Personal Rapid Transit Systems (PRT)

A Contribution
to the
Newcastle Urban Renewal
Strategy

ultra
global prt

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Newcastle Urban Renewal
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Summary

This submission on Personal Rapid Transit systems addresses Guiding Principle 6 - Transport, access and connectivity of the Newcastle Urban Renewal Strategy and in particular the issues:

- Maximise accessibility and convenience of public transport to and within the city centre, and prioritise a range of transport modes to reduce private vehicle use.

- Promote connections and way-finding between precincts and to the waterfront, and encourage pedestrian activity throughout the city centre.

- Support infrastructure and public domain improvements to attract people to the city centre.

which were identified as major concerns that need to be addressed to meet the 21st century challenge for Newcastle to become more productive, sustainable and liveable.

A modern Personal Rapid Transit (PRT) system offers an excellent match to these priorities. Conventional transport such as bus, heavy rail and light rail operate along a transport corridor between two termini with intermediate stops to allow passengers to board or disembark. While ideal for mass transport, modern transport theory argues that these systems become progressively more inefficient as they penetrate a CBD and instead they should terminate at transport hubs around the CBD while the CBD and its environs are serviced by an internal network. PRT integrated with pedestrian precincts and malls provides such a network allowing a person to travel from any starting point to any finishing point within the network without stopping. Because the PRT stations are off-line and the intersections are free flowing, the travel is a non-stop, point to point personal service. A modern PRT system is fully automated with driverless vehicles under the total control of an operations centre. Transport is available on demand, 24/7, will go anywhere within the network and is abandoned on reaching the destination. There is no waiting or queuing prior to, during or at the end of transit. Travel time is approximately half that of conventional corridor transport. PRT systems have a capacity equal or better than bus, light rail or car. The transport is safe and secure. It has much lower capital and operating costs compared to corridor transport systems. It integrates well with other modes of transport and there are major environmental benefits. A prototype system has been operating overseas for 35 years and two 2nd generation systems have now been operating for over 2 years very successfully. Further systems are being planned and commissioned.

Within the Newcastle context it is argued that PRT could supply a convenient and accessible public transport system that is better than the car. It will promote inter and intra travel between precincts and encourage access to the waterfront. It will integrate into existing and new infrastructure and promote the city as a centre for commercial, retail, social and recreational activity.

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Introduction

"Individual mobility is a major driver of personal growth
and economic well being."
Prof. Julia King VC Aston University and
British Low Carbon Business Ambassador.

The Newcastle Urban Renewal Strategy 2012 has identified nine guiding principles to meet the challenges associated with the city's development during the 21st century. The 6th guiding principle deals with transport:

Guiding Principle 6.
Transport, access and connectivity

- Maximise accessibility and convenience of public transport to and within the city centre, and prioritise a range of transport modes to reduce private vehicle use.
- Promote connections and way-finding between precincts and to the waterfront, and encourage pedestrian activity throughout the city centre.
- Support infrastructure and public domain improvements to attract people to the city centre.

While specifically mentioned as a guiding principal, transport also forms a critical component to the success of the other eight principles.

Although focussed on the city of Newcastle, the general tenor of the Newcastle Urban Renewal Strategy is similar to that expressed in the Infrastructure Australia *State of Australian Cities 2010* reports, Infrastructure Australia (2010a and b). These reports identified transport as one of the engines for economic growth and emphasised the need for greener and safer transport systems that improve the quality of life of communities. National and State government transport policies are now encouraging solutions that result in reduction of greenhouse emissions and reduce congestion. In moving to more sustainable transport modes the policies must also give people a real choice about how they travel. They emphasise that local plans should support a pattern of development that facilitates:

- The efficient movement of people and goods.
- Enhances the environment for the pedestrian and the cyclist.
- Provides access to high quality public transport facilities.
- Creates safe and secure layouts that minimise conflicts between traffic and pedestrians or cyclists.
- Incorporates facilities that use ultra-low carbon emission vehicles; and
- The transport needs of people with disabilities.

Meeting these objectives will require a significant shift in both thinking and application. There is no one, universal transport system, but the spectrum of transport systems available will need to undergo a major change and permit the introduction of new systems that meet the transport policies of the 21st century.

A transport data base is a necessary prerequisite to any transport policy aimed at modifying transit behaviour. **Table 1** is drawn from the latest publication by the New South Wales Bureau of Transport Statistics (2013) and summarises the current nature of travel within Newcastle. The Newcastle metropolitan areas are identified as Inner City, Outer West and Throsby. The table also includes a summary for the Newcastle region and the Greater Metropolitan Area of NSW (GMA) which incorporates the Illawarra, Sydney and Newcastle metropolitan regions.

Table 1 Transport characteristics for Newcastle

		Newcastle Inner City	Newcastle Outer West	Newcastle Throsby	Newcastle region	GMA
Av. trip length, km		5.7	7.3	6.2	9.4	8.5
Av. Trip duration, min		17	17	16	18.0	22
Av speed km/hr		20.1	25.8	23.3	31.3	23.2
Mode	Car	69%	89%	76%	82%	68.1%
	Train	1%	1%	0%	1%	5.3%
	Bus	3%	2%	3%	3%	5.9%
	Pedestrian	25%	7%	18%	12%	18.3%
	Other	3%	1%	3%	2%	2.4%

Comparison of the data between individual areas within Newcastle, the Newcastle region as a whole and with the NSW GMA shows a common pattern with an average trip length between 5.7 to 9.4 km, a trip duration of around 20 minutes at an average speed between 20 to 30 km/hr, and with the car as the dominant form of transport. Minimum trip length and average speed is observed in the CBD, with these parameters increasing towards the outer suburbs. There is very low use of public transport. Pedestrian traffic rises within the CBD to 25%. “Other’ modes of transport only rate 3%. ‘Other’ includes the cyclist, motor-cyclist, ferry and taxi.

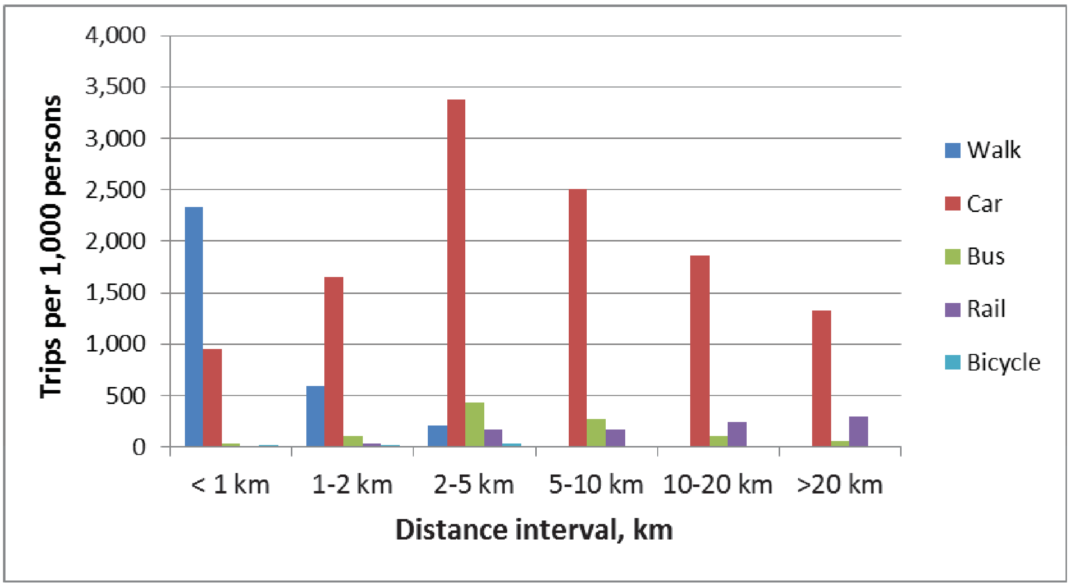

Figure 1. Trips made by mode and distance for the NSW Greater Metropolitan Area

These travel characteristics are also observed when the data is reported in terms of trips made by mode and distance, summarised by **Figure 1** for the GMA. Short distances less than 1 km are dominated by the pedestrian while the most frequent trip is made by car and is only 2-5 km. The bus is the principal mode of public transport for short trips (2-5 km) and is progressively replaced by heavy rail for trips greater than 10 km.

