References

Blunden W.R and Black J.A (1984) The Land-Use Transport System, 2nd edition, Sydney, Pergammon Press.

Cochran J.K and Lin L (1989) Application of computer simulation to freight transport systems *Journal of the Operations Research Society* Volume 40 Number 5 London, Mac Millian Press.

National Association of Australian State Road Authorties (1984) The NAASRA Roads Study 1984, Use of Urban Transport Planning Techniques, Technical Report Number 8, Brisbane, Magenta Press.

LITRES: A Proposal for an Application of Information Technology to Urban Commuting

John Smith
Division of Information Technology
CSIRO

Abstract:

The LITRES concept exploits information technology to harness two complementary transport system features, vehicle re-use and ride sharing, to combat the major threats to cities posed by continued use of the private motor car. It is claimed that lower generalised costs and the potential to create a different mentality towards the motor car will persuade users to adapt to the system. When information technology is combined with new vehicle technology, the system can make large cities ecologically sustainable while still answering the demand for the ad hoc convenience of the motor car.

Contact Author:

Dr John Smith
CSIRO
GPO Box 664
CANBERRA ACT 2601

Telephone: (06) 275 0928 Fax: (06) 257 1052

Introduction

Over the last decade computing and communications technology has evolved from "back-room stuff" to pervade our daily lives (eg personal computers, facsimile, Sky Channel, intelligent phones, compact discs, and so on). Information technology is now delivering sophisticated large scale systems on which we totally depend. For example, airliners are "flown" by computers and projects are underway to automate air traffic control. It is only a case of how long before our urban transport systems are revolutionised by information technology.

This paper is targeting two types of reader. In the first place, we want to create a general awareness amongst professionals and planners in the transport industry that major changes in urban transport are going to occur over the next few decades, based on information technology. Secondly, the paper is part of a case being developed for a collaborative research and development project, involving CSIRO and other bodies, on technology related to road transport, as illustrated by the specific proposal developed below.

The proposal concerns a novel approach to meeting urban commuting needs. Usually the commuter has a number of choices such as walking, cycling, motor cycle, private motor car, taxi, and mass transport vehicles (eg buses, trams and trains). Public transport is normally regarded as consisting of taxis and mass transport vehicles. While we can anticipate some significant technology changes, these basic vehicles are likely to remain (in character) as the main alternatives.

Almost everyone is familiar with the frustration of commuting in a large city. The de facto situation is that a large proportion of commuting is done by private motor car in preference to using public transport. When we superimpose this traffic on that of commerce and industry, in most cities the result is serious traffic congestion, and an insatiable demand for roads and parking. In addition there is concern about energy consumption, particularly with fossil fuels. Fossil fuel consumption is seen as a problem both because of the associated air pollution and because of the perceived greenhouse effect.

Most cities have developed haphazardly but originally with a logical star-topology, that is all roads led to the port and the main area of commerce. On this basic pattern has been superimposed a newer layer of distributed development. The latter was in the first place aided by fast transport, but in large cities this has probably ceased to be the case. Instead distribution is now aided by the revolution in communications and by sheer necessity.

Distribution of journeys is the main factor working against public transport. A fixed network (typically operating on an underlying radial grid) cannot satisfy a consumer demand for transport between random points. Generalised costs of public transport are unacceptable. In addition, having invested in a motor car, the incremental costs of private transport are seen as competitive to the use of public transport. The commuter ignores the various hidden costs relating to infrastructure and environment. On the other hand the motor car offers many benefits to the commuter which are also difficult to quantify. Some of these relate to the freedom to choose one's direct destination, time of departure, route and degree of privacy.

There are two major changes which are likely to parallel any direct affront on urban transport problems. These should be recognised lest we attempt to tackle problems which may be resolved by other means. The first is the move underway in the automobile industry to find replacements for the internal combustion engine. The use of electric motors as the direct means of propulsion is well advanced and this has many attractions. The problem of energy storage cells is the Achilles heel. Thus the use of hydrogen in a hybrid electric design, and as the basic propellant, is also being developed. The relevant implication here is that the motor car is unlikely to be replaced because of pollution related matters. (We also imply that any long term issues related to greenhouse

effect will be compensated by access to clean energy sources, renewable or nuclear).

The second type of change will arise from current studies and proposals for more efficient use of the infrastructure associated with urban living (viz the services provided to a residential block). There is no consensus on this issue. Most researchers predict higher urban population densities, at least in localised areas (Newman and Kenworthy (1991)). Black (1992) speaks of the need to identify "environmental capacity", in which transport is just one parameter. However these densely occupied areas are likely to be complemented with open areas for aesthetic reasons and for leisure. Results in this area might lead to radical approaches to urban transport, especially if a completely new city were to be designed.

The remainder of this paper concentrates on two related themes. The first is the rapid growth of road transport informatics (computers and communications applied to road transport). The second is a proposal for a radical development in this technology which involves a completely different way of exploiting the motor car for urban commuting. *The proposed system can deliver the ad hoc convenience of the motor car to commuters at lower cost, while significantly reducing traffic congestion and parking requirements.*

Road Transport Informatics (RTI)

The use of information technology (computers and communications) in road transport and traffic systems has been the focus of very large research and development projects around the world (see DRIVE, 1991). Hence the term road transport informatics (RTI) has arisen in Europe. This work accelerated during the 1980's so that a number of systems are now becoming operational. This section includes a brief summary of a report compiled by De Cata et al (1990) after a joint study mission to Singapore, Europe and the USA. Some of the notable activities reported were:

• A road pricing scheme intended as a congestion reduction measure has been in operation in Singapore's central business district for many years. Conversion to electronic operation is currently proposed.

• In Berlin a demonstration fleet of 700 vehicles carry receiving, displaying and transmitting equipment for a system called ALI-SCOUT. The system provides real time navigation and is capable of many other traffic applications. The equipment communicates with beacons installed at traffic lights using infra red transmission. The driver is told which lane to be in and where to turn.

• Many cities (including Sydney) are experimenting with automatic tolling. Systems are operational in some cities (eg Dallas North Tollway). The Amtech system uses microwave communication to sense a tag, carried by the vehicle, as it approaches a toll collection point. The owner of the tag makes payments to an account associated with the tag id.

• Heavy vehicle fleet management is also in demonstration. One system is based on writable vehicle tags which are read through in-pavement antennas. Tags can be read on vehicles travelling up to 130 km/h. This system is aimed at traffic management and mass/distance taxation schemes.

The broad conclusions of De Cata et al were:

• New (information) technology offers significant opportunities for traffic management and reduced congestion, initially through route guidance systems;

• Traffic demand management through electronic congestion pricing is feasible, but generally unpopular at present. However, electronic tolling is acceptable to many communities, and privacy concerns can be addressed in many ways.

We now summarise the RTI research activities and industry groups already in existence in Australia, and known to us.

