An Activity-Oriented Urban Passenger Transport Model

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Abstract:

The application of information technology (computers and communications) is the basis for the development of future public transport systems. Such systems will respond to individual requests with attractive generalised costs. This paper describes a modelling system designed to investigate the performance of urban passenger transport systems offering a range of fixed and demand responsive transport services The system called LITRES aims to link simulation, resource optimisation, census databases, and geographic information systems to traditional transport models.

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1. Introduction

Urban passenger transportation is a major operational and planning problem. Public transport is the key component. Traditionally it has been based on mass transit vehicles (train, bus, and light rail). While these will continue to have the most important role, it is proposed that newer forms of public transport will arise to complement mass transit.

Over the last decade there has been a great deal of r&d in the application of computing and communications technology to transport (cf DRIVE (1991), IVHS America (1993) and IVHS Australia (1992)). This is raising the prospects of public transport systems characterised by demand response, continuous availability and point to point service. These services will be provided by road vehicles in the form of extensions and hybrids of bus and taxi services

Ideally public transport is planned and operated as an integrated system. Thus it is important that a good understanding of the new types of services be developed, both in their individual potential and in their effect on a renewed and integrated system. This paper addresses the modelling of passenger transport systems in the light of the new technology and planning requirements

2. Intelligent Vehicle and Highway Systems (IVHS)

The use of information technology (computers and communications) in road transport and traffic systems is termed road transport informatics (RTI) in Europe and IVHS in America. Recently an Australian IVHS society has been formed so we use the latter term.

IVHS America has identified five major transport areas in which the technology will develop. These are labelled:

- Advanced Traffic Management Systems
- Advanced Traveller Information Systems
- Advanced Vehicle Control Systems
- Commercial Vehicle Operations
- Advanced Public Transportation Systems

This paper primarily addresses the last area, although there is considerable overlap in both the technology and the operational interaction of such systems. At the technology level there are important moves afoot in the United States to establish an IVHS system architecture. This is divided into two main areas: (1) infrastructure and (2) in-vehicle systems. The development of appropriate standards around this architecture will allow generic technology modules to support different types of system.

In operational contexts, the passenger is paramount. Traveller Information systems impact Traffic Management and Public Transport. Vehicle Control technology such as vehicle location and dispatching provide the basis for the real time control necessary for both Commercial Operations and advanced Public Transport. In passenger systems real time control will have to be highly adaptive if it is to accommodate the dynamic electives of the passenger. Thus modelling and simulation have an important contribution in assisting our insight

3. Modes of Passenger Transportation

Glazebrook (1993) has given a conceptual overview of how innovative IVHS based systems might be used in conjunction with established modes of passenger transport. A summary of the key characteristics of the various modes is given in Table 1. Conventionally urban transport modes are classified as private (self-drive), public (mass transit) and for-hire (taxis). IVHS will enable new forms of multi-hire, on-demand services. These will be akin to some of the paratransit operations common in developing countries, but will utilise the new technologies. A wider range of modes with different characteristics will then be available.

Table 1 Passenger Transport Modes and Key Characteristics

Mode	Vehicle	Typical Cost (cents/pass-km)	Spatial Characteristics	Temporal Characteristics
Fast Rail	Heavy Rail	10-20	Fixed Routes Limited Stops	Fixed Schedule
Standard Rail	Heavy and Light Rail	20-30	Fixed Routes Frequent Stops	Fixed Schedule
Express Bus	Standard or Maxi-Bus	20-30	Fixed Routes Limited Stops	Fixed Schedule
Standard Bus	Bus (various sizes)	20-40	Fixed Routes Frequent Stops	Fixed Schedule
Feeder Bus	Minibus	30-50	Fixed or Variable Route serving major activity/transfer point	Fixed or On-demand
Multihire	Taxi, Minivan, Minibus	50-70	Flexible	On-demand and Pre-booked
Single hire	Taxi	80-130	Flexible	On-demand and Pre-booked
Shared Ride Car Pool	Private Car	low or zero for passenger	Flexible	On-demand and Pre-booked

In addition the integration of various technologies will also enable development of new public transport systems based on the Personal Public Transport (PPT) concept (Glazebrook, 1993). In particular the following systems will be utilised.