The New South Wales Bureau of Transport Statistics database has allowed the Newcastle Urban Renewal Strategy to propose the following initiatives for achieving its transport objectives for the Newcastle CBD:

1. *Promoting a shift to public transport in the city centre*
   by investigating strategic bus corridors, park-and-ride facilities, improved bus stops, behaviour change programs, and improving connections between transport modes.

2. *Creating a connected pedestrian and cyclist network*
   by improving the physical environment to encourage more people to walk and cycle, providing end-of-trip facilities and implementing council's cycling and pedestrian strategies.

3. *Providing dedicated cycle lanes in Hunter Street*,
   which will promote a balance between the car, public transport and active transport along a key transport and movement corridor in the city centre.

4. *Providing new and enhanced connections across the rail corridor*
   for all users.

5. *Improving the efficiency of the road network*
   including intersection upgrades that accommodates all transport modes.

6. *Managing the impact of car parking*
   through an overall car parking cap, reviewing commercial car parking rates, promoting innovation for heritage and large development sites, and investigating car-pooling and sharing programs

This balanced set of initiatives is aimed at reducing the dependency on the car for local travel, improving the pedestrian environment and raising the public transport profile.

In order to reduce the dependency on the car, a public transport system is required that:

- Is available on demand;
- Will go anywhere;
- Does not stop between destinations;
- Is environmentally friendly;
- Is safe and secure;
- Is low cost; and
- Integrates with other modes of transport

Not even the car meets these requirements, and the current forms of public transport fail on all points. New solutions are called for and while every transport solution will contain elements of compromise, it will be argued that the introduction of a Personal Rapid Transit system into Newcastle will create a more efficient and satisfactory form of local travel, better meeting the public's transport needs and the city's transport objectives than is currently offered.

Personal Rapid Transit, known as PRT, is non-stop, point-to-point personal transport anywhere within a network, using computer controlled driverless cars on a dedicated guide-way. All intersections are free flowing, transport is available on-demand, 24/7, and the vehicle is available for the next passenger upon completion of the journey. An empty vehicle management system repositions vehicles as required for optimum service. The journey time is half the journey time of conventional urban transport. It is a true network system. It is competitive in terms of capital and operating cost compared to alternate transport systems, exceeds bus or light rail capacity and has the minimum overall journey time. It has the lowest energy demand per passenger kilometre and its primary power source is 'green' electricity.

A prototype system, Morgantown PRT, has been operating for over 35 years. Three 2nd generation systems are at the stage of commercialisation. The 5 station UK ULTRA system has been operating at Heathrow, UK, for two years, Ultraglobal (2013). The Dutch *2getthere* system installed at Masdar, Abu Dubai, has been operating for a similar time, *2getthere* (2013). Both the Heathrow and Masdar operations are undergoing significant expansion. The Korean/Swedish Vectus system will come on line at Suncheon, Korea in 2013, Vectus (2013). A full prototype system has been reported by the Modutram team at the University of Mexico, Modutram (2013), and a large number of systems are at the design stage in Europe, America and Asia, Wikipedia PRT (2013). PRT should be seen as an important component of the 21st century transport options.

It will be argued in this submission that Personal Rapid Transit systems can make a significant contribution to the redevelopment of the Newcastle CBD by providing an integrated, safe, accessible and more sustainable transport system that supports economic growth whilst reducing car use and CO_2 emissions, enhances the environment and generally improves health and the quality of life of the community.

Characteristics of an urban transport system

Improving transport options

The optimum characteristics for any urban transport system, public or private, are:

Passenger's needs

- to be available on demand,
- to provide point-to-point travel, non-stop from start to finish,
- to be easily accessible and offer a full choice of destinations,
- to be environmentally sustainable,
- to have low cost,
- to provide a high degree of security, safety and reliability,
- to integrate well with other forms of transport.

Users perspective

- easy to use,
- be comfortable and convenient,
- available to all sectors of society,
- should be flexible and have a rapid response,
- provide a natural link to existing systems,
- meet any privacy needs,
- be effective and low cost.

Environmental perspective

- environmentally friendly with a small carbon footprint and minimal pollution,
- be an attractive vehicle in physical structure and internal design,
- have minimal impact on non- users,
- allow for revitalisation of a city centre on a human scale,
- have minimal construction impact.

Technical specifications

- outstanding cost/resource effectiveness,
- a journey time better than current public transport,
- emissions/energy use to be one tenth of cars,
- have minimal use of space,
- fully exploit modern information technology,
- provide security better than current transport,
- provide a safety level better than current transport,
- a high reliability and tolerance of local or system faults,
- technological adaptability,
- resistance to crime and vandalism,
- to be independent of the weather,
- to integrate with other transport systems,
- to be ease to install,
- provide considerable flexibility in use.

A key component in achieving these needs is the use of a dedicated network.

Networks

"Make everything as simple as possible but not simpler."
Albert Einstein, physicist and Nobel laureate

Personal Rapid Transit systems are designed to operate on a network. There is a subtle difference between corridor and network transport systems. Corridor transport occurs between two termini with stops in between to allow passengers to board or depart as illustrated by **Figure 2**.

Figure 2 Corridor Transport

Bus, light-rail and heavy rail transport agencies claim to run transport networks, for example the map of the Sydney suburban rail system is titled "City Rail Suburban Network", but in reality the Sydney suburban rail system is a collection of rail corridors and in the interests of improved efficiency Sydney City Rail have been very busy removing network components out of the system so that they operate as true line haul corridors. The Metro Trains Melbourne web site includes a Network Map page, Metro Melbourne Trains (2013) but it is a corridor system. The only public transport system operating on a true network is the taxi, which uses a city's network of public roads.

A true transport network is a series of interconnected cells allowing a vehicle to travel from any starting point to any finishing point, **Figure 3**. In the ideal case the stations are in off-line loops so that they do not compromise vehicle flow, intersections are free flowing and the network operates on a dedicated easement.