• The University of SA and CSIRO have been funded under a GIRD grant to work with

Adelaide-based International Railroad Systems for the scheduling and control of trains.
• Dynamic Transport Management Pty Ltd of Melbourne offers the following products:
Despatch Manager, an automated fleet control and real time management system;
V-Loader, which optimises delivery and pick-up schedules;
V-TRAK, an automatic vehicle location, tracking, route finding and navigation system;
IDAC, a traffic detection and congestion avoidance system.
•AMSKAN (Melbourne) has proposed the National Transport Management Information System, and is focussing on the control of containers.
•Under the TRIMS project, Vic Roads has let a contract for the supply of vehicle transponders which will communicate through in-pavement antennas to the SCRAM traffic light communications system in Melbourne. This project will develop a database of vehicle identification, location, time and date records for subsequent query and analysis.
• AWA Traffic have developed transponder and interrogator equipment for the RTA's Automatic Network Travel Time System (ANTTS).
• The NSW Road Traffic Authority (RTA) has developed the SCATS real time signal control system which is the most advanced in the world. The RTA has recently let a contract to prototype automatic tolling on the Sydney Harbour Bridge.

The above summary is included as clear evidence for our position that complex transport applications of information technology are now feasible. We propose research towards a strategic and radical commuting system in the remainder of this paper.

A Future Commuting Scenario

It is conceivable that a future city built from the ground up (it is too early to cite any contribution from the MFP) could have a transport/commuting infrastructure incorporated in its design whereby mass transport vehicles meet the bulk of commuting needs. A number of combinations of subdivision and transit network topologies and appropriate passenger vehicles could be proposed. However the more important and more challenging problem is to address the needs of existing cities. Because of the distribution of population and commerce in existing cities, *the commuting system must provide fast point-to-point transport for a large population,* whose routes conform to a quasi-random spatial distribution. Therefore we believe that low capacity self-drive vehicles (viz the motor car) will remain the dominant type of commuter vehicle. As stated in the introduction we expect the air pollution problem to be solved by new vehicle propulsion technologies.

Under these assumptions the major problems are concerned with traffic volumes and parking space. These problems were addressed in the design of Canberra, by composing it of five towns, each with its own commerce and tertiary industry centres. This has the effect of reducing trip lengths, thereby increasing the opportunity for walking and cycling. Trip lengths can also be reduced by other relocations of the working place, for example the various types of urban village proposal. The following complementary mechanism remains.

• *The way to reduce traffic volume is to increase vehicle occupancy:* therefore we have to look closely at single occupant car trips. Newman and Kenworthy (1991) state that the average vehicle occupancy for cars in Canberra declined from 1.81 in 1971 to 1.79 in 1981 to 1.66 in 1989/90. A recent spot check taken by the author on a weekday morning peak hour measured average car/station wagon occupancy at 1.27. While the latter statistic is clearly the journey-to-work category, it is the more significant for our purposes.

The main reason that there are so many single occupant car trips undertaken is that the commuter has to plan ahead and provide a vehicle for his next trip (return or on-going). In addition, this planning has to allow for the unanticipated. Commuters become committed to their particular vehicle for the day, and leave it to "rot in a parking lot". If a system could be devised whereby commuter vehicles are provided on-demand, there would be no necessity to plan ahead, and much more sharing of vehicles by family, neighbours and associates would occur.

For example, two drivers from the same household leave for work at approximately the same time, and travel in the same direction. However they drive separate vehicles because each person returns home at a different time. If both were assured of rides in a commuter vehicle on their return journey, they would share the same commuter vehicle on the outward journey. This important subject of ride-sharing is discussed later in the paper.

• *The way to reduce parking requirements is to re-use vehicles:* therefore we have to develop an attractive alternative to private ownership of the motor car.

By making a large scale, on-demand, short term car rental system the basis of commuting, all requirements for passenger vehicles (corporate and individual) could be met with a fraction of the number of cars in today's city. In the following section we examine some traffic profiles which support the thesis that a significant degree of vehicle re-use is possible.

Later sections in this paper discuss how an on-demand vehicle rental system could be developed and why it might be attractive to commuters.

Vehicle Re-use - Canberra Traffic Profiles

In the previous section we referred to the potential vehicle re-use arising from the natural phase difference between the private individual's demand for commuting and the corporate individual's demand. This is already exploited to some degree in the provision of vehicles as part of "package salaries". However there is a more significant mechanism for vehicle re-use arising from the low duty cycle to which most privately owned cars are subject.

Newman and Kenworthy (1991) provide the following profile of commuting by motor car in Canberra in 1989/90.

Number of cars and station wagons = 130,100
Total annual Vehicle Kilometres Travelled (VKT) in cars = 1,920,000,000
Average road network speed = 49.5 km/h
Urban road length = 2205 km

From the first three parameters we conclude that the average daily car duty cycle in Canberra is 49 minutes.

We now examine some average weekday traffic flows recorded on one major route and one secondary route in Canberra recorded during 1990 and 1991. Detailed statistics for two road segments are given in Figures 1-3. Segment A is on Belconnen Way, a major inter-town route. Segment B is on Maribyrnong Ave, Kaleen, where total traffic is probably a composite of inter-town and intra-town traffic, and it is not necessarily focussed on town centres.

Figure 1 shows a 24 hour profile (weekday average) for Segment A, recorded during the week of April 12, 1991. In these and subsequent figures three parameters, East Traffic, West Traffic and Cumulative Difference are plotted against the left hand