- Vehicle Location Systems
- Automatic Multi-Hire Vehicle Dispatching Systems
- Mobile Data Communication Systems
- Real-Time Passenger Information and Display Systems
- Automatic Billing (as opposed to ticketing) Systems
- Personal Communications Systems and "Electronic" Bus Stops

PPT differs from conventional public transport in that it will enable fixed route, fixed schedule public transport systems provided by buses, trains, etc to be integrated with a range of on-demand and semi-on-demand systems provided by taxis, minivans, minibuses and other road based vehicles to provide a seamless multi-mode real-time system. Furthermore individual passengers will be offered choices of modes and combinations of modes, enabling demand response in the total public transport system.

In large urban areas many medium- to long-distance trips by public transport will involve at least two modes. Typically these will be an access mode using a demand responsive or high frequency scheduled feeder service combined with a high speed, high frequency, long distance line haul service (fast train or express bus). The combination will allow passengers to minimise walking, waiting, transfer and in-vehicle times whilst utilising the relatively low individual and social cost of the line haul system. In addition, this will greatly expand the effective catchment area of the express line haul services. Shorter (under 5 - 10 km) trips will typically be taken by either conventional or high frequency bus services, or demand responsive modes.

4. Modelling Requirements

The framework of a comprehensive modelling system has been described by Auxhausen et al (1991). This is shown in Figure 1. The scope of the work addressed in this paper includes daily scheduling and the layers below. Modelling requirements can be divided into four main areas.

- trip demand and service expectations
- fleet and infrastructure
- routing and scheduling
- mode choice

The associated analysis concerns trip performance and fleet performance and the output data must be translatable into personal, economic and commercial measures.

Trip Demand

The major parameters have been described traditionally by origin/destination matrices, and the time period over which these statistics apply. From Figure 1 we note that this should be expanded to model a daily schedule. Another part of the model must represent the expectations or requirements of the traveller in terms of elapsed journey time, wait time, and generalised costs. The realities of modelling are determined by established transport network models and census data.

Fleets

The fleet is described by modules which have service capacity and mobility constraints. These can be partitioned into fixed route, time-tabled services (eg bus, train, and light rail) and demand response fleets (eg taxis). The latter category will expand in the future to include numerous types of chauffeured multiple hire service enabled by IVHS. In order to complete the model the use of the private car should be included. A future possibility is short term (one trip) car rental (Smith (1992)).

Geographic Information

The infrastructure is largely described by data held in geographic information systems and related modelling systems. Thus it is important that the model be properly interfaced to such systems. Example data describes residential and urban topography and transport network topology.

Real Time Control

This is simplified in the case of systems operating under pre-planned, advertised schedules. The main issues concern adherence to schedule and overload. Routing and scheduling are a major modelling and system optimisation challenge for demand responsive services.

