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Towards advanced transport for the urban environment

Generalization of the evaluation results of the Heathrow PRT trials and studies and transfer to other applications.

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Summary

The CityMobil project includes three demonstrations of advanced transport systems. One of these is a pilot installation of Personal Rapid Transport (PRT) at the new Terminal 5 of London's Heathrow Airport. BAA's purpose in building the Pilot System was to **prove the concept of PRT** as a means of transporting passengers around Heathrow.

The Heathrow PRT uses small vehicles transporting people individually or in their own private groups, non-stop from origin station to destination station on the network, and with little or no waiting. The system uses battery-electric powered four-seater vehicles running on rubber tyres on a passive flat guideway. Vehicles are self-navigating according to their internal electronic map, using laser guidance (lasers situated on the vehicle reflect off the kerbs of the guideway) to regularly update their positional data. A vehicle's entry onto the main guideway is controlled by a central controller which ensures it operates in a time slot which separates it from other vehicles. All stations are off-line, so vehicles can travel non-stop between their origin and destination stations. Empty vehicles can be automatically directed to empty station berths to ensure there is usually a vehicle already waiting when a passenger arrives, but if not a vehicle will be called up quickly.

This Heathrow system is small, with 3.9 kms of guideway providing a shuttle loop between a business car park and the new Terminal 5. When it is seen to work reliably BAA will consider further expansion. The pilot system is adequate to prove that the PRT system works, but not sufficiently expansive to show the full flexibility and convenience PRT offers for point-to-point travel anywhere on a widespread network.



❖ **The Heathrow system is described in CityMobil Deliverable D1.2.2.2.**

BAA has fully funded the PRT system. The CityMobil project is to ensure that it is fully evaluated. For this purpose, a survey was made in March 2009 of passengers on the transfer bus service between car park and Terminal 5, which operated prior to PRT.

❖ **The bus passenger survey is reported in CityMobil Deliverable D1.2.4.1.**

A survey of PRT passengers, in exactly the same format as for the bus passengers, was made in May 2011.

❖ **The PRT passenger survey is reported in CityMobil deliverable D1.2.4.2.**

❖ **The two surveys are compared in CityMobil Deliverable D1.2.4.3.**

This Report examines the assessment of the Heathrow PRT system, and combines it with other case studies and information on PRT to consider the advantages and weaknesses of PRT generally, and the potential for its wider application.

Section 2 briefly describes the Heathrow pilot system.

Section 3 compares the results of the passenger surveys for bus and PRT

These show very clearly that

- ❖ **Passengers prefer PRT to bus with a mean score across 12 aspects of the PRT vehicle and service of 4.63 ± 0.04 out of 5, compared with 3.82 ± 0.05 for the transfer bus service**

Passengers were asked to mark their rating of a range of aspects of the transport systems on a five-point scale, using identical questionnaires. They show a clear statistically-significant preference in all of the aspects, except for ease of finding the Terminal 5 station, which was not properly sign-posted at the time of the survey. In particular

- ❖ **PRT was preferred for its image, personal comfort and space, personal safety, waiting time, environmental friendliness, and for the overall experience.**

It was particularly encouraging that PRT received its second highest score (after image) for **personal safety**, at 4.71 ± 0.04 , whereas the familiar bus achieved only 4.06 ± 0.05 . This is an important result given that the service is driverless and most of the guideway is elevated. 94% of passengers preferred PRT to bus, 6% considered it much the same, and nobody preferred bus to PRT.

Section 4 describes four comprehensive case studies of PRT in different environments. These case studies have been made by ULTra PRT Ltd, and concern PRT networks and routeings which have been designed in considerable practical detail, tested in micro-simulation, and properly costed via a comprehensive costing spreadsheet. Such detailed costing has not been available to various other case studies which are also described briefly in this section, where costing has been at an average unit cost level. The costings in the original ULTra case studies have been updated in the light of the Heathrow experience. Each case study also makes a realistic prediction of the demand for the PRT systems, generally via a modal split model. The ULTra case studies refer to:

- An expanded **Heathrow** network
- A network connecting the rapidly-developing Bay area of **Cardiff** with the city centre
- A comparison of PRT with LRT serving new greenfield developments around **Corby**, a post-industrial town
- A network connecting the inner areas of **Bath** with its architecturally historic centre

In all cases PRT showed an excellent socio-economic return, and a financial case which easily covers operating costs, and seems capable of covering capital costs at a public 6% discount rate. Some of the main findings are summarised in the table below.