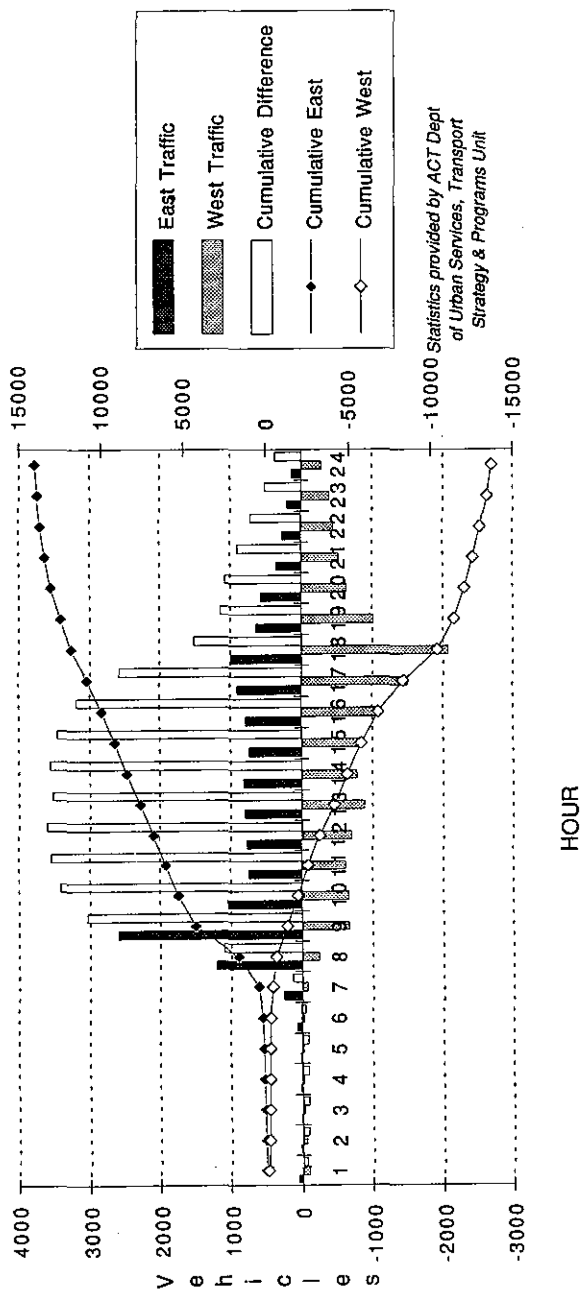

Figure 1 BELCONNEN WAY: Eastern Valley Way - Haydon Dr; Weekday Average 12/4/91

ordinate axis, while the two Cumulatives of East and West traffic are plotted against the right hand ordinate axis. These directional statistics are given as hourly totals, and accumulated as just described. In the absence of detailed modelling, we argue below that the smaller the peak Cumulative Difference is, as a percentage of total daily traffic, the more potential there is for vehicle reuse.

In Figure 1 the familiar peaks flowing east in the morning and west in the evening are prominent. Easterly movement is mostly towards Canberra's Central Business District (City and Civic Centre). Westerly movement is towards Belconnen and its town centre. (The rather small peaks in the westerly morning traffic and easterly afternoon traffic suggests that, in accordance with the distributed multi-town development, a significant percentage of local jobs are filled by local residents.)

The cumulative difference between easterly and westerly traffic has almost reached its peak of 3600 vehicles (25% of the daily total vehicle movements in one direction) by 9.00am and has reduced to less than 500 by 11.00pm. Throughout the intervening period there is a much more balanced flow, except for the evening peak. Therefore, as a first approximation, we can conclude that the long duration return trip component is 3600 vehicles, or 25% of the traffic. All journeys in Canberra take less than half an hour, and for Segment A the most traffic dense half-hour period involves 5% of trips. We can conclude, with the same approximation, that up to 70% of trips comprising the daily traffic could re-use vehicles. Since we only wish to consider private commuter traffic, the above aggregate figures should be revised to exclude public transport vehicles and commercial vehicles.

Figure 2 shows the equivalent statistics to Figure 1 for Saturday traffic over the same road segment. The peak cumulative difference is only 4.7% of total trips. The Sunday statistics are similar in this respect. Thus the potential for re-use may be greater at weekends. However, as traffic volumes are higher and the percentage re-use potential is lower during weekdays, we should concentrate on the weekday scenario.

Figure 3 shows a 24 hour profile (weekday average) for Segment B, recorded during the week of September 8, 1990. It is not clear what the make-up of this traffic would be, but destinations are probably more dispersed. Peak hour traffic is less dominant and the peak cumulative difference in directional flows is 17.4% of total trips.

The above statistics lend support to the theory that the major potential for vehicle re-use is in the low duty cycle of all vehicles and the large number of round trips of relatively short duration. However, we also believe that the sharing of corporate vehicles by employees could also be exploited to a much greater degree in the system to be defined below.

It has been reported (Vorheus) that average trip length increases with city size. Thus we expect that the duty cycle of private cars will increase with the size of the city and the amount of traffic congestion. In Sydney the geography, employment distribution and travel patterns differ considerably from Canberra. In particular the use of mass transit public transport to the CBD of Sydney is very high. The town concept is not evident in Sydney, which is characterised by dormitory suburbs and concentrated industrial or commercial centres. However the potential for vehicle re-use is still likely to be considerable amongst the total private-car traffic statistic.

LITRES

LITRES (Local Inter/Intra Town Route Encompassing System) is an advanced system employing RTI to operate a radical commuting system based on self-drive vehicles and the principal of vehicle re-use. The LITRES system controls thousands of commuter cars (cc's)! In the next section we outline the general characteristics of the system as seen by the commuter, and then expand on the main information technology modules.