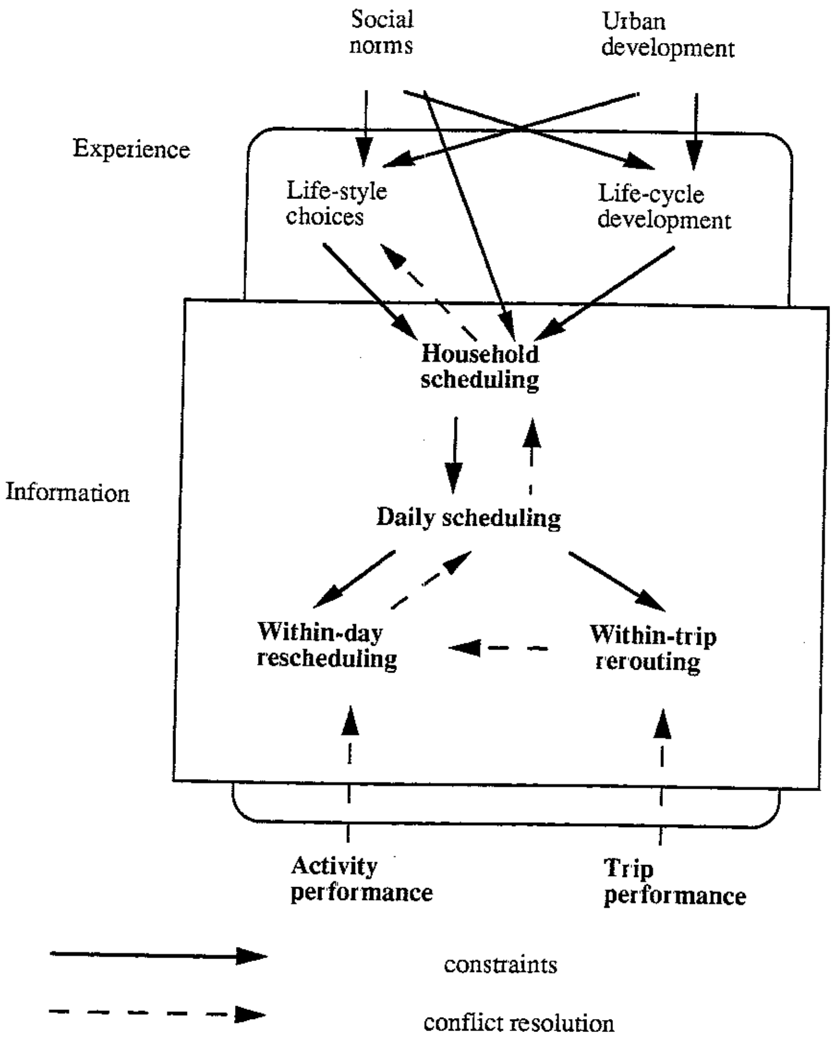


Figure 1 Framework proposed by Axhausen et al (1991) for event oriented simulation.

Mode Choice

The significant simulation results will be those for the relevant mode choices. Mode choice determines the dynamic mapping of demand to the available fleets. It is not a component of the modelling and system described here. It is an area which is the subject of other work (eg Altinoglou and Smith (1992)) and it is one which calls for the interoperability of models.

Interoperability of Models

The aim of the work described in this paper is to extend transport modelling to support transport planning including the impact of IVHS. There is no point re-inventing the wheel, nor can the whole of the transport spectrum be included in one model.

Transport network models are the source of some important parameters, as well as base topological network data. In addition there is the transit services data. Together this data will support the generic distance/travel time components of the current model.

Trip demand statistics arise from trip generation models. More recent sources are the various census such as the Sydney household travel survey (Itorralba and Balce (1992)). Finally there is the requirement for mode choice statistics.

The new systems being modelled can substantially change mode choice and improve network capacity. Traveller information systems and new services with improved generalised costs are two real life factors. Thus the interoperability of models should be a closed loop with iterations based on a two way flow of data between models, with models becoming more tightly coupled in the future.

Analysis

The purpose of this model is to support the evolution of passenger transport and the exploitation of IVHS technology. The approach is to rely on other models to provide the infrastructure capacity, and the consumer demand and behaviour profile. The analytical capabilities of this model must support the comparative performance of various fleet and infrastructure alternatives. The performance parameters must allow measurement of both the service delivered and the cost of provision. The opportunity exists to exploit modern software engineering and visualisation techniques.

5. LITRES

LITRES is an activity based modelling and micro-simulation system aimed at the above requirements. It is subject to on-going development. The current features of the system are described below.

Trip Demand

The system supports two means of modelling trip demand

Stochastic Demand This conforms to well known Monte Carlo methods. The model also includes the concept of a daily schedule as implied by Figure 1. Thus each traveller is represented by a sequence of trips with the length of stay at each destination being described stochastically. The starting point for the daily schedule is generated from the geographic description of residential areas. Destinations are generated similarly from other types of region.

OD Matrices. This interfaces to the export of statistics from census and other trip generation models. This is based on the aggregation of statistics to a zone level. Each element in an input matrix gives the number of inter-zone trips occurring during the time interval covered by the matrix. Matrix data can be assigned to each sub-class of the population (see below).

The temporal and spatial distribution of trips may be described by non-continuous distributions, typical of real life, but not easily accommodated in analytical models. For example the density of demand can be clustered to correspond to phenomenon such as ranks, bus stops, and mass transit arrivals (eg at railway stations).