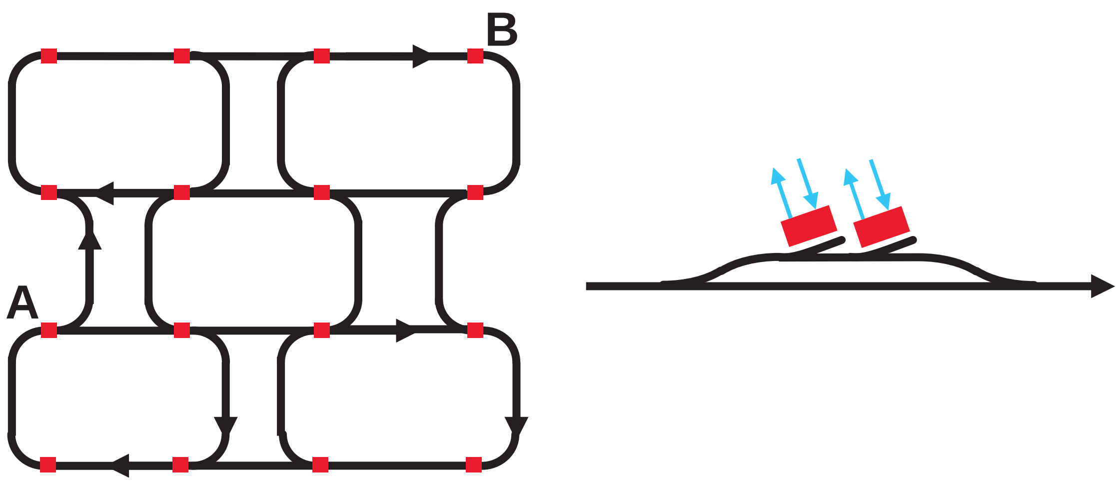

Figure 3 Network Transport with off-line stations

A true network allows a passenger to travel from any point A on the network to any point B without stopping at an intermediate station. Should the selected path be blocked, there are alternative paths to reach the destination. Vehicles are stored either at a main depot or are queued near those stations where there is an anticipated high demand. The network itself acts as a dynamic car park with empty vehicles that are returning to the depot or a station queue, being able to respond to a new request.

The network has to be on a dedicated easement, since sharing an easement significantly compromises the operating efficiency of any transport system and its safety. A Melbourne Tram is quite capable of running at 80 km/hr, when a Melbourne Tram has to share an easement with other users the average speed is drastically reduced. The average travel time down Princes Street, Melbourne is observed to be 8 km/hr, Morton (2007). The average speed of a Sydney bus based on the published timetable is 13 km/hr during peak periods and only rises to 20 km/hr in the late evening. These times cannot be improved because buses and light rail run on shared easements between two termini with stops for taking on and letting off passengers as well as accommodating other users of the easement at intersections or pedestrian crossings.

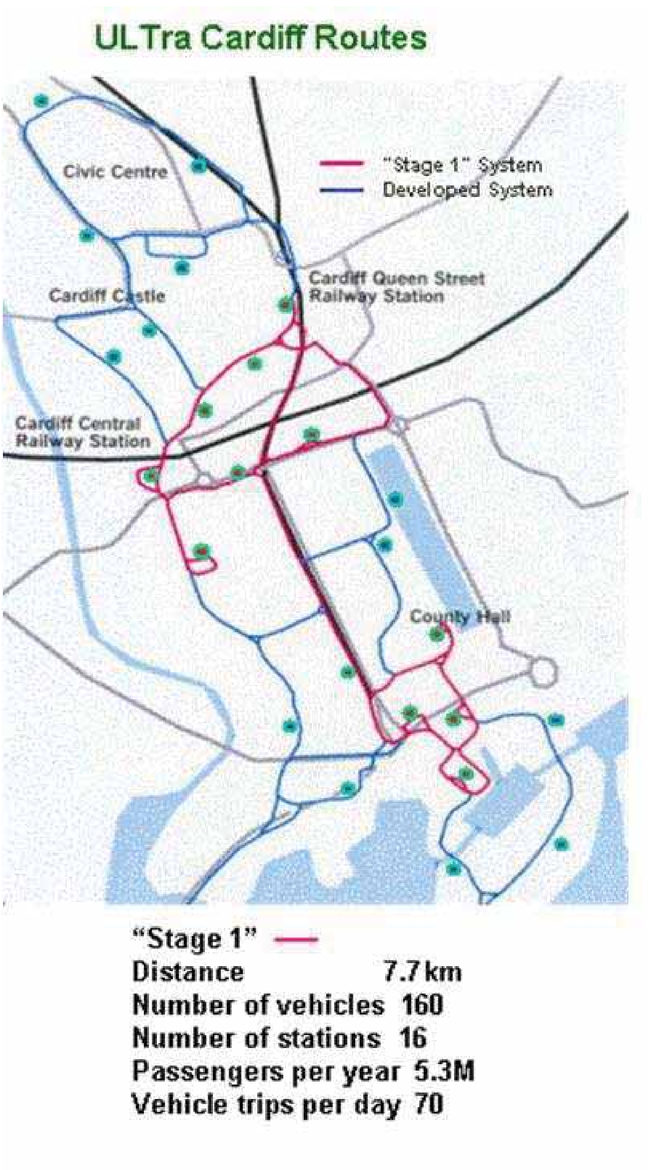

Figure 4 A practical PRT Network for Cardiff, Wales

The Personal Rapid Transit Concept
Utilising smart infrastructure

"I managed to stop being stupid long enough to see something
that should have been obvious all along."
Sir Alan Walsh, Australian scientist and
inventor of the Atomic Absorption Spectrometer

The concepts of PRT may be traced back to the late 1950s. The first documented study was that of Don Fitcher, Irving (1978) while the first prototype system was developed by Blake in the UK in the 1960s, Langdon (1971). Since then a number of systems have been examined employing a range of tracks and suspension systems, see **Table 2**. Of these the Cabtrack system was the most developed as a true PRT system while the others tended to undergo metamorphosis into group transit systems before being closed down. An exception is the Morgantown system in the United States. This is a local transport facility for the University of West Virginia and has been running successfully for 35 years, Raney and Young (2005). While claiming to be a PRT system, the cab capacity is 20 people and in reality it is a linear, group system uniting two parts of a university campus. However, it does demonstrate that a fully automatic, demand responsive system with off-line stations is technically achievable.

Table 2, Prototype Personal Rapid Transit systems

System	Cabtrack	Aramis	Cabinen Taxi	CVS	Aerial Transit System	Raytheon PRT 2000
Country	UK	France	Germany	Japan	US	US
Dates	1966-1972	1967-1988	1969-1974	1970-1979	1970-1974	1990-1999
Track	0.2 km	1 km	2 km	4.8 km	0.54 km	~ 1 km
Vehicles	1	3	5	19	?	3
Passengers	4	4+	3	4	6	3
Payload	400 kg	350 kg	400 kg	330 kg	410 kg	400 kg
Top speed	40 km h^{-1}	50 km h^{-1}	36 km h^{-1}	80 km h^{-1}	56 km h^{-1}	40 km h^{-1}
Headway	1 s	60 s	1 s	1 s	10 s	2.5 s
Type	Rubber on concrete	Rubber on concrete	Overhead support	Rubber on concrete	Monorail	Rubber on Steel

It is instructive to ask why none of the systems listed in Table 1 were successful. In summary there was:

- an over emphasis on high capacity systems,
- an inadequate emphasis on total system design,
- an inadequate consideration of "soft" issues such as the passenger/vehicle interface,
- inflexible mechanical technologies,
- unavailable technology for the demands of the system.