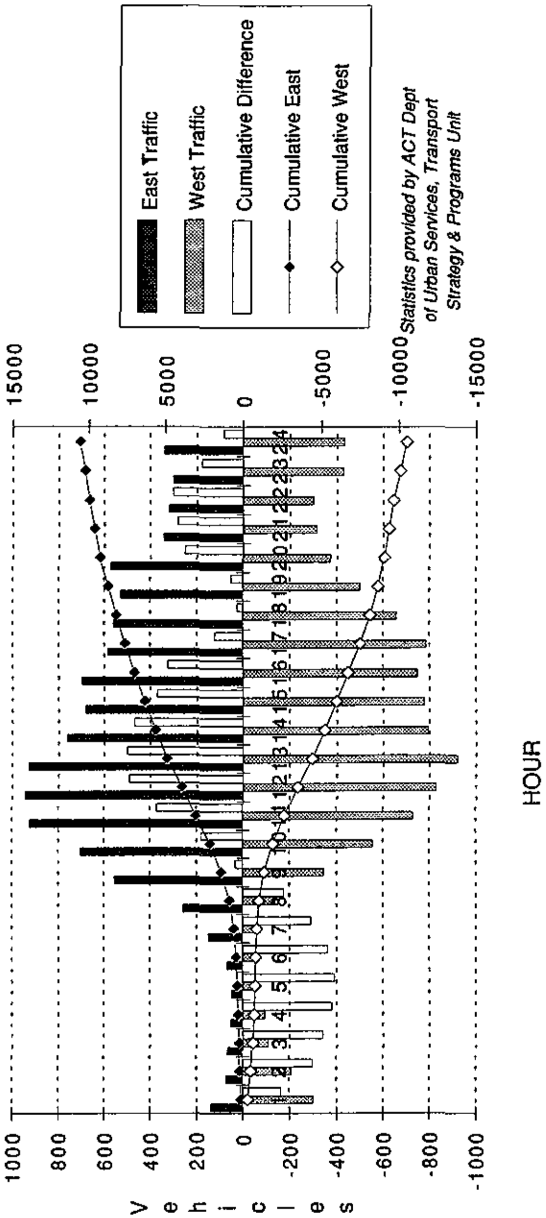

Figure 2 BELCONNEN WAY: Eastern Valley Way - Haydon Dr; Saturday 13/4/91

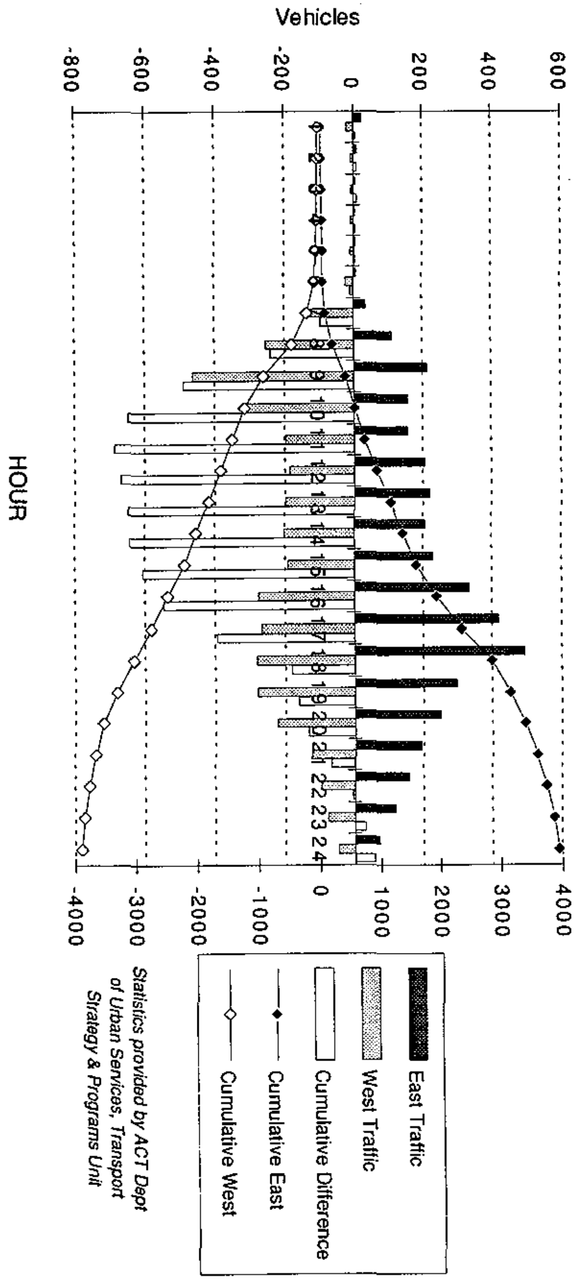

Figure 3 MARIBYRNONG AVE: Baldwin Dr - Diamantina Cres; Weekday Average 8/9/90

LITRES will provide the following overall services and benefits for urban passenger transport.
1. Fast point-to-point commuting, on-demand;
2. Reduced traffic volumes;
3. Reduced parking requirements.

In addition to these criteria LITRES must deliver the following operational performance: attractiveness and convenience, ease of use, reliability, and be price competitive.

System Outline

The focus of the system is the commuter car (CC) which is visually distinctive and ultimately the predominant type of vehicle in sight. Each CC displays an identification easily read from some distance (eg a combination of colour and alphanumeric identifier), and a semaphore indicating its availability. The equipment on-board the CC can process the following four transactions for the commuter, each requiring the use of the commuter's personal key (credit card, cash card or smart card).

A1. Unlock and gain assignment of an available vehicle;
A2. Unlock a preassigned (publicly unavailable) vehicle;
A3. Lock and relinquish a CC on completion of journey;
A4. Reserve a CC for a limited time (eg maximum 5 minutes) prior to locking.

The most common mode of use will be for the commuter to walk to a street or parking lot, get an available CC, drive it to a destination, park it legally, lock and relinquish the CC. Another way to access a CC will be by using terminals placed regularly throughout the suburban street network. These terminals will process two types of transaction, the second requiring use of a commuter's personal key.

B1. Query the location of the nearest available CCs;
B2. Reserve a CC (identified in B1) for a limited time (eg maximum 5 minutes).

Information and Control System

The information system which is the hub of LITRES is divided into six main modules
- Vehicle Location System (VLS)
- Vehicle Transaction System (VTS)
- Pedestrian Navigation System (PNS)
- Distributed Real-Time Control System (DRCS)
- Registration and Accounting System (RAS)
- Networking

Vehicle Location System (VLS) & Pedestrian Navigation System (PNS): The VLS is only concerned with parked CCs. This set of CCs provides the candidates available for re-use. The system is based on unique CC identification with a corresponding unique label displayed on the CC. There are several alternative technologies but all will require wireless interrogation of the CC or broadcast from the CC, and the means for determining its precise location. This is subsequently transformed into a description suitable for pedestrian navigation to the CC.

In focal areas (eg central business district) the functionality provided by the VLS is not essential. CC locations would be well known (eg kerb, car parks and other legal parking areas). However in suburban areas it will be essential for convenient and reliable service to have a VLS. (In a worst case scenario the suburban commuter may have to walk several blocks to obtain a CC, but this should be within expectations of a public transport system. This is discussed in the next section.)

Vehicle Transaction System (VTS): The VTS is based on conventional hardware on-board the CC for reading an encoded card, and controlling the CC locking and semaphore system. It initiates and acts on the DRCS responses to A1, B2 and A3 transactions, and processes A2 and A4 transactions locally. In addition to the public transactions, the VTS will generate the following DRCS transactions internally.

C1. Buffer transactions in the case of failure of communication system modules;
C2. Maintenance transactions;
C3. Security transactions;

Distributed Real-Time Control System (DRCS): The DRCS is distributed because LITRES must provide real-time response and it must scale up from systems involving thousand of CCs to systems involving millions of CCs. The system is responsible for processing all the transaction types except A2 and A4.

Registration and Accounting System (RAS): The registration and accounting system registers new users, issues credit cards and cash cards and carries out the crediting and debiting of user accounts. It is not discussed in this paper but it will have to implement a charging policy and possibly interface with other electronic funds systems. In more sophisticated systems there will be dynamic charging policies for influencing customer behaviour.

Networking: Networking must connect the CCs to the DRCS using wireless communication or a combination of wireless and terrestrial communication. It also provides the communications required for the VLS.

Discussion of Some Issues

In discussing the LITRES concept with people and asking them to read earlier versions of the paper, a number of criticisms have arisen. This section is an attempt to explain the LITRES concept in the light of some of the more common reservations expressed.

Assurance of Vehicle (when required)

The system will stand or fall on its quality of service, particularly its *reliability*. What is the right degree of assurance of a vehicle being *available* on-demand? Should this approach (or exceed) that of well known modes of transport (viz private car, taxi)? One parameter is the *accessibility*, which reflects the walking and other effort necessary to board an available vehicle. Seneviratne (1985) examines the distribution of walking distances, for the purpose of estimating acceptable distances. For public transport a distance 300 metres might be regarded as an acceptable upper limit. Clearly this effort is not insignificant in the other forms of passenger transport mentioned above. It will be necessary to investigate this key performance factor in conjunction with user expectations/requirements and cost of service.

One of the early steps associated with this proposal is modelling to provide performance predictions, fleet requirements and parameters effecting user behaviour.

User psychology is crucial and it will be important that factors, such as those described under Ride Sharing (see below), have an opportunity to come into play.

The system will have the usual critical threshold of patronage necessary to enable quality of service to be afforded. Similarly it will require consumer confidence in on-demand availability of vehicles in order that counter productive user behaviour patterns do not arise.

Number of Cars Required - Fleet Establishment

A complete and fully developed system will require a fleet size which is mainly determined by peak demand and certain geographic distribution parameters. For a large city this means a large fleet, but one which will be considerably smaller than the total of the private-citizen fleet and the independent corporate fleets which are currently in use.