Case study	Size of network kms of one-way guideway	Cost per passenger ⁺	Reduction in journey generalised cost	Revenue "surplus" ^δ	Benefit/cost ratio* 30-year NPV	First year rate of return [†]
Heathrow	7.6	€1.38	65%	NA (no fare)	223%	332%
Cardiff	7.7	€1.30	53%	-€0.07M	248%	254%
Corby	30	€1.50	23%	+€6.9M	184%	430%
Bath	45	€1.48	30%	+€4.3M	Not calc.	271%

+defined as (annual operating cost + 6% of capital investment)/annual passengers. Costs in euros are converted from £ sterling at 1.12 €/£

δ defined as (annual revenue - operating cost - 6% of capital cost)

**defined as NPV of (value of total passenger time savings relative to transfer bus + saving in bus operating cost)/(capital costs including vehicle replacement + operating cost)*

† defined as (first year passenger benefit + saving in bus operating cost)/(first year PRT operating cost + 6% of capital investment)

The mean cost per passenger, which includes both operating cost and a contribution to capital costs, is fairly similar in all the networks, despite the extent and intensity varying substantially. In all cases PRT has a journey time much less than for the alternative bus journey, but in addition to this it also attracts substantial transfer from car use, with consequent reductions in congestion in Cardiff and Bath, and environmental benefits. In Cardiff it encourages transfer from car as users transfer to rail (and, to a lesser extent, bus) in from the suburbs, because PRT then provides a more convenient interchange onward to the Bay than presently exists.

Modelling predicted that 8% of current car users to Cardiff Bay would transfer to rail plus PRT, despite the fact that PRT covered only the last 2 kms of the journey at the city end. In Corby 18% of car users were predicted to transfer to PRT, and in Bath 17%.

It is especially interesting that:

❖ **The Corby study was able to compare PRT with LRT**

using a model developed by Colin Buchanan and Partners to assess an LRT proposal, evaluating both modes on exactly the same basis. This suggested that PRT would attract 19% of all trips in the area served, compared with 11% by LRT, while LRT would reduce car trips by 9% compared to 18% with PRT. Both modes would cover operating costs, but LRT could make only a small contribution to capital costs, whereas with a slight increase over the existing bus fare PRT would cover investment at 6%.

Other studies, generally based on the overall unit costs previously quoted for ULTra, have come to similar conclusions about the superiority of PRT over conventional public transport,

and in particular a study of PRT in a retail complex near Stockholm suggests that PRT would reduce the public transport journey time by 26%, triple the overall public transport modal share, reduce car use by 9% and produce 3% more growth in total usage of the retail centre.

Of course, transport modelling is of uncertain reliability, though it is the best quantitative approach we have. But it is obvious that PRT will attract more passengers than conventional public transport, other things being equal. It offers minimal waiting, an uninterrupted journey at an average speed (35kph for ULTra) which is high for urban road traffic, and without interchange. Unlike mass transport, which is most effective when serving one or a few focal destinations, it is a true anywhere-to-anywhere mode of transport. It has the characteristics of the private car, except for the need to get to the station.

**Provided that it can compete on cost, and it seems that it can,
PRT will inevitably outperform conventional public transport.**

Section 5 discusses the appropriateness of PRT in different environments.

5.1 considers the practicalities of installing PRT. The discussion notes that while passengers like PRT, and it performs better than conventional public transport financially, it has the disadvantage of requiring segregated routes, and much of the guideway would have to be elevated to avoid severance. However, the light-weight and small scale of PRT can minimise problems here. The study in Bath, while not fully resolving how the detailed design of infrastructure and vehicles might be adapted to an architecturally historic city, showed that there were practicable routes for PRT guideway close into the city centre, and that people seemed willing to accept PRT in this sensitive environment. PRT would also play a valuable role in Park and Ride sites.

