from the driver to the control center. On the other hand, two-way communications enable information from the vehicle to be passed to the central control as well. This allows vehicles to be accurately tracked along the route.

There are limited recent developments in electronic communications and navigation aspects in the Australian context although, there has been number of recent paratransit case studies in Australia that has attempted deviations from the conventional transit strategy.

6. SIMULATION ANALYSIS

The objective of this analysis is to account for access, waiting and travelling components of the public transport journey.

6.1 Effects of Journey Time

The effect of passenger demand on the average journey time of passengers for different operational strategies is shown in Figure 2. For the purposes of illustration, it is assumed that the width of route corridor is 1 km; the route length is 10 km; the walking speed is 5 km/hr; the average vehicle operating speed is 30 km/hr and the total boarding and alighting time for each passenger is 6 seconds. For conventional transit operation, it is assumed that the stop spacing is 0.5 km. Headway of bus service is selected as 30 minutes. The simulation has been repeated 25 times to obtain each data point shown.

As seen in Figure 2, the average of waiting time increases rapidly as passenger demand level increases for the paratransit operation. The paratransit is suitable only in low demand density areas. This strategy is not suitable for demand density levels of more than 4 pas/km^2/hr under the service parameters adopted in the simulation.

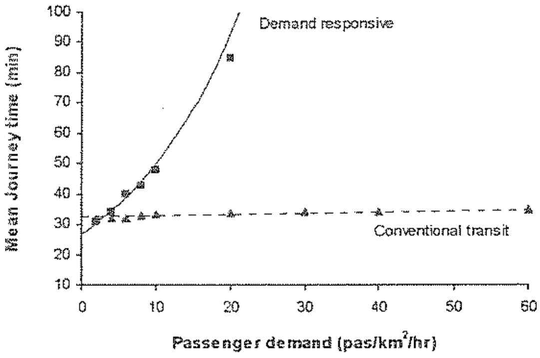


Figure 2. Average journey times.

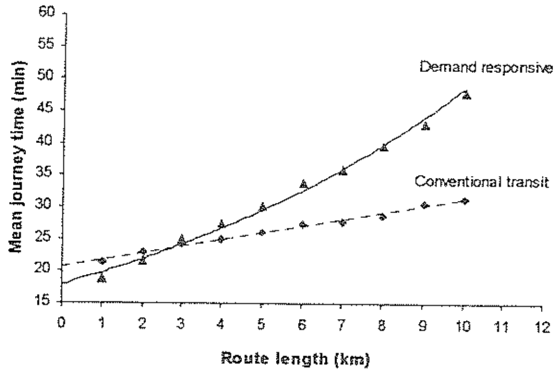


Figure 3. Effect of route length.

6.2 Effect of Route Length

Figure 3 shows the effect of route length on mean travel time. Here, the simulation has been repeated for different route lengths. The demand level for these conditions has been selected as 10 pas/km^2/hr. From the point of view passenger travel time, the demand responsive strategy provides lower mean journey time compared to conventional operation for up to 3 km of route length under these conditions.

6.3 Effect of Route Length and Demand Level

Figure 4 shows the effect of varying the level of demand as well as route length on journey time. These graphs are plotted by selecting points of intersections of graphs in Figure 3 to identify the operational strategy suitable under a given level of passenger demand. The simulation has been repeated for different values of passenger demand to obtain the Figure 4.

Journey time is a minimum with the paratransit option at low levels of route length and passenger demand as discussed earlier. There is an inverse proportionality like relationship observed here.

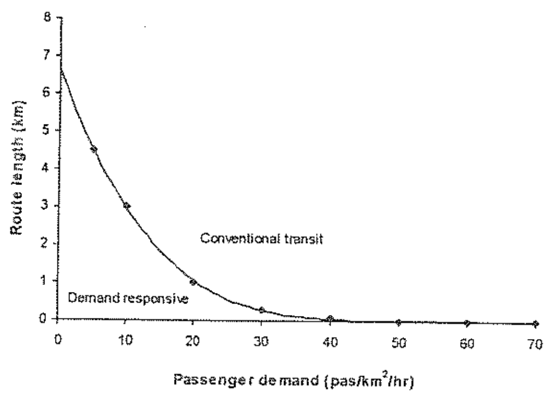


Figure 4. Operation selection according to travel time minimisation.

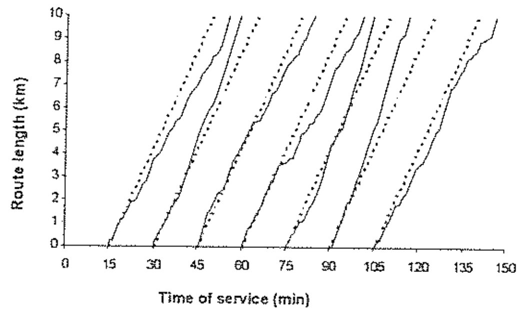


Figure 5. Bus trajectories.

6.4 Effect of Demand Level on Reliability

Identifying the level of reliability of bus operations is achieved by comparing the simulated operation with the scheduled trajectory diagram. The performance measures considered are maximum and average of lateness and earliness, and average passenger occupancy.