One of the main hurdles to the introduction of LITRES is to devise a practical growth strategy for the fleet. This strategy is likely to be multi-faceted and it requires investigation. Three independent ideas are briefly mentioned here. The first strategy is to facilitate joint ownership of motor cars by first introducing appropriate technology for individual trip accounting. This would lead to corporate fleets being reused by employees on a much larger scale than currently. The second strategy is to undertake other developments in public transport which will also contribute to the move away from private ownership of the motor vehicle. Candidates include para-transit systems, such as the Shellharbour project (Shellharbour Municipal Council, 1991), and evolution of existing taxi and rental systems. These evolving systems would employ some of the infrastructure technology proposed for LITRES. The third strategy is to grow the consumer base incrementally along with the fleet. One strategy is to exploit population cross-sections (eg neighbourhood clumps distributed throughout the city) whereby an initial small fleet could deliver some of the reuse expected from a large scale fleet. Ultimately a number of independent fleets may be merged.

As the statistics in Figures 1 - 3 clearly illustrate a city breathes over a 24 hour cycle. Within this complex process made up of millions of trips, the major process is the relatively long daily cycle associated with attendance at employment/education. This produces the peak demand and it will also determine a lower bound for the size of the fleet.

A question has been raised about the suburbs being drained of vehicles after the morning peak hour (leading to locationally disadvantaged people), and similarly from the focal points in the late evening. The fleet size has to be such that availability is maintained, within an accessibility level yet to be determined (eg how far should one have to walk from a suburban home at 10.30am, before boarding a vehicle). In the latter case the provision of precise directions to an available vehicle will be important in reducing the required size of the fleet while retaining user satisfaction.

Modelling will be necessary to predict fleet requirements and to understand the balancing flows (eg morning flow to a suburb from staff at the local primary school, shopping centres and small businesses). Ride Sharing is important in limiting peak demand and total fleet size. It will be necessary to understand the parameters of ride sharing, and whether it occurs more intensely in one particular phase of the daily traffic.

The capital cost of the fleet has been questioned. There would be severe doubts about the worth of LITRES if it does not lead to a large reduction in the size of the privately owned car fleet (see below). Thus we are proposing a shift in the capital base, and ultimately a decrease. As already mentioned this shift in the capital base demands an appropriate strategy. The requirement for a commuter car will also influence this strategy. However, under stable operation the system will maintain full cost recovery (just as the private fleets that it will replace, do now).

Duplication of Vehicles

The expectation is that LITRES will largely replace the use of privately owned cars for urban commuting, and a key measure of the success of LITRES will be that duplicate

Table 1

	Mazda-323		Toyota-Corolla		Nissan-Pintara		Ford-Falcon		Holden-Calais	
Depreciation Period	3 yrs	5 yrs	3 yrs	5 yrs	3 yrs	5 yrs	3 yrs	5 yrs	3 yrs	5 yrs
Total Costs ($ per week)	151	121	137	111	170	142	194	156	278	220

vehicle fleets are not maintained. It will then become financially attractive for urban dwellers to satisfy their other road travel requirements (viz out of town trips) by renting conventional vehicles, thus leading to the demise of the privately owned motor car. (Initially two car families will reduce to one car.)

The main source of inducement for this change is the hip pocket. SA Motor (1991) provides a detailed breakdown of the running costs of a motor car. The analysis includes all the major cost factors such as depreciation, but does not include any indirect costs (eg environmental costs, or infrastructure costs paid through general taxation). Typical private running costs for cars travelling 15,000km per annum are given in Table 1, with depreciation factored in for a 3 year average and a 5 year average.

Can quality service be provided by LITRES with significant cost savings compared to Table 1? Does the necessary margin exist to convince John Smith to convert from private ownership to complete reliance on car rentals for both commuting and long haul requirements? How strong is the status symbol of private ownership compared to the prospect of significant financial savings?

Financial leverage will arise through a number of important factors
- extensive reuse of the fleet (private cars are parked 95% of the time in Canberra)
- standardisation of vehicles
- lower infrastructure investment (parking and roads)

Note that it is not proposed that LITRES should replace the use of taxis or bulk passenger vehicles where they are appropriate. LITRES should be considered as part of the public transport spectrum. Naturally more will be gained if the combined use of these various transport fleets can be managed under the one umbrella.

Concerning the expectation that LITRES will result in the demise of the privately owned car, we imply that there is a level of CC availability and accessibility maintained by LITRES which meets the consumer's criteria of cost/convenience. If this threshold can be achieved, the on-going financing of the commuter car fleet will be achieved at a much lower investment level than for the private fleets.

Ride Sharing

This is a key concept. The system will generate a high degree of ride sharing through several distinct factors:

Cost: ride sharing means money in the pocket. Sharing the cost of a ride can be done informally by the parties, or by the system through the aid of a slightly more complicated fare transaction. The accounting system could introduce a non-linear fare scale according to the number of riders.

No Vehicle Commitment: reliance on a private vehicle requires a full commitment to that specific vehicle (you have to take it and bring it home at the end of the day). This precludes ride sharing in many commonly occuring situations (eg within households). The need to plan ahead for vehicle availability on the next leg- or for the unanticipated - is

now removed, making ride sharing the norm.
Public Transport Ethos: once this form of transport is seen as a component of public transport, ride sharing will become instinctive. At the moment ride sharing in private vehicles is somewhat taboo because each owns his/her vehicle and is assumed to have a "private schedule" (see No Vehicle Commitment).
No Liability: sharing of rides will bear no liability (all insurance will be borne at the fleet level with premiums integrated into the overall pricing).
Car Pools: this established concept becomes more flexible because in a contingency there is always a fall back available for the defaulting rider.
Impromptu Sharing: all the above factors create a climate for impromptu sharing amongst neighbours, friends and associates.

The comment has been made that more ride sharing will occur in the to-work direction (eg people from the same household who leave for work at the same time, but who return at different times). However the total effect of all ride sharing cannot be accurately estimated, and it needs proper investigation. We believe the effect will be very substantial. If the results are unbalanced then adaptive system parameters such as differential pricing will have to be applied.

"Private schedules" will always exist, such as individual having preferences for privacy and security. This must be accommodated by availability and appropriate pricing.

Sources and Sinks

In any real world system, there will always be some sinks and corresponding sources of vehicle accumulation. Two possible reasons for this behaviour in the system are:
- asymmetric patterns of ride sharing within the LITRES system
- patterns of use involving different forms of transport (eg CC and train)

We alluded to the first case in an earlier example where it was suggested that ride sharing may be more pronounced in to-work journeys. This would lead to an excessive source of CCs in the residential areas.

An example of the second case might be that commuters take CCs to the nearest railway station in the to-work journey, but on the return journey they leave the train at one particular station (eg for shopping activities) and seek CCs at that location. Vehicles then accumulate at the other railway stations.