5.2 considers where it might be installed. Swedish studies have suggested that PRT may only be viable in cities larger than 50,000 to 100,000, yet UK studies have suggested viability in much smaller towns, and it is clear that smaller networks in specialised environments such as airports or business campuses can be justified.

5.3 considers costs, and gives costing equations to estimate ULTra costs for a specified network reasonably accurately. The current developers of PRT systems are described, though for commercial reasons they give little or no cost information. A rather dated comparison of LRT costs shows that LRT costs per track-km are likely to exceed PRT costs substantially: updated costs across the ULTra case studies have an average cost of 6.5M€ per km, compared with a range for LRT likely to update to at least 15 to 23 M€ per km.

5.4 considers safety, and notes that the Heathrow passengers rated PRT safety higher than for the transfer buses. Hierarchical vehicle protection systems provide mechanical safety, while monitoring and control of the vehicle interior, and the absence of waiting at stations, provides passenger security.

5.5 considers environmental aspects and quantifies energy use and emissions. PRT's low-energy, electric vehicles have advantages over conventional public transport in energy use, emitted air pollutants, and greenhouse emissions. They have no tailpipe emissions, and are also very quiet, and impose a very low floor loading, so they can be routed through buildings, improving access and integrating transport more closely with other activities. Energy use per passenger-km is less than that for bus or urban rail, and the reductions in emissions are proportionately greater, with no emissions at the system location, and greenhouse gas emissions per passenger-km typically a third to a half those of bus or rail services.

5.6 discusses the steps involved in the decision to install PRT, providing advice on how a preliminary examination of the case might be undertaken, but noting that eventually a detailed demand model would be needed, and this will require expert support.

Section 6 considers the future of PRT.

Heathrow is the first publicly-operating PRT system in the world. First adopters of radically new technology take substantial risk. BAA decided this was justified because of the obvious advantages of PRT as an airport's core transport system. It offers a higher quality of service than conventional transport, with its ability to go non-stop and with little waiting from anywhere-to-anywhere. It also provides the futuristic, high-technology image airports value, even though the mechanical technology of PRT is in fact modest. And there are few problems of routing and incorporating the infrastructure into the existing development. The Heathrow pilot has proved the concept, with a service reliability of 99.7%, and it seems certain that other airports, high-value campuses and retail developments will adopt PRT in a growing market.

But PRT was developed for **urban public transport**. It has clear and substantial advantages in improving and integrating passenger transport in towns and cities. It is important to prove PRT in the urban environment, not as a small demonstration loop, for Heathrow has already shown that this works, but as a proper, if limited, network which serves a real demand. Analysis in Cardiff showed that even a small PRT network acting as a distributor from a transport hub can encourage substantial transfer from car to public transport. But the public sector is generally risk-averse, and is unlikely to take the initiative in the same way as the private sector. Individual urban authorities cannot be expected to take the risk of becoming first adopters. Unless we are prepared to wait decades for these next steps, it seems likely that national governments, or international governments, will have to provide support and funding to offset the risk.

Section 7, in conclusion, makes the point that PRT can be made to work reliably and at acceptable cost, and that passengers prefer it. BAA have taken considerable risk in achieving this, and CityMobil has shown the benefits which PRT can achieve more widely.

Its adoption in airports and campuses seems assured, but the more difficult step is to demonstrate that it can be acceptable and cost-effective as a general urban public transport system. More work and support is needed, probably at an international level. to achieve this.

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Generalization of the evaluation results of the Heathrow PRT trials and studies and transfer to other applications

1 Introduction

The objective of the CityMobil project is to achieve a more effective organisation of urban transport, resulting in a more rational use of motorised traffic with less congestion and pollution, safer driving, a higher quality of living and an enhanced integration with spatial development. Its focus is on **automated vehicles**, whether operating on general-purpose roads or in segregated systems.