Figure 5 shows an example of trajectories for a sequence of buses collecting passengers by a paratransit system. The vertical axis represents the length of corridor. The horizontal axis represents the times of service.

Dotted lines represent bus trajectories when the schedule is perfectly maintained. Solid lines indicate the simulation result. Newell and Potts [1964] have provided a theoretical justification for this phenomenon in the context of conventional bus operations. For example, if one bus is delayed, it gets behind schedule and collects more passengers than its target occupancy. Thus, the next bus collects fewer passengers and gets ahead of schedule. The separation between solid and dotted lines in Figure 5 show the earliness or lateness of buses.

A set of simulations has been conducted to examine the effect of different passenger demand levels on reliability. Seven levels of demand density has been considered for each operational

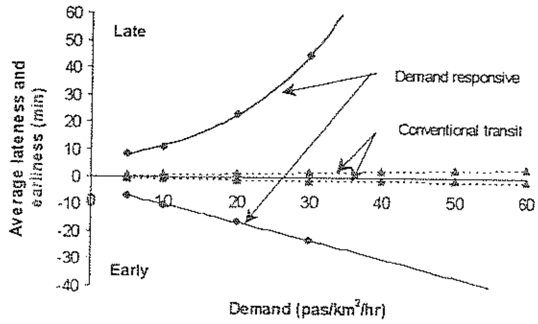


Figure 6. Average lateness and earliness of transit arrival time.

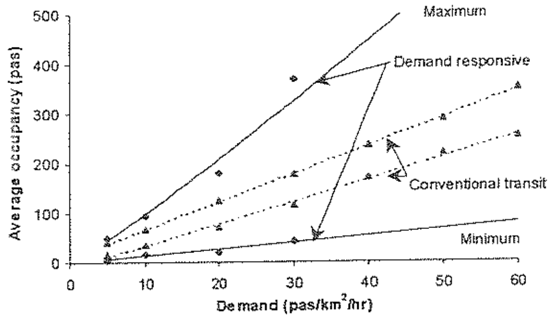


Figure 7. Average occupancy of transit service.

strategy. Demand density is varied from 5 pass/km^2/hr to 60 pass/km^2/hr. Each demand density level is covered by 25 simulations. The catchment area and operational parameters are as mentioned in section 6.1.

Figure 6 shows average lateness and average earliness of bus arrival time. It shows that as the demand density increases the average lateness and average earliness of bus arrival time increases. For paratransit strategies the average lateness and average earliness is higher than conventional operation. Thus, Figure 6 shows that the conventional strategy provides a better on-time performance under the range of demand densities considered.

Figure 7 presents the average of maximum and minimum of arrival occupancy at the terminus under different demand densities along the route. It is shown that increase of demand density increases the average occupancy. This graph is important to analyse the suitability of vehicle size at the selected demand density.

7. CONCLUSIONS

A simulation model has been developed to account for access, waiting and in-vehicle component of the passenger journey and mimic movements of buses. Conventional transit and paratransit systems have been analysed in this paper.

The model is able to determine the effect of varying the level of demand and route length on journey time. The simulation model reveals that the passenger demand and route length are significant determinants in selecting the operating strategy.

Simulation analysis of level of reliability of bus operations shows that the increase of demand density reduces reliability of bus service. It is observed that on-time performance behaviour of paratransit systems require a relatively large tolerance under all demand levels considered. A related performance measure covering occupancy levels has also shown similar results according to the simulation.

8. REFERENCES

ABS (Australian Bureau Statistics), *ACT in Focus*, Report 1307.8. Australian Bureau Statistic, Australia, 1998.

Bates, J.W., Definition of Practices for Bus Transit On-Time Performance: Preliminary Study, *Transportation Research Circular*, 300, 1-5, 1986.

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

Bus Australia, *Welcome to Bus Australia*, http://member.rivernets.com.au/busaust, accessed on 7 February 2001.

DoT NSW (Department of Transport New South Wales), *Sydney Public Transport Directory*, NSW Government, Australia, 1998.

Lave, R., and R. Mathias, State of the Art of Paratransit, In: *Transportation in the New Millenium*, TRB Publication, 2000.

McDonald M., and G.D. Lyons, Driver information, *Traffic Engineering & Control*, 37(1), 10-15, 1996.

Newell, G.F. and R.B. Potts, Maintaining a bus schedule, *Proceeding of the 2nd ARRB Conference*, 1, 388-393, 1964.

Nicholson, A.J. and Z.P. Du, Improving transportation system reliability: a framework, *Proceeding of the 17th ARRB Conference*, 6, 1-17, 1994.

NRC (National Research Council), *Management Toolkit for Rural and Small Urban Transport Systems*, TCRP, Report 54, 1995.

OECD (Organisation for Economic Cooperation and Development), *Urban Public Transport Evaluation of Performance*, Road Research Group, Paris, 1980.

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

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

Turnquist, M.A., Strategies for improving reliability of bus transit service, *Transportation Research Record*, 818, 7-13, 1981.