The new PRT designs have taken these issues on board as well as taking advantage of modern electric motor technology, innovations in battery technology and materials technology, and the massive development in Information Technology. This has produced lightweight vehicles with the battery pack only ~8% of the gross weight. The vehicles are fully automatic and autonomous, but are equipped with a continuous back to base communications system so that they are under full supervision of the operations centre. The vehicles are completely wheel chair accessible, with the station platform and cab aligned so that the user does not need any assistance. The doors are automatic. The cruise speed is 40 km/hr. While this may appear to be somewhat low compared to other transport systems, the lower cruise speed is compensated by the point-to-point travel thus removing all stops on the way and the average trip speed is close to the cruise speed, twice that of existing alternative transport systems.

PRT Specifications

PRT designs have included guide-way, binary rail, and suspending or supporting monorail. The first three PRT systems to reach commercialisation, ULTRA, *2getthere* and Vectus, use various forms of guide-way. Suspending or supporting monorail concepts have not passed the design stage. There is a trade-off between guide-way and conventional rail. Guide-ways are much simpler and permit shorter headways between vehicles, but require the steering mechanism to be on-board. Conventional rails require mechanical points and switching, which are prone to failure and require longer headways between vehicles but there is no on-board steering and the vehicles are mechanically simpler. At this stage guide-way systems with on-board steering appear to be more cost effective for passenger vehicles, while binary rails with points are preferred for the lightweight (30 kg) freight vehicles used at airport baggage handling centres.

Figure 5 The ULTRA PRT system installed at Heathrow, UK

The PRT systems now at the point of commercialisation use conventional, rubber tyred automotive technology. The vehicles, which have become known as pods, are battery powered and typically take four passengers each with 30 kg of luggage.

Typical vehicle parameters are:

- Gross weight 1300 kg
- Tare weight 850 kg
- Maximum speed 40 km/h
- Length 3.7 m
- Width 1.45 m
- Height 1.6 m
- Passengers 4-6
- Continuous power 2 kW
- Battery top-up time 1 minute
- Battery pack 64 kg (~8% of gross weight)

And typical guide-way parameters are:

- Overall concrete at-grade guide-way width 1.75 m
- Overall steel/concrete elevated guide-way width 2.1 m
- Internal guide-way width 1.6 m
- Internal guide-way height 0.25 m
- External guide-way depth (for 18m spacing) 0.45 m
- Typical elevated guide-way headroom for main road crossings 5.7 m
- Typical elevated guide-way headroom for pedestrian crossings 2.5 m
- Radius 5 m
- Maximum gradient 20 % of grade
- Maximum operating gradient 10 % of grade
- Typical column spacing 18 m
- Typical "long" column spacing 36 m
- Typical column load 10 tonnes
- Floor loading 2500 N/m^2

A gradient of 10% of grade is readily achievable with rubber tyred technology. The easement may be elevated as at Heathrow, ground level as at Suncheon or below ground as at Masdar. The floor loading for a fully laden weight of 1300 kg is 2500 N/m^2. This floor loading is much lower than that required for pedestrian pathways or for commercial buildings (5000 N/m^2). The light floor loading leads to a lower cost of construction. Elevated sections have wide column spacing, which minimises visual intrusion within the streetscape. The light loading also allows the easement to pass through buildings, reducing the spatial footprint and delivering the passenger literally to the front door.

PRT Control Systems

Operation of the network employs synchronous control. The ability to operate a synchronous control system is now possible due to the advances in desktop computing power. Desktop computers now have the computer power of the so-called 'super' computers of the mid 1990s, **Figure 6**. Synchronous control allows a route to be identified and assigned before the start of the journey and maintained throughout the journey through allocation of easement space and time for each vehicle at the prescribed headway. System optimisation includes algorithms for effective management of empty vehicles including maintenance and recharging.

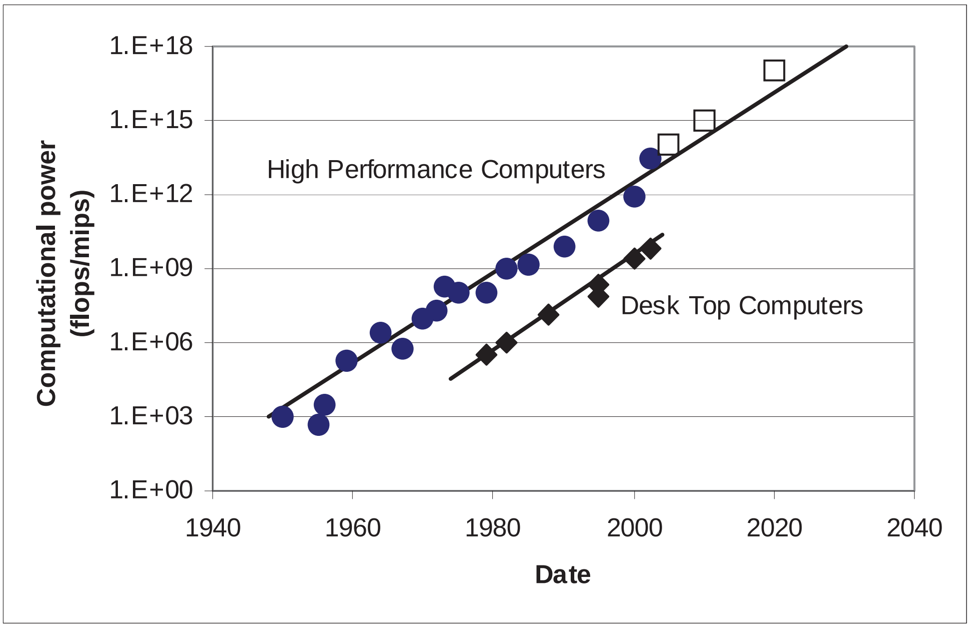

Figure 6 The development of computational power
McGuffie and Henderson-Sellers (2005)

Security
The need for personal security is a fundamental human survival mechanism and in recent times it has become a highly leveragable tool for the populist press, vocal campaigners and politicians. Fortunately the personal nature of PRT ensures that passengers feel safe and secure at all times. Passenger surveys during trials on the Ultra system showed that all the passengers felt secure in the driverless system. Service is on demand. Often vehicles will be available at stations for the immediate use of the passengers, and if not there will be minimal waiting time. Passengers have exclusive use of their vehicles or travel only with chosen companions. Once the journey starts the vehicle does not stop to pick up other passengers and expose the traveller to people with criminal intent. The vehicle is continuously monitored by the operations centre, passengers may contact the system controller at any time with an emergency call button and the controller can talk to the passengers, see them via onboard CCTV, and immediately respond to any concerns. The destination station can be located close to (or even within) the building to which the passenger wants to go.

Computer controlled automation introduces a very high level of operational safety. The vehicles are controlled autonomously, thus removing the potential issue of driver distractions, and an independent Automatic Vehicle Protection (AVP) system is in place to stop the vehicle in an emergency, providing ultimate protection to the vehicle and its passengers.

From the operator’s point of view the system eliminates fare evasion and malicous damage. Modern sensors can detect graffiti paint in real time. Similarly, character recognition software can detect the occurrence of physical damage again in real time. In either case this can be brought to the attention of the operator and the vehicle redirected to a secure station for apprehension of the offender. The impact of visual graffiti on static structures may be resolved by inviting potential offenders to decorate the structures during installation and subsequent maintenance.