One of CityMobil's three large-scale demonstrations is the world's first publicly operating Personal Rapid Transit (PRT) service at London's Heathrow Airport. PRT uses small automatically-guided vehicles on a network of segregated guideways to carry passengers, either individually or in their own private group, non-stop from any station of the network to any other station. It does not run to a schedule, but passengers arriving at a station indicate their desired destination, and a vehicle will be called up to take them there. Since the system uses a large number of small vehicles, and is normally controlled to keep vehicles distributed across the stations when not in use, mostly, and especially at off-peak times, passengers will find a vehicle already waiting for them when they arrive, and there is no need to wait at all. At busy times a station may not have a waiting vehicle, in which case one will be called up from the most efficient location, appearing generally within a minute or two. Since vehicles are on segregated track, with off-line stations, and running within carefully controlled time slots, vehicles are rarely required to stop in transit, and travel is non-stop from any station to any other, with no need for interchange. Vehicles are comfortable and car-like, so passengers travel within their own personal space.

The concept has been around since the late 1960's, but although some prototype systems were developed at that time their technology was too costly and, for the most part, their infrastructure was heavy and visually-intrusive. None were put into public use. A system operating between the centre of Morgantown and the campus of the University of West Virginia is often described as the first PRT, and it was intended to operate as PRT, but ultimately this was too expensive and the system opted for larger (12-seater) shared vehicles with intermediate stopping. It became collective transit rather than PRT. It has, however, operated automatically for almost 40 years now, without any personal injury.

The pilot installation of PRT at Heathrow Airport serves a Business Car Park and links it to the new Terminal 5. This system has been installed by the airport's owners, BAA, to prove the concept of PRT, to demonstrate its reliability and efficiency, and to ensure passenger acceptance. Once PRT is shown to work successfully, BAA's will consider whether to expand the network. The pilot system is essentially a shuttle system, and cannot fully demonstrate the advantages of PRT as a network where passengers can travel directly from any point to any other point on the network, without interchange. Thus it is not intended that the Pilot Scheme will of itself be economically justified, but it is intended to be the start of a wider PRT system which can justify itself economically and in terms of passenger satisfaction. The design of the Pilot system is as detailed and functional as will be required for the larger network.

Evaluation is an important part of the CityMobil Project, and the methodology is addressed separately in Sub Project SP5. For the Heathrow Demonstrator, the PRT system has been judged against the alternative conventional transport, in this case the transfer bus services which are currently in use across the airport to connect the Terminals with car parks, car hire, hotels, public transport hubs and staff workplaces. Deliverable D1.2.4.3 compared the performance of PRT with that of the buses in terms of passenger assessments and management opinion, and gave the relevant operating statistics.

This Report considers the likely costs and benefits of PRT in more general and wider applications, so that conclusions can be drawn about the applications and circumstances where PRT might provide a valuable solution to transport problems.

2 The Heathrow Pilot PRT Scheme

Deliverable D1.2.2.2 describes the system. This is the ULtra PRT system developed by ULtra PRT Ltd of Bristol, UK. It uses lightweight 4-seater vehicles, 48v battery-powered, navigated autonomously on a simple 2m wide guideway, with a running surface formed of steel mesh on elevated sections, and on plain concrete at grade. It has 3.9 km of guideway, connecting two stations in the car park with a single station located in a short-term multi-storey car park alongside Terminal 5. The car park stations each have two berths, while the T5 station has four. The berths are arranged in a chevron, so that vehicles enter the berth forwards, but then reverse out before resuming their onward journey. The control systems of ULtra facilitate this, since each vehicle carries its own electronic map of the whole network and, once despatched by the central control system into a safe-guarded time slot, steers itself according to its internal map, updating its exact location at short intervals using laser guidance off the kerbs of the guideway. Otherwise the guideway is totally passive, though it also contains a secondary safety Vehicle Protection System. The guideway has the kerbs to provide a fail-safe restraint if all guidance mechanisms should fail, but otherwise the vehicle requires no more than a flat surface to run on. All guideways are one-way, and in a more extensive network would normally be arranged as a network of interconnecting loops, but since this limited system is essentially a shuttle service the line-haul section of the network is constructed as parallel guideways alongside one another, as shown in Figure 2.1.