How can CC resources be maintained at a satisfactorily distribution? There are two types of solution
- using controls to modify commuter behaviour
- having an effective technology for relocating vehicles

The available controls are basically penalties and rewards which influence ride sharing, and the starting points and destinations for CC journeys. If CCs are accumulating in the residential areas ride sharing may be discouraged by offering free use of a CC to single commuters. Similarly commuters may be rewarded if they divert and pick up a vehicle at source locations (eg rejoin the train to the local station in the above example). If the accounting system accumulates credits, there could be an adaptive use of driver labour on an as-required basis.

The complementary role of penalties can also be applied to the above situations. Certain journeys may be made more costly to encourage ride sharing and the accessing of vehicles where accumulation has occured.

Adaptive controls such as those described will require monitoring of the system and a knowledge base of user behaviour and events. Control of the system will be undertaken by an expert (system?).

Special CC vehicle technology will develop. For the vehicle accumulation problem the ability to connect vehicles into small trains which could be moved under the control of one driver is required. Redistribution would be determined by the expert controller. This activity would be incorporated in fleet maintenance.

Diversion from Existing Public Transport

The system is proposed as a public transport component, albeit a very large one. Thus more detailed planning should take into account the full spectrum (bike, bus, ..,taxi, CC).

The obvious control parameter for undesirable diversion from existing public transport is relative pricing.

In Canberra which appears particularly well suited to the system, public transport accounts for only 5% of commuting, and thus patronage rather than diversion is the issue.

Disadvantaged Groups

LITRES will not directly cater to a non-driver. However its form of transport would become more available to the disadvantaged for the following reasons.
- ride sharing will be more common;
- standard vehicles (CC) may permit the eligible driver age to be lowered;
- cost of use is lower than for equivalent private vehicle commuting;
- the accounting system is amenable to subsidising individuals.

Every public transport system requires a huge subsidy. LITRES can achieve cost recovery, enabling the other forms of public transport to be adapted to meeting particular needs, and serving high volume mass transit routes.

User Behaviour

It will be normal for commuters to take vehicles onto private premises to achieve door-to-door convenience. However it is essential that, when a commuter surrenders a vehicle, it is parked near the street or other designated parking area. Certain actions would degrade the performance of the system and these will have to be prevented.

Hiding Vehicles: The case to consider is where a user is attempting to retain a vehicle without paying for its reservation (this would be illegal). The case of reserving a vehicle for a long period is negated by pricing strategy.

If no user is paying for the vehicle in question then the most recent user has executed a lock and relinquish transaction (A3). This transaction cannot be executed unless the vehicle is "electronically visible" which, in the context of the proposed VLS technology, also means visible and "in a public place". Thus if a user is hiding a vehicle then payment at trip rates is being levied. (Stealing parked vehicles from a public place would require the use of machinery.)

In order to allow for contingencies the transaction system must continue to function in the event that power failure renders the VLS inactive. An A3 transaction can then be logged locally on the CC's Vehicle Transaction System. This is checked against contingency reports when the logged transaction is transferred to the main system.

Anti-Social Behaviour: Anti-social behaviour by commuters can be controlled, both by holding commuters accountable for the state of the vehicle which they accept, and by having a standard amount of policing. Security alarms can be built into the VTS and DRCS.

Privacy

There are at least two semantically different privacy issues. The first is that a commuter may want private "space" in transit from one forum to another (eg from work to home). Furthermore a commuter will normally want to strictly choose any companion rider.

The second privacy matter is to guarantee that a commuter cannot have his/her trips subject to monitoring on an individual basis. (On the other hand the system will need to monitor its performance in a statistical way.) A commuter can be guaranteed this type of privacy by allowing use of the system with a cash card (eg Telecom call card). However it would be desirable to encourage some identification to prevent anti-social behaviour. Privacy against recording or disclosing trips undertaken can still be guaranteed.

Information Technology Research and Development

Some of the modules and functionality implied above are beyond the state of the art and will require particular research and development. The solutions must be deliverable at very low per-unit cost. This is essential because of the very large number of CCs and network nodes required in large cities.

Vehicle Location Technology

There are two electronic methods for locating vehicles in experimental use. The first method is the generic satellite location system (Global Positioning System - GPS) which operates by obtaining fixes from three navigation satellites amongst a network of satellites deployed by the United States Department of Defence. Equipment required is a receiving antenna, and a signal decoding and computational device. There are four reservations concerning the use of this method for LITRES. The last point will be resolved in time by the growing demand for GPS in the civil arena.
(1) There may be too many parking situations which are obscured from satellite signals.
(2) The per-unit cost is currently far too high and is likely to remain above acceptable levels.
(3) A translation problem remains to relate geographic coordinates to the street network.
(4) Availability of the appropriate signals for the required positional accuracy is not guaranteed.

In addition to the above reservations, the basic requirement remains for the car to notify the control system (DRCS) of its location. The ramifications of this additional communication step together with the need for the control system to be distributed is discussed below. An example system based on GPS is V-Track marketed by CEA-NET (1991).

The second method in experimental use is called dead reckoning. This requires an on-board computer, with directional and odometer inputs from the vehicle. The vehicle is tracked continually from a known origin, with reference being made to a digitised map of the locality. The map may be held in the on-board computer, adding to the complexity of the local system, or it may be held in a central computer which handles location transactions by wireless link for all the vehicles under its control. As the number of transactions in LITRES will require a distributed system, there would have to be handover as a CC moves through regions, if there is no on-board map. Thus there are concerns about cost, complexity, reliability and map maintenance with this method. An example system of this type is V-Trak, marketed by Dynamic Transport.