Safety

The Bureau of Infrastructure, Transport and Regional Economics reported that in 2006 there were an estimated 653853 road crashes involving approximately 1.16 million vehicles, BITRE (2009). From these crashes 1602 people died and 31204 people were admitted to hospital; and that there were an additional 216500 people treated for road crash injuries who were not admitted to hospital. BITRE estimated that 4619 people suffered a disability as a result of the road crashes. While there is some improvement in the figures compared to 1996, there is also some evidence that the figures are reaching a plateau. The social cost of road crashes for 2006 was estimated to be $17.85 billion or 1.7 per cent of GDP. In spite of these figures, the general public’s familiarity with the car allows it to be considered a safe form of transport.

Unlike QANTAS, light rail does not have a perfect safety record. A review of statistics from the Alfred Hospital Melbourne has shown that between 2001 and 2008, 1769 presentations at the emergency department were due to tram trauma, Mitra et al (2010). This trauma arose either through a fall or being hit by a tram. While the majority of cases were minor, 107 cases were categorised as major and of more concern there was an upward trend over time. For the period 2001 to 2008 there were 15 tram-related deaths, including nine pedestrians hit by trams, five passengers who fell from trams and one cyclist struck by a tram. The Wikipedia entry for ‘Tram Accident’ disconcertingly illustrates the topic with a picture of an Australian collision between a truck and tram on Botany Rd, Sydney in the 1920s, Wikipedia Tram Accident (2013). The tram trauma experienced in Australia mirrors that in Europe and America, and analysis of the statistics from the USA and the UK show that street running trams kill more people per passenger mile than cars. Tram trauma is due to design flaws and the sharing of easements. Increased use of shared easements by light rail will cause a further rise in tram trauma.

The modern PRT system has drawn on the experience of the avionics industry where safety and reliability is accorded the highest priority. Extensive redundancy has been built into the system to cover local failure and eliminate catastrophic failure. The use of a dedicated easement eliminates the safety issues experienced by light rail. The safety record of the Morgantown PRT system demonstrates the efficacy of this approach. This system operates on a dedicated easement and has completed over 250 million passenger-kilometres over the past 35 years without serious injury or death. It has been estimated based on US Bureau of Transportation Statistics that the Morgantown PRT is at least an order of magnitude safer than public transport and two orders safer than cars, PRT Consulting (2011b).

Reliability

Most Automatic People Mover systems have achieved availability levels between 97.5% and 99.5%, and are more reliable than manually-driven alternatives. During its two years of operation Ultra has now carried 500,000 passengers at a System Availability of 99.6%. The net-work wide on-time running target for Sydney City Rail, with 'On time' defined as within 5 minutes of the timetabled time for suburban services and within 10 minutes of the timetabled time for intercity services, is 92%. This is generally met, however, on-time running on the Western and Northern lines has consistently been poorer than the network-wide target and at times has been below 70 per cent, Independent Pricing and Regulatory Tribunal (2008). The service reliability of PRT at >99% has to be rated as excellent.

Headway

The ULTRA and *2getthere* systems are operating with a headway of 6 seconds. This was selected due to the low demand levels of the pilot systems and easily meets the "brick-wall" stop criteria of the UK Rail Inspectorate. Headway is the minimum allowable space between two vehicles expressed as the travel time under cruise conditions. It is unused, empty space within a transport system. Excessive headways degrade the overall capacity of the system. The most effective mechanisms for increasing system capacity are to change from asynchronous systems (such as road transport) to synchronous systems with central control (such as PRT), the use of off-line stations, and free-flowing intersections.

The brick-wall stop criteria was developed for 19th century steam locomotion with manual signalling for section control. A section could measure several kilometres. Modern car drivers with a reaction time of 1.5 seconds are able to operate well within the brick wall stop distance by assessing the behaviour of the traffic in front of them. A PRT vehicle has a reaction time of microseconds and the system controls the behaviour of all the vehicles within the network. Thus the brick-wall stop criteria is inappropriate to PRT and it is anticipated that as experience is gained in system operation the headway will be reduced towards 2 seconds with a trebling of system capacity.

Capacity

Headway has a direct impact on capacity. Comparing the capacity of different passenger transport systems is fraught with difficulty because there are multiple measures that can be used. It would be more correct to say that any particular system operates within a capacity envelope, illustrated by **Figure 7**. The figure demonstrates that there is no one universal transport system for all situations; rather a spectrum of options exists allowing the transport planner and operator to select and tailor the system to the local needs of the travelling public.

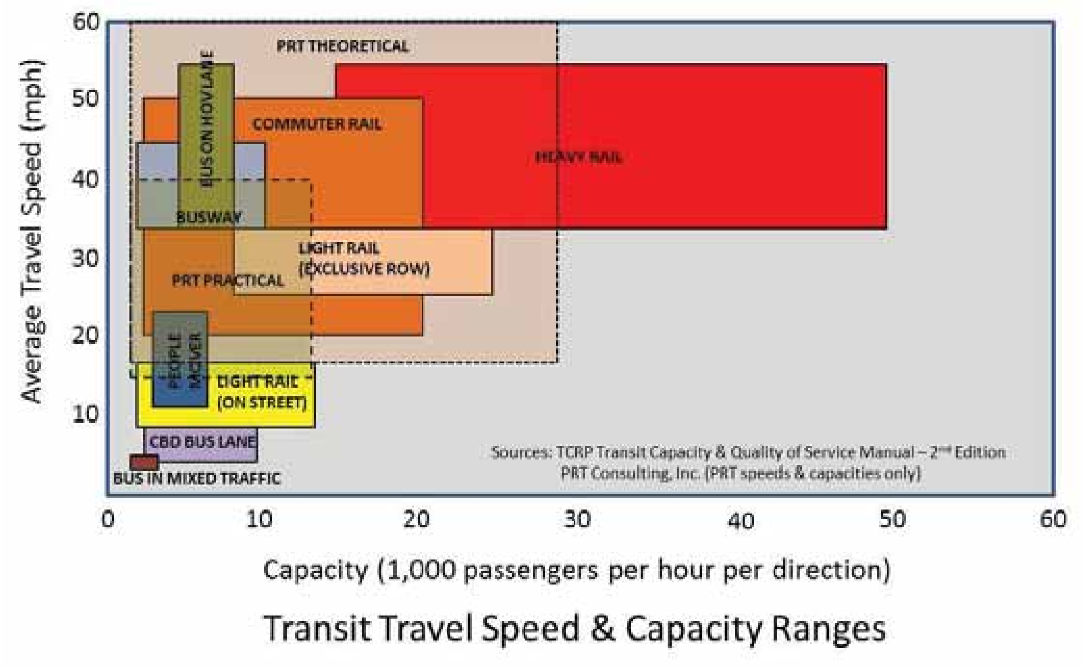

Figure 7 Capacity envelopes for various transport options, PRT Consulting (2011a) (used with permission)

A starting point is the base capacity, which is simply the number of seats times the frequency per hour. However no system actually fills all the seats all the time and there is a tendency for transport agencies to quote passenger numbers at the busiest time of the day as the capacity of the system. This introduces uncertainties when choosing a suitable time frame. The rush hour in one city is not necessarily the same as in another city and the demand rate will vary depending on the local population density. Some systems incorporate standing room as part of the design, as is the case for Light Rail. **Table 3** lists base capacities for different transport systems operating under a range of headways and frequencies. In terms of base capacity, PRT out performs the bus and Light Rail and is on par with the car.