Figure 2.1 PRT Vehicles at Heathrow

ULtra vehicles are relatively light (850kg plus a 450kg maximum payload) and operate with low power (the motor is rated at 7kW, but has regenerative braking and operates typically at about 2.5kW). It has no direct emissions, and even when power station emissions are taken into account it has lower emissions of either regulated pollutants or greenhouse gases than conventional transport, on a per passenger-km basis. It is very quiet, and could readily run within buildings, since its floor pressure is well within normal building floor loads. In the pilot, however, the Terminal 5 station has been located for constructional convenience in the existing multi-storey car park rather than within the Terminal building itself, where with an integrated airport transport system passenger access would be much easier.

Vehicles carry closed-circuit video and audio communications with the central control centre, so that in any sort of emergency passengers can obtain immediate help. They also include continuous “vehicle health” monitoring so that any developing fault can be identified and rectified, or the vehicle taken out of service. In extremis there is an escape hatch whereby passengers can evacuate the vehicle, but normally if a vehicle were to fail in transit a special vehicle would be sent to recover it with its passengers.

The system has 21 vehicles, and has been operating in commissioning mode since the summer of 2010. During the autumn of that year and into early 2011 it operated continually in what has been described as “Simulated Revenue Service”, during which it operated in almost all respects as it would in public service but carrying only airport staff, not the general public. BAA have been very keen to ensure that, on its public opening, the system proved itself to be very reliable and free of even small faults. Indeed, during the commissioning there were inevitably a considerable number of faults to be fixed, but these were almost entirely connected with aspects peripheral to the PRT operation itself – items such as the touch-screen destination selectors, the door closing sensors, and the emergency voice communication with central controllers proved irritatingly persistent. These are items which had not been proved on ULTra’s prototype system at their test track in Cardiff, and in a system which is the first of its type such technical problems are to be expected.

The system began public operation in April 2011. Since then it has operated with 98.7% reliability (99.7% if one extended shut-down is omitted), and without any incidents threatening passenger safety, carrying around 1,060 passengers per day.

3 Passenger acceptance

Passenger attitudes to the transfer bus service were surveyed in March 2009, and exactly the same questionnaire was administered to PRT passengers in May 2011, with the addition of two questions at the end of the original questionnaire. Some 300 passengers were included in each survey, and the methodology was the same so far as possible: surveyors could address several passengers on the transfer buses, while they had to deal with individual passengers, or their private groups, in the PRT vehicles, but surveyors’ treatment of passengers was essentially the same in each case.

The great majority of the questions required passengers to assess an aspect of the service on a five-point scale, from 1=“extremely poor” to 5=“excellent”. The sample sizes had been designed to discriminate between the standard deviations on the mean markings by 0.1 of a mark or better, and achieved mostly the ± 0.05 level.

The detailed results of the surveys were described in **Deliverables D1.2.4.1** and **D1.2.4.2**, and the results for bus and PRT were compared in **D1.2.4.3**, which also contains views of the BAA management and operating data for the survey period. Figure 3.1 summarises the survey scores for PRT and bus. The weather was better overall during the PRT survey than during the bus survey, and both surveys showed that better weather increased passengers’ scores, so the PRT scores have been adjusted downwards slightly to allow for this effect.