Population

The model allows the travelling population to be subdivided into classes. The associated classification discriminates on the basis of the requirements and expectations of transport services, and thus provides a basis for interfacing to mode choice models.

Fleet

The current system only models demand response fleets. Fleets are divided into subclasses according to vehicle performance and service characteristics, routing and scheduling policy, and the policies for the deployment and withdrawal of idle vehicles.

Fleets are associated with depots which have a limited fleet size. Ranks may have a daily time profile for the number of idle vehicles which are permitted to stand on each particular rank.

Geographic Model

The geographic model can be subdivided into geometric classes and topology. Geometry is either region, line or point. A rectangular cellular decomposition underlies region geometry, with support for composite objects.

Other classes in the model have these geographic properties. Residential, commercial and institutional areas have region geometry, as do the zones underlying OD matrices. Locations associated with fleets (eg depots and ranks) may be point or region based. Point locations describe the origins and destinations underlying schedules and OD matrices.

The model of distance is euclidean on a uniform two dimensional space (future versions will use transport networks). Each trip is computed as the crow flies and adjusted by a constant factor to account for road distance. However "gateways" can be declared between zones so that individual trips are subdivided into two or more component legs involving a gateway.

Routing and Scheduling

This is the simulation equivalent of future real time control systems. For demand responsive fleets some of the underlying optimisation problems are unsolved. Thus the simulation may only provide local optima in a global problem.

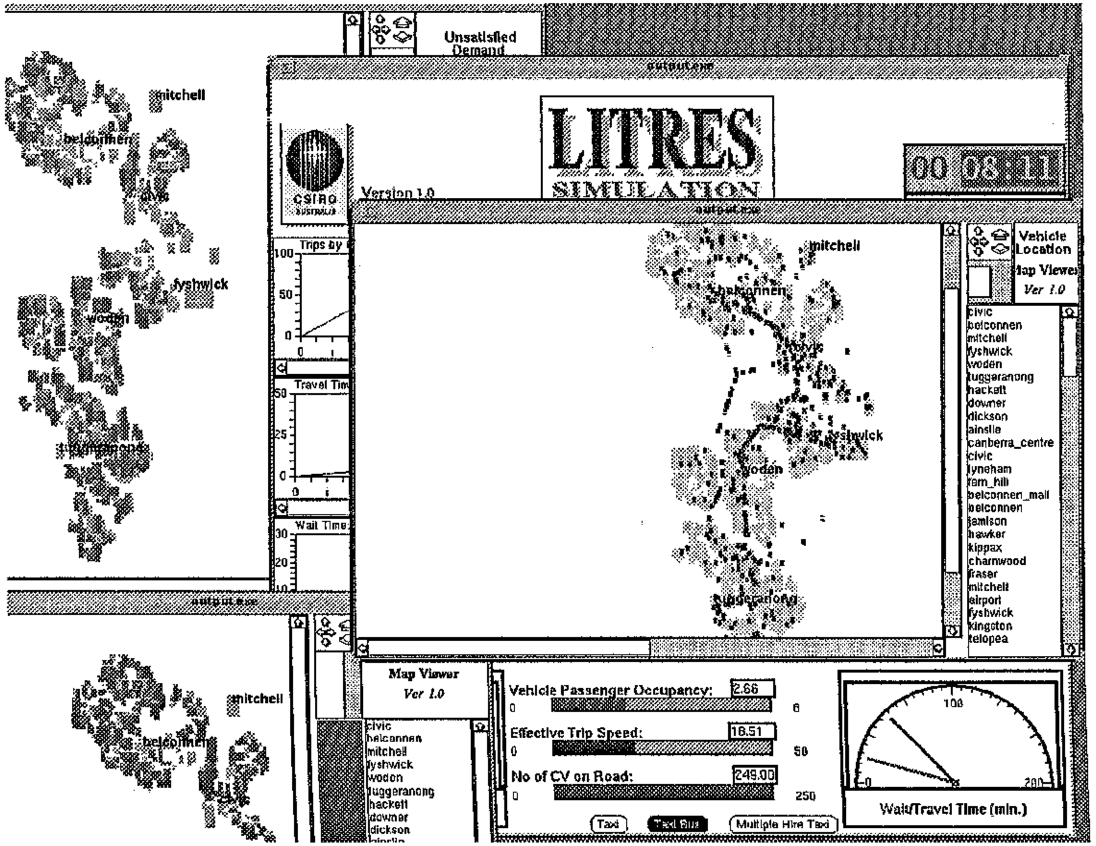
The basic function is to allocate a vehicle to service a demand when it arises. The origin and destination and the level of service are evaluated against each candidate vehicle in the light of its existing commitments. The generic policy is multiple-hire, but no new passenger commitment should cause the level of service to passengers to whom commitments have already been made, to drop below the contracted standard.