Table 3 Base capacities of passenger transport systems

Type	No of seats	Headway/ Frequency	Vehicles per hour	Base capacity Passengers per hour
PRT	4	6 s	600	2400
	4	3 s	1200	4800
	4	2 s	1800	7200
Bus	50	10 min	6	300
	50	5 min	12	600
	50	2 min	30	1500
Light rail	200	15 min	4	800
	200	10 min	6	1200
	200	5 min	12	2400
Car	1	2.4 s	1500	1500
	4	2.4 s	1500	6000

Peak demand

While the transport operator tends to be more concerned with hourly capacity, the transport planner tends to give the highest priority to peak demand as offices, industrial complexes and entertainment centres disgorge their workers and patrons. Time frames are now reduced from hours to minutes and public safety requires that the concentrated mass of humanity is handled in an efficient and timely manner. A failure of the 1st generation PRT designs was to handle peak demand by enlarging the cab to take larger groups of people. This reduced the efficiency of the system due to increased journey time during peak demand by inclusion of multiple destinations, and of lower occupancy during the rest of the day. A better solution is to expand the stations at high demand areas to multiple berths. Other factors also come into play for example higher occupancy can be expected during peak demand due to familiarity with fellow travellers with a common destination, or travel by family groups especially to and from entertainment centres. The peak flow at a headway of 6 seconds is 10 people per minute with single occupancy and at a headway of 2 seconds is 30 people per minute with single occupancy. At full occupancy the peak flow rises to 40 people per minute and 120 people per minute respectively for a four-person cab. These peak flows can be doubled with a second track in the vicinity of anticipated nodes of high demand. It is not necessary to double the track across the whole network because the very nature of a network is to disperse traffic from a node not to concentrate it. PRT can handle peak demand when designed to be part of a fully integrated transport system.

Figure 8 Four berth station at Terminal 5, Heathrow

Energy Demand

Reducing resource consumption

The Climate Change debate has highlighted the need for sustainability and cost effectiveness. There is now a general consensus that a sustainable level of energy use for passenger transport is 1.8 kW per passenger, Dürr (1994) and Bouwmann (2001). This value is based on an evaluation of the energy constraints of solar radiation on the earth's surface. Lowson (2009) reported that the Ultraglobal PRT was the only transport system capable of meeting this target, **Figure 9.**

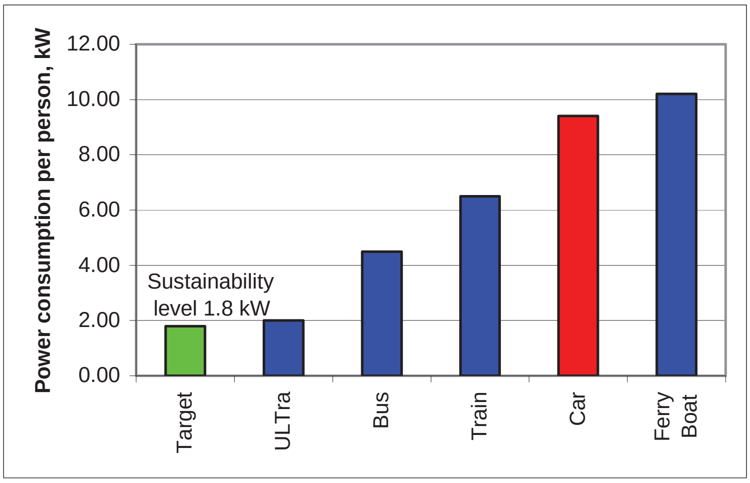

Figure 9 Power consumption for various transport options

Cost effectiveness of transport is strongly tied to energy use and energy efficiency. Coffey and Lowson (1996) reported on comparative energy use for various modes of transport with the data presented as mega joules per passenger kilometre, **Figure 10**. The data uses average values for the number of passengers per mode of transport, for example the average number of passengers in a car in the UK is 1.6 while the average load of a bus is 20%. The numbers indicate that the most energy efficient forms of transport at present are buses and Metro trains. The only transport system that meets the energy target is the Ultra PRT system. The surprising and controversially high value for Light Rail was re-evaluated and basically confirmed both for the UK and for the USA, Lowson (2002a, b).

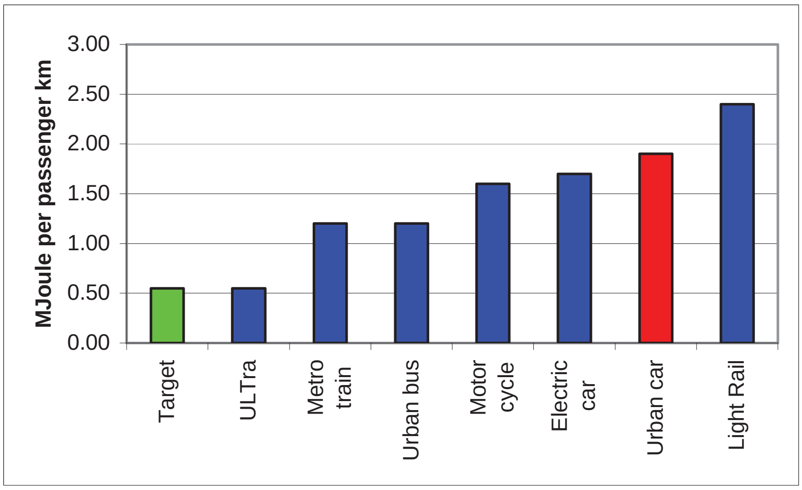

Figure 10 Comparative energy for various transport options

Costs

Investing in urban transport systems

Where there is not order, there is confusion.
Fria Luca Pacioli, 'father' of Double Entry Accounting
De computis, Venice, 1494,

Comparative costs for different transport systems are hard to come by. Inter-comparison is usually made at the bid stage of a project by the client and remains Commercial in Confidence; usually only the costs of the successful bid are published. **Table 4** lists comparative costs reported by Lowson (2009) for different transport options. These inter-comparison costs are based on a number of UK studies reported over the past 10 years. The PRT option has a range of 5.5-14.5 AUD$M/km with the lower figure reflecting the cost at a 'greenfield' site with the guide-way at ground level while the higher figure reflects an urban application with extensive accommodation of existing infrastructure and total elevation of the guide-way. Stage 1 of the Ultra PRT installation at Heathrow comprises of 3.9 km of guide-way, 21 vehicles, and 3 stations. The guide-way traverses 2 rivers, 7 roads, Green belt land, and bridges over or under airside and landside services which include a tank farm. The guide-way and stations had to conform to Terminal 5 architecture and look 'intended'. It is especially noteworthy that the system required zero service diversions, testimony to the flexibility and low footprint of the infrastructure design. Most fabrication was off-site. Erection of the guide-way was achieved at rates of over to 1 km/week. The average cost was AUD$M10.5 per kilometre.