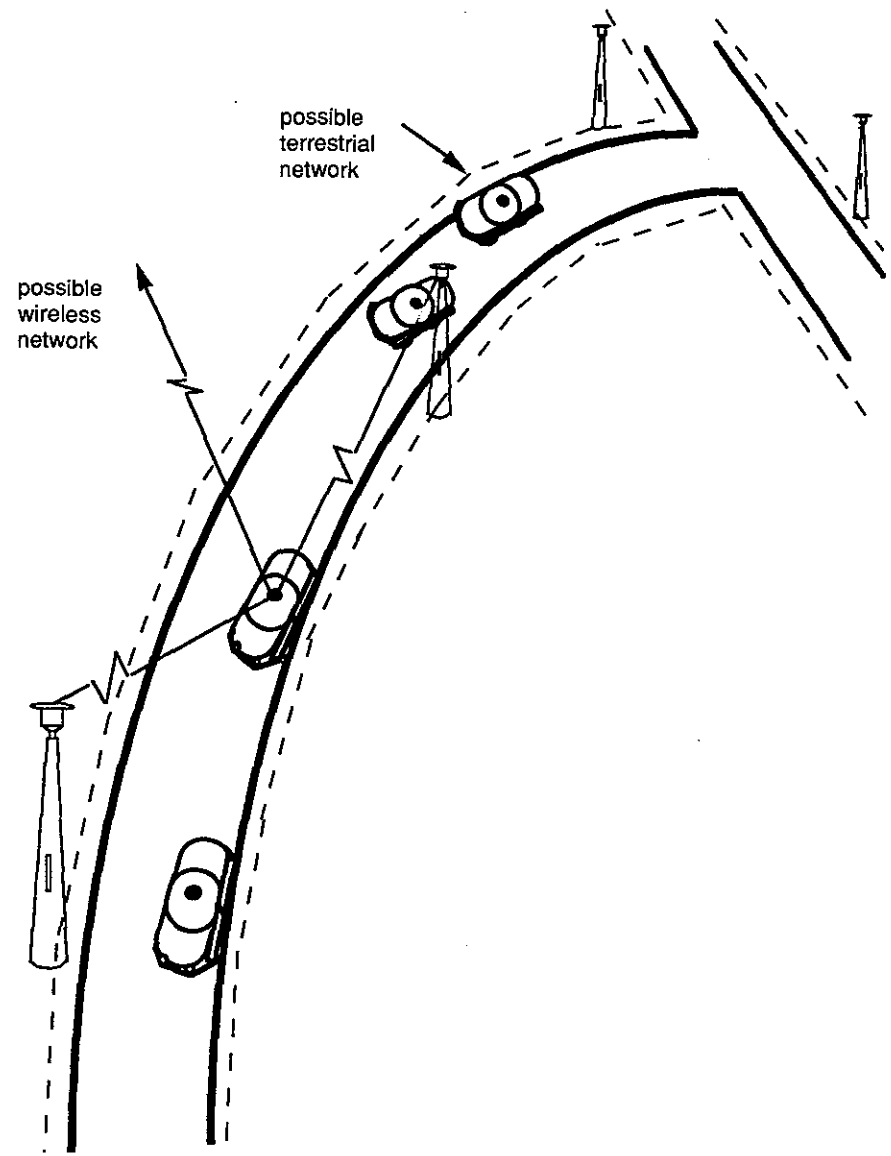

Figure 4 : Locating the parked CC

Overall considerations of networking, distributed systems, per-unit costs, reliability, and adapting the VLS to pedestrian navigation, has led us to the following proposal. Street Lighting is an existing infrastructure which offers several important advantages for meeting the LITRES requirements:

1. The street lighting network has the same geographic coverage as the LITRES system.
2. It carries a source of electrical power for a network of microwave (or millimetre) beacons which could form the basis of a VLS.
3. The street lighting system maintains the placement of lights to achieve the most cost effective lighting of the street and its perimeter. The same placement goals are required for the beacons to be described below.
4. Beacon location on street light poles translates automatically into a pedestrian navigation reference system.
5. The street lighting electrical network is a terrestrial network on which we could superimpose a communications protocol carrying the DRCS transactions.
6. This network is divided into sub-networks, each with a geographic coverage (about 3km of streets) which on the one hand forms a convenient local area for the control of the available CCs, and on the other hand maps to a logical fragment in a distributed processing system. Thus a hierarchical network node (and local area processor for the DRCS) could be installed at each street light circuit control point.

The requirement posed here begs the development of a dual purpose device which plugs to the street light socket and provides both illumination and directional low-bandwidth communication in the illuminated spatial range.

Vehicle Location System (VLS)

A graphic depiction of a VLS to be investigated is given in Figure 4. Each street light pole carries a low power microwave transmitter (and also a receiver if networking is based on this infrastructure), and reciprocally for each CC. The minimum role of the logic on the pole is to provide the pole's identity to the transactions defined previously, thereby contributing the locational information.

Logic distributed (according to the approach adopted) between the pole and the CC detects the presence of each newly arrived and available CC in the vicinity of the pole (about 50 metres of street length). Once the two fragments of information (CC identity and pole identity) have been merged a transaction is forwarded to the local DRCS via the LAN. The LAN might be terrestrial (using infrastructure associated with the street lighting or dedicated low bandwidth communication cable) or wireless from the vehicle.

Vehicle Transaction System (VTS)

Much of this is well understood technology. Generic transactions have three standard properties, CC id, pole id and commuter id. Thus corresponding messages will be small (approximately 50 characters). The system must be able to operate independently in the event of network failure or "lost vehicle" (eg from microwave (or millimetre) shadows). In these cases there will be a requirement to temporally store some accounting information in the on-board system.

Transactions will be transmitted using the low level protocol developed for the VLS.

Pedestrian Navigation System (PNS)

When a commuter cannot find an available CC within visual range or at a nearby depot (deployment strategies should be investigated), he will press the inquiry button on a pillar which has a "you are here" local map displayed. The location of some available vehicles in the vicinity will be indicated. In more sophisticated terminals the facility to reserve one of the designated vehicles would exist.

Some finessing of digitised maps and search techniques will be required to allow shortest pedestrian routes to be found (eg traversal of walkways and open space). In addition the boundary problem exists, as cross-over to an adjacent local area may frequently realise the nearest vehicle. The local map database will be stored at the hierarchical node of the local area network, thereby minimising database maintenance (compared to having map databases stored in each CC). The hierarchical node is the interchange between the local area network and the wide area network on which the DRCS is based.

Distributed Real Time Control System (DRCS)

As already indicated this is an excellent example of a distributed system in which the fragmentation corresponds to a geographic fragmentation in the real world. Consequently there is scope for optimisation of the cross-over transactions so that they are only sent to topologically neighbouring nodes.

The design of the VLS will have important implications for this module. It has been suggested that low power, short range microwave (or millimetre) communications be used. However two or more street light nodes may detect the same newly arrived CC. These nodes may be on the same or adjacent local area networks. Unambiguous detection and avoidance of multiple reassignment of a CC are essential.

High rate transaction types (A1 and A3) must be handled on a global basis.

Registration and Accounting System

This will use well established technology together with some interesting application of replicated data. It will be important that the global processing does not become a bottle-neck for the critical high rate transactions (A1 and A3). The distributed system characteristics can be exploited. For example, commuters having debit accounts will have their reference account maintained in the local area node covering their place of residence. Adaptive replication can occur so that an "accounting trailer" can follow the commuter to contiguous destinations. This should help maintain a balanced processing load.

Networking

Networking is essential to process the basic transactions (A1 and A3) and to process B transactions in those areas where a fully electronic form of VLS is operating. In any case the VLS development is likely to determine the type of wireless networking to be used from the CC. Conventional networking can be employed to link the hubs of each local area network into a wide area network.

Some investigation of protocols for the support of the VLS system will be required. Also the problem of redundant reception of wireless transmissions as described in the VLS proposal will have to be solved.

Other Issues

Previous sections have provided a sketch of this complex large scale system. While information technology issues are important and challenging, there are larger issues concerning the vehicle fleet, the overall feasibility, and the means of establishing the system and its user base.

Change

The famous economist and commentator Kenneth Galbraith has said that there are only two types of economist, those that don't know, and those that don't know that they don't know! Whenever a theory has to cope with human behaviour, and human values and attitudes, this is the case. Thus the major question about LITRES is not its technical feasibility, but the human factor.