A difficult step in the sophistication of this module is to translate the optimisation problem from the individual demand to the global population/fleet level. A useful step in this process is the modelling of reservations, a real life mechanism which is akin to the prediction of future demand.

User Interfaces

Input to the system is concerned with establishing the relatively large number of parameters and data sets for a run. This is done through a graphical user interface.

The output interface provides a real time visualisation of the simulation model in execution, based on an advanced colour graphics workstation. It provides useful insight not available from statistical reporting. An example snapshot is shown in Figure 2, with much of the visualisation power lost in this media. The maps show demand density and unserviced demand density. The graphs show a rolling average of the percentage of



Vehicle Passenger Occupancy: 2.66

Effective Trip Speed: 16.51

No of CV on Road: 249.00

Figure 2 Example output for Canberra.

demand being serviced by two different fleets, and similarly for the waiting time and ride time The fleets being simulated in Figure 2 cannot cope with the peak hour demand.

The second component of the output is the reporting of summary and detailed statistics describing the performance, together with the identifying parameters of the run.

Computing Characteristics

The design and implementation of this system has been done using modern object-oriented techniques. This enables the model to be reused and specialised to provide a simulation of any particular urban environment, and to be adapted to the relevant adjunct models.

The implementation illustrated in Figure 2 uses Sun workstations, but has a high degree of portability. Because of the demands of large scale micro simulations some applications may call for even more powerful computing resources.

6. Example

A demonstration simulation based on journey to work in Canberra is described. The example is designed to contrast the performance obtained from three different types of fleet, each consisting of 500 chaufeurred vehicles servicing the same demand load. In the first case the fleet consists of 500 taxis, in the second case 500 multiple hire taxis, and in the third case 500 minibuses (taxi-buses). The demand is modelled by 20,000 commuters whose schedule corresponds to a round trip journey to work. The residences of this population are distributed throughout the residential areas of Canberra, and the work locations are independently distributed throughout the town centre, commercial, industrial and institutional areas, subject to the constraint that no trip is longer than 20 km. The probability distributions of departure time from home and duration of stay at work is given in Figure 3. Class A commuters constitute 90% of the population and class B constitute the remaining 10% These distributions are not based on any survey data and were chosen for demonstration purposes only

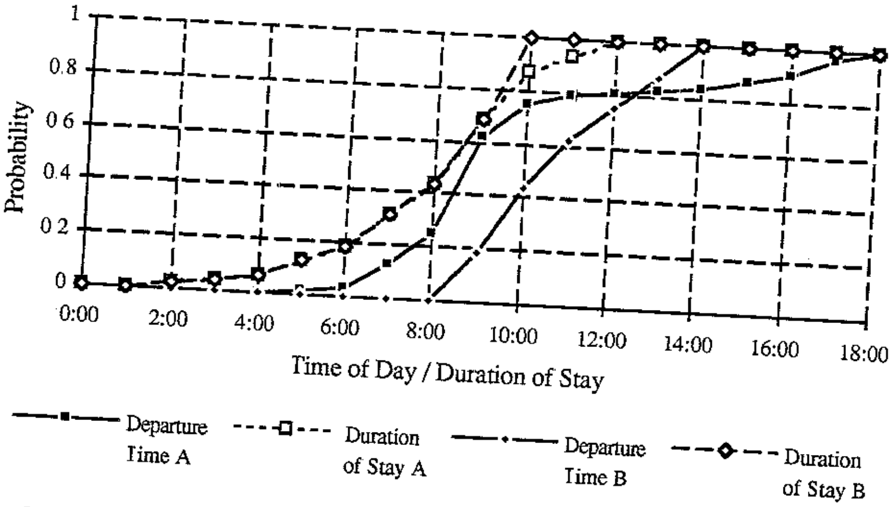


Figure 3 Trip time probability distributions.