Table 4 Comparative costs of different transport options

Transport option	Cost, AUD$M/km	Capacity, passengers/hr
PRT	5.5-14.5	900-2500
Guided Bus Way	4.5-7.2	450-1500
Light Rail	18-27	900-2500
APM	36-54	1000-5000

Intra-comparison of costs within a single system such as only light rail or only Bus Rapid Transit is fraught with difficulty. There is a wide range of issues that render such a comparison quite opaque to any attempt at identifying the source of the variation. These issues include:

- Land costs are sometimes included, sometimes not.
- The transit system may take over a road or in the case of Sydney Light Rail an abandoned heavy rail easement; sometimes the transit system has to build all its own road, rail or track.
- There may be extensive diversion costs as occurred on the Sydney-Macarthur line as they quadruplicated the track and encountered infrastructure that did not exist when the easement was first gazetted.
- The number of interchanges has a big effect.

- Major separations with other services such as railways, motorways, rivers will add major one off costs. For example a major item for the Brisbane Bus Rapid Transit was the tunnel at Bogga Road.
- A high proportion of costs are in the stations, and costs here strongly depend on the level of ambition of the client and architect. Is it to be a humble shelter or an architectural masterpiece worthy of a prize?
- Station costs may or may not be fully included, particularly when they become part of a commercial complex.
- Vehicle costs may be included or not
- In many developing countries there are additional costs associated with getting the necessary permissions.

Hensher and Golob (2008) reported an intra-comparison for the Bus Rapid Transit option based on a survey of 26 sites around the world. They obtained costs ranging from AUD$0.38 to 57 M/km with capacities varying between 1000 to 45000 passengers/hr. The wide range in costs and capacity demonstrates the difficulties involved with transferring intra comparisons across to inter comparison costs and the need to draft initial specifications for a transport system that allow all options to be considered.

Table 5 is a listing of cost estimates for the proposed PRT system for Cardiff, Wales, Bly and Teychenne (2011). The costing is for 7.7 km of single-track guide-way, 80% elevated, 12 stations and 134 vehicles. The staff cost is 32% of total operating cost. This is very low, staff costs are usually much higher towards 75% of an operating cost and the low value is due to the absence of drivers and the high degree of automation. This is a significant saving in the operating costs of the PRT transport system and results in the PRT system becoming very competitive when compared with other systems.

Table 5 Cost estimates for a Cardiff Personal Rapid Transit system

Capital Costs	AUD$M	Annual Operating Costs	AUD$M
Design	6.2	Staff	1.4
Project Management	7.2	Maintenance	2.2
Infrastructure	27.9	Energy	0.5
Vehicles (including spares)	8.9	Professional Fees and Insurance	0.3
Control System	2.9	Total Operating Costs	4.3
Planning/TWA	0.9		
Testing and Commissioning	4.2	Operating Costs per Vehicle Trip	$1.10/trip
Capital Expenditure Total	$58.5m	Annual Revenue at a fare of $2.70 per vehicle and average1.4 passengers	$10.3M
Capital Cost per km	$7.6m/km	Annual Operating Profit	$5.9M

A PRT Future for Newcastle

Reducing our dependence on the private vehicle

Every truly creative act reverses some basic assumptions
about the situation under consideration.
Albert Einstein, physicist and Nobel laureate

There is a strong correlation between Gross Domestic Product and kilometres travelled by passengers or freight, UK Department of Transport (2000). The new super highway of the Internet does not transport mass, and the transport of passengers and goods remains a crucial part of a modern day economy.

The Henley Centre noted in a questionnaire 'which one of the following resources of time, energy, money, information and space is the most/least valuable to you in everyday life', John Citizen identified time as the most valued resource, **Figure 11,** Henley Centre (2006).

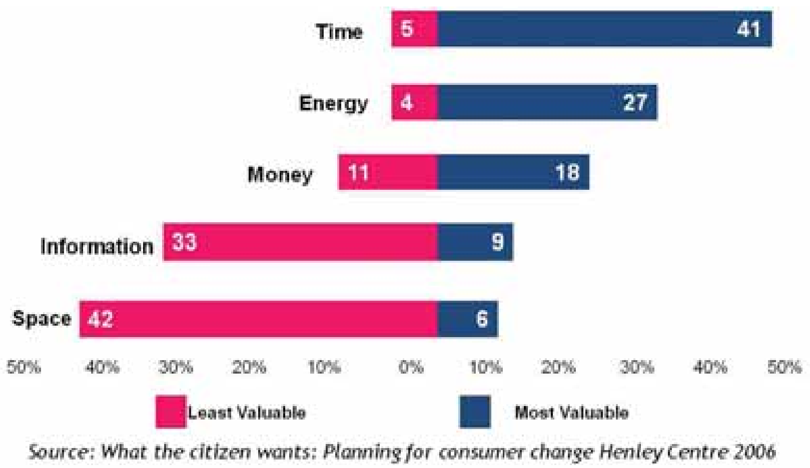

Figure 11 Percent response to the question: '*Which one of the resources is the most/least valuable to you in everyday life?'*

In this context, travel is viewed as a time waster and following the invention of the wheel there has been a continuous demand to reduce travel time. This demand continues to this day with calls for Very Fast Trains and supersonic aircraft. Historically, there has been a lag of between 50 to 100 years between the invention of a new transit technology and its uptake by the public. The canal required the invention of the lock; the railway required the invention of the high-pressure boiler by Trevithick; and the car required the invention of the internal combustion engine by Daimler. The new transport system, be it the canal, rail-way, trunk road (motorway) would then pass through a peak construction phase before being replaced by an alternative that better met the demands of industry and commerce, **Figure 12**, Lowson (1998).

The current decline in motorway construction reflects the diminishing returns from this form of infrastructure in terms of cost, productivity, efficiency and carbon footprint. This will be accelerated as peak oil starts to impact on transport systems. There is a need for a new transport system. Changing from corridor to automated network transport could be the new system but it required the invention of the transistor by Bardeen, Schockley and Brattain in order to build a computer with sufficient power for the network to operate.