LITRES is highly significant in the ESD (ecologically sustainable development) context. However, some say that a disaster will have to be at least imminent before change which might be seen to restrict freedom or quality of life is accepted. Experience says proceed by evolution not revolution, and avoid social engineering.

Thus it may be quite important to consider how the infrastructure of LITRES could be introduced in a gradual yet practical (ie cost recoverable) way. A significant part of the research and development cost of the system is associated with the VLS and PNS. By introducing CCs which have completely self contained systems (accounting logs read out periodically onto a portable device) a limited version of the system could operate, possibly for a restricteded clientele (eg corporate fleets). However it is most likely that this infrastructure will evolve through various precursor para-transit systems.

Vehicles

While the CC will be based on currently available vehicle technology it cannot be a production car as we know them today. The CC must accommodate the lowest common denominator in driving skills and wear and tear. We expect that the CC would be compact, ruggedised in fittings, have a simple automatic transmission, and be of performance adequate for city driving.

Maintenance of the fleet would be a large scale operation which might well deliver economies of scale. The serviceable life of vehicles could be optimised and many inefficiencies which arise with vehicles under private control could be eliminated (cf pollution). Monitoring of major components for serviceability could be a part of the LITRES control system.

Operation

There are sure to be numerous operational considerations. For example, refuelling vehicles would best be initiated by the commuter. With a system under real time control there is considerable scope for manipulating the overall fleet performance according to defined criteria. This could involve rewarding drivers for particular actions such as refuelling, or for driving a CC to a given location.

The operation could trigger a completely new concept of the function and infrastructure provided by a service station. Mobile fleet maintenance crews would also be part of the system.

Transport Policy

Transport policy is under scrutiny at all levels and there will undoubtedly be significant changes in the future, as already described by De Cata et al (1991). Road pricing is one such policy. What is the cost of the road system and should this cost be levied on a user pays principle? Clearly such pricing policies could be easily accommodated in the LITRES accounting system (RAS).

As mentioned in the introduction new propulsion systems will replace the internal combustion engine. Establishment of large commuter fleets will provide an infrastructure well suited to adapting to new technology, such as electric vehicles.

An important policy would concern the eligibility to use a CC. RTI systems in use (eg tolling) require the user to be registered and in credit.

Other benefits

The main benefit of LITRES is to the urban environment through more efficient use of roads, parking and vehicles, while delivering a higher general standard of commuting. Numerous other benefits will follow.

- CCs would contribute to road safety through having vehicle handling characteristics and performance designed specifically for urban conditions.
- Theft of vehicles would become an unprofitable exercise.
- Vehicle re-use eliminates the need for parking meters in focal areas, because vehicles are reused as soon as they become available. All other parking charges can be levied by the system.

Many revenue functions can be factored into the LITRES accounting system. For example, parking, registration and insurance, and road pricing could be included in the rental fee.

System Integration

During more detailed analysis and design stages it is possible that LITRES could integrate with other RTI applications such as route guidance, driver support and accident prevention, traffic management and control, cooperative driving and vehicle communication.

While the electrical layer of a LAN can be superimposed on an electrical power cable, it would be strategically and financially advantageous to have a communications cable (probably no more that a twisted pair is required) laid in the same trench as the power cable providing the street lighting. This would be particularly useful in prototyping. Minor additions to poles to terminate the communications cable and provide power to the microwave (or millimetre) node could also be done before installation. At the same time consideration could be given to the provision of "luma control" switching to each individual light, so that continuous power can be made available at the pole.

Future Work

The most urgent requirement is to substantiate some of the claims made in this discussion paper by modelling and simulation. The author has already commenced this work (Smith, 1992). However good data with which to verify the simulation results may only be available from RTI projects such as that proposed below. Modelling and simulation can be done for a number of prototype systems such as that described in Smith (1992).

We believe that in order to advance this proposal there also needs to be wide exposure at the earliest possible time. A pilot project is essential. Ideally the project should achieve several objectives. Where possible it should instigate significant technology research and development, or else demonstrate requirements and feasibility. It should establish an experimental base. It should address the problem of fleet establishment. The project should be a source of some statistics for further modelling and simulation.

An information technology scenario has been sketched in the paper. At this point we see a pilot project addressing the following areas:

• pedestrian navigation (this is part of a generic problem in the application of geographic databases for route finding, dispatching etc.); note the requirement here is to get people to cars, as opposed to the taxi requirement which is to get cars to people;

• vehicle location (feasibility and demonstration based on street light identifiers and geographic database);

• networking (It is proposed to avoid any development work in this area at this stage by piggy-backing the pilot fleet on a taxi real-time control system. For this purpose the Motorola system used by Aerial Taxi Cab in Canberra (Motorola, 1991) is a suitable candidate, having the potential to grant control of the vehicle and provide trip accounting via a credit card transaction.)

An independent step, which has potential to aid in the establishment of commuter fleets is to provide the mechanisms for the accounting and sharing of the total running costs (see Table 1) of a vehicle by joint owners (eg the corporation and the employee, family members, neighbours or businesses where requirements are complementary). If a general mechanism for sharing costs is available, any growth strategy for a client population and fleet can be supported. With the availability of credit card access mentioned above, all the technology is well within reach.

Once a vehicle is instrumented with the above components, an investigation into the social and psychological aspects of sharing vehicles can be carried out. In addition a number of useful statistics can be gathered.

Acknowledgements

The Canberra traffic statistics were provided by Dr Paul Ratcliffe of the Transport Strategy and Programs Unit of the ACT Department of Urban Services. We also acknowledge a number of people who have read and discussed earlier versions of the paper. In particular we would like to acknowledge the constructive criticisms of John Black (UNSW), Patrick Troy (ANU) and Doug Quail (NSWRTA).

References

Black, J A (1992) *Environmental Capacity* (private communication)

CEANET (1991) V-Track: CEANET

De Cata, L Donald, G S Lay, M G and Quail, D J (1990) *New Technology for Road Transport - Report on a Joint Study Mission to Europe and USA*

DRIVE (1991) *Advanced Telematics in Road Transport* Proc DRIVE Conf, Brussels: Elsevier

Dynamic Transport Management Pty Ltd (1991) *V-TRAK Automatic Vehicle Location, Tracking and Route Finding System:* Dynamic Transport Management Pty Ltd

Motorola (1991) *TaxiPak Driver's Handbook:* Motorola

Newman, P and Kenworthy, J (1991) *Towards a More Sustainable Canberra - An Assessment of Canberra's Transport, Energy and Land Use* Institute for Science and Technology Policy, Murdoch University, Perth, Western Australia

Seneviratne, P N (1985) *Acceptable Walking Distances in Central Areas* Journal of Transportation Engineering Vol 111 No 5, 365-376

Shellharbour Municipal Council (1991) FOCCS Description and Development: Shellharbour Municipal Council

Smith J L (1992) *A Simulation Model of Multiple Hire Taxi-Buses Version 1 - Demonstration Results for Canberra* : CSIRO Division of Information Technology

Royal Automobile Association of South Australia Inc. (1991) *Car Running Costs - Not Cheap*, SA Motor, June