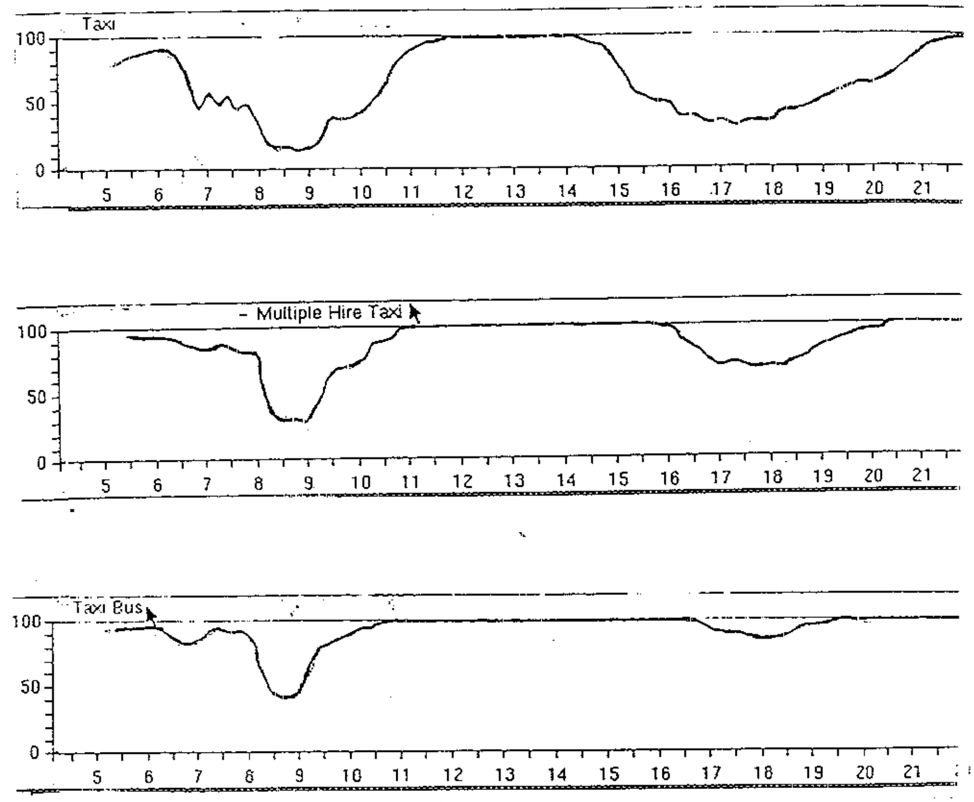


Figure 4 The percent of demand met by each fleet plotted against time of day. The statistic is an average over the preceding 20 minutes.

In each case demand arises spontaneously (eg by telephone, electronic bus stop, or other forms of direct communication with the real time control system). There are no advance bookings in this example. The expectation of each commuter is modelled by a parameter p ($0 < p < 1$). This is used in the computation of the maximum acceptable elapsed time from notification of request to arrival at destination (viz T_d/p where T_d is the time for a direct journey from origin to destination). The elapsed time also has a threshold waiting time of 10 minutes for short trips in this example.

A taxi can only convey one client at a time. The other types of vehicle can convey multiple clients having independent origins and destinations. For each request a search of the fleet is made for a vehicle which can meet the request within the time constraints specified. Other parameters such as empty (dead) mileage, proximity, and fastest service are also applied in the choice. The order of pickups and set-downs is revised every time a new client is allocated to a multiple-hire vehicle. A new client is not allocated if any existing client would have his elapsed journey time degraded below the minimum expectation.

If no fleet vehicle can satisfy a request, a failure statistic is logged. The unserviced movement is modelled to occur at the same speed as if serviced by a dedicated fleet vehicle. Thus the next trip on this individual's schedule will arise in due course, at the intended destination.