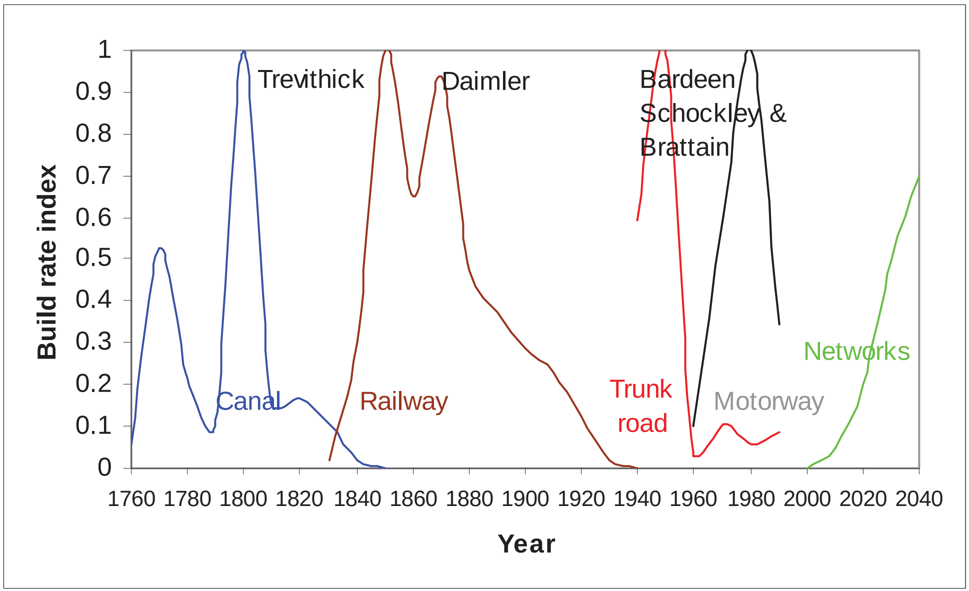

Figure 12 Surface transport history for the UK

Any change in transport technology will impact on the structure of a city. Cervero (1998) categorised cities around the world in terms of their economic structure. Melbourne for example may be viewed as a city with a strong core and radiating suburbs compared to Sydney which may be described as a city of cities. Historically Newcastle's structure was defined by a strong industrial core associated with its port and surrounded by suburbs servicing this core. However, the industries have moved on leaving a legacy transport structure which no longer has an industry to serve and fails to meet the new needs of the CBD. For example, the rail easement between Wickham and Newcastle is under-utilised and effectively sterilises the harbour foreshore from the city. Moving the under-utilised terminus back to Wickham will significantly improve the connectivity between the city and its water-front, a priority policy within the Newcastle Urban Renewal Strategy. It will also release valuable land for alternative development and allow integration of commercial, retail, entertainment, and professional services with passive and active recreational space. It will be important not to replace the rail easement with an alternative at grade dedicated easement such as a motor-way, bus-way or light rail. This will simply repeat the errors of the past by once again separating the city from its harbour.

All transport systems have strengths and weakness and a weakness of the otherwise highly efficient mass transport services, be they rail, bus-way, motorway is that these systems become progressively more inefficient as they penetrate a CBD. In the past there has been no alternative and a consequence is that the transport system starts to dominate an area within a CBD, sterilise valuable land from other uses and create impenetrable barriers. Examples can be seen in cities around Australia. Consequently a new model must be sought where transport becomes a service rather than the master. Modern transport theory argues, and it is a model being adopted in a number of cities around the world, for the mass transport services to terminate at transport hubs, and then service the CBD and its environs with an internal transport network which does not compromise the operations of the CBD and its interaction with its surroundings. The London underground could be regarded as a prototype for this model and Personal Rapid Transit systems are modern examples. A conceptually design is shown in **figure 13**.

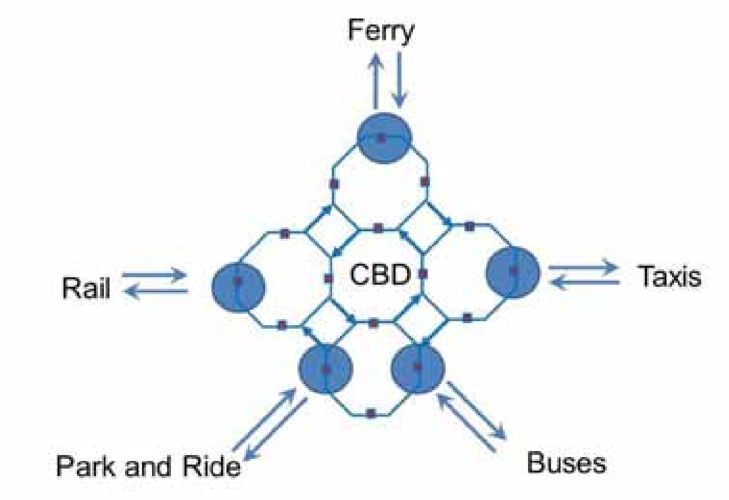

Figure 13 An internal network interlinking transport hubs with a CBD

There is no one universal transport system for the internal network, instead it will be defined by local geography, social and commercial need, capacity and cost. Not every city requires a London Underground. In short the internal transport network needs a set of specifications. These specifications will have to be somewhat elastic. The NSW Bureau of Transport Statistics studies report that within the Greater Metropolitan Area of NSW pedestrian travel is the preferred option of transit for distances less than 1 km. This is being progressively accommodated around Australia with pedestrian precincts and interconnected malls. However, beyond 1 km mechanical assistance is sought, and the car is the current system of choice. Consequently, at least within the Australian context an internal transport network linking a city's transport hubs with its CBD and its environs, will consist of pedestrian malls and precincts which seamlessly integrate with a public transport network that better meets the demands of the travelling public than the car.

The specifications for such a public transport network are that it:

- Is available on demand
- Will go anywhere within the network
- Does not stop between destinations
- Is environmentally friendly
- Is safe and secure
- Is low cost
- Integrates with other modes of transport

At the moment PRT is the only public transport system that can meet these specifications in that it:

- Has an average wait time <15 seconds
- Can go to any point on the network
- Has no stops between origin and destination
- Has a >50% reduction in energy and emissions
- Is very reliable and secure
- Is less than half the cost of other modes
- Can integrate seamlessly with other modes of transport at transport hubs

PRT has a very low spatial footprint. The low floor loading, absence of a catenary for motive power, ability to pass through buildings, ability to tackle high gradients and travel below grade, at grade, or elevated, allows PRT systems to integrate with infrastructure be it commercial, social or recreational, rather than compromise it. PRT will release land otherwise used for car parking for alternative more beneficial use, but its most important contribution to modern life is the return of time, John Citizen's most valued resource.

To achieve the optimum outcome when moving from concept to specifics will require detailed planning studies similar to that undertaken by Zarafu for Macquarie Park, Sydney (Zarafu, 2013), but there is no doubt that PRT is a transport solution for the cities of the 21st century.

'The European Commission has studied four potential (PRT) schemes and concluded that hesitant local authorities are the only significant obstacle.'
Economist, March 10th 2007, Technology p. 10-12

Conclusions

Guiding Principal 6 - Transport, Access and Connectivity of the 2012 Newcastle Urban Renewal Strategy identified three priority transport issues; it is argued that Personal Rapid Transit (PRT) could make a significant impact in addressing these issues in terms of:

Maximise accessibility and convenience of public transport to and within the city centre, and prioritise a range of transport modes to reduce private vehicle use.

> PRT provides true network transport. It is capable of connecting mass transport hubs with a CBD and its immediate environs. The transport is available on demand and will go anywhere within the network. There is no waiting or queuing prior to, during or at the end transit. It operates 24/7, 365 days a year. The transport is safe and secure both for the patron and the operator. It better meets the demands of the travelling public within a city environment than the car.

Promote connections and way-finding between precincts and to the waterfront, and encourage pedestrian activity throughout the city centre.

> The ability of PRT ability to travel below grade, at grade, or elevated, move effortlessly between grades and pass through buildings, allows PRT systems to integrate with infrastructure be it commercial, social or recreational, rather than compromise it. It will not sterilise valuable land and it will promote transit between precincts and the waterfront.

Support infrastructure and public domain improvements to attract people to the city centre.

> PRT meets the urban and city transport needs of the travelling public and is more effective than the car in these environments. It is more cost effective and environmentally acceptable than alternative systems. If properly integrated into mass transit systems it will attract passengers back to public transport and promote the city as a centre for commercial, retail, social and recreational activity.

PRT is a cost effective form of public transport infrastructure. Its capital and running costs are typically a third of the cost of other forms of urban transport. It offers higher levels of sustainability. It integrates well with other modes of transport and there are major environmental benefits. Two modern PRT systems have been operational for over 2 years and more systems are coming on-line. It justifies serious consideration as part of a modern transit system for Newcastle.

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