The results in Tables 2 and 3 show that the taxi fleet can only service half of the demand, whereas the same number of 8 seater mini-buses can service 7/8 of the demand. The way in which the fleets fail to meet peak hour demand is shown in Figure 4. The differential in average trip distances serviced by each fleet arises largely because of this variation and the associated routing and allocation. The vehicle allocation strategy used in these runs causes the suprisingly poor relative performance of taxis in terms of wait time. Requests are given a yes/no commitment at the time they arise (a reasonable strategy for traveller information). In situations of excessive demand this results in some taxis being committed to relatively unsuitable fares in advance, whereas a more suitable fare would arise before the current fare is discharged. The multiple hire vehicles have the flexibility to fill in the "gaps" in such situations. On the other hand passengers in multiple hire vehicles suffer some deviation over their direct routes, and thus their ride times are proportionately longer. In this case, by almost all measures, the service delivered by taxi-bus (minibus) is better than the multiple hire taxi, which is in turn better than the taxi.

Fleet performance is also significantly in favour of the multiple hire vehicles. The effective occupancy (based on a passenger's direct route distance) of taxi-buses is almost double that of the taxi. On-road time is also lower, because fewer vehicles are needed to service the off peak demand.

Table 2 Average passenger service for fleets described in Table 3, schedule trips (Figure 3) randomly chosen between Canberra residential areas and the town centre, industrial and institutional areas, minimum trip distance 1.5km, maximum trip distance 20km.

Fleet Type	Trip Distance	Wait Time	Ride Time	Trip Time	Effective Speed	Trip Deviation
Taxi	13.5km	26.8min	16.5min	43.3min	18.7kph	0%
MH Taxi	13.0km	18.5min	20.3min	38.8min	20.1kph	<30%
Taxi-Bus	12.7km	12.7min	23.3min	36.0min	21.2kph	<53%

Table 3 Average fleet performance for the situation described in Table 2, serviced by a fleet of 500 vehicles, with return to rank policy for idle vehicles.

Fleet Type	Vehicle Capacity	Requests Serviced	Occupancy	Effective Occup-	Time Deploy'd	Distance Travelled	Effective Distance
Taxi	1	52.7%	0.64	0.64	17:08hr	839km	536km
MH Taxi	3	77.1%	1.32	1.04	15:14hr	732km	763km
Taxi-Bus	8	87.1%	1.83	1.24	14:15hr	677km	837km

7. Conclusion

The results quoted in the previous section should only be taken as a stimulus for more investigation. We believe that there are several underlying factors in the relative performance of the fleets. One is the healthy degree of back-loading arising from the inter-town trip patterns (a possibly pronounced feature of Canberra) which enables a multiple hire vehicle to maintain an economically significant load advantage. Another is the assumed time probability distributions for trips, which seem plausible, but which are not based on any survey. The average trip length shown in Table 1 reflects the distributed characteristic of the Canberra plan, and thus may not be typical of other cities.

All the results shown here are subject to improvement. The general routing and scheduling problem is unsolved. The above results are based on local optimisation, treating each request individually at the instant of its generation and matching it to the fleet. Intuition says that better results will be obtained by maintaining a time window of non-committed requests. These requests should be matched to the fleet in a global manner, with a request only having to be committed when the delay in its commitment has reached the permissible limit.

LITRES is a planning tool which can play an important role in future urban passenger transport planning. It has been designed as a generic tool which can be specialised for any urban environment. There are two major enabling design features. The first is its software engineering platform, being based on object-oriented tools. The second is its modular view of other modelling systems and information systems, such as geographic information systems.

There are several areas in which evolution of the LITRES system is planned. As a step towards developing the complete model of passenger transport in a city, the other forms of passenger transport (eg bus routes and private car in Canberra) will be modelled along with measures which provide cost comparison. Network topology and capacity is required for more accurate modelling of trip performance and fleet performance. The modelling of advance bookings for demand responsive systems is a practical requirement of some importance.

As the detail of the model increases so the need for more powerful computational resources will arise. Thus the porting of the model to new parallel computer systems is a technology-level exercise which has to be considered. This will have additional value in terms of the experience gained for future real time control systems.

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