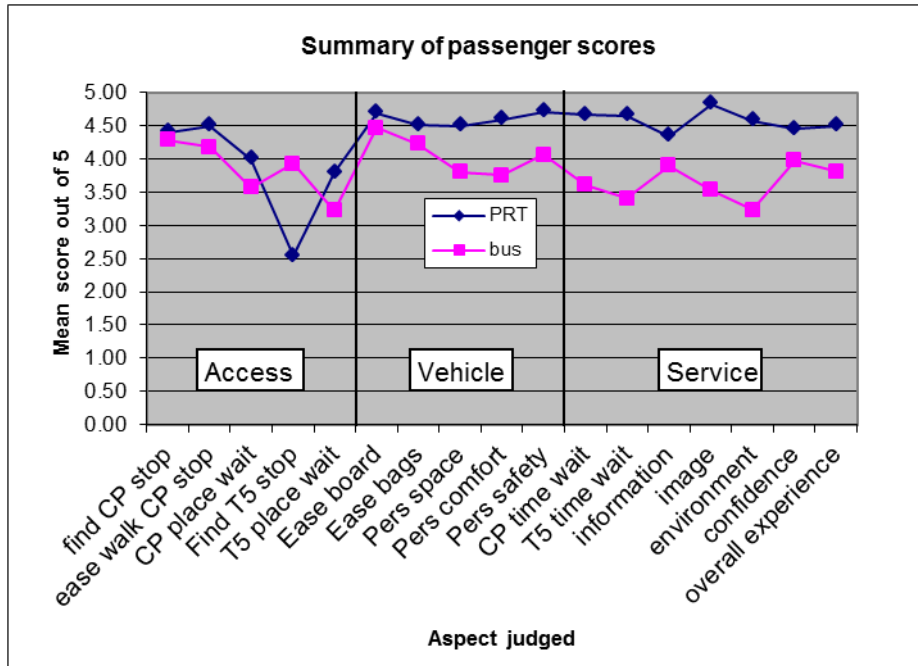


Figure 3.1 Comparison of the passenger assessments of PRT and transfer bus

* PRT scores have been adjusted downwards to allow for better weather during PRT survey than bus survey

It is noticeable that passengers have marked “finding the T5 PRT station” very low. This is because at the time of the survey the signs inside the Terminal directing passengers to the station had not all been fixed, and passengers had to ask. The pilot PRT station has been located inside the short-term multi-storey car park alongside the Terminal building, and at a level midway between Departures and Arrivals. Reaching it requires taking a lift, and walking through part of the car park. Passengers’ irritation with lack of direction probably also affects their marking of the T5 station as a place to wait, and although the station is modern and well-lit it is rather hidden away in a corner of the car park. If the PRT system were to be designed permanently into the airport it would locate stations inside the buildings, since vehicles are quiet and emissions-free, and access would then be much easier.

But for all other aspects than ease of finding the T5 station (and direction signs were fixed shortly after the survey) the PRT service scores much higher than the bus service. All the differences are highly statistically significant. Ease of walking to the car park stations is marked more highly than walking to the bus stops, even though the distances involved are, on average, slightly longer. Passengers’ appreciation of PRT has coloured all their scoring.

These aspects connected with the stations are not intrinsically attributes of PRT itself. **For the 12 aspects directly concerning the PRT vehicles and service the mean score is 4.63 ± 0.04 , compared with 3.82 ± 0.05 for bus, and PRT is clearly regarded much more highly than bus.**

Unsurprisingly, PRT gains its highest score for **image** (4.83 ± 0.03). For many people this is a transport system out of the future, as was emphasised by many subsequent unsolicited remarks on the Twitter website. Nevertheless, despite its appearance the vehicle is largely based on tried-and-tested automotive components, and the guideway is simple structural engineering. It is given high marks for being “**environmentally friendly** (4.47 ± 0.04). Of course, passengers have no technical data about ULTra, which is indeed low-energy and zero emissions, so passengers are presumably judging from the small size of the system, the electric propulsion, and the low noise.

It is particularly encouraging that the second highest score is for **personal safety** (4.71 ± 0.04), whereas bus achieves only 4.06 ± 0.05 despite being regarded generally as very safe. PRT is a wholly new transport system, without a driver, and on guideway elevated by several metres for much of the journey, yet passengers clearly feel very secure in it. **Personal comfort** also scores much more highly than bus (4.60 ± 0.03 cf 3.76 ± 0.05).

Naturally, **waiting times** score highly for PRT, with 4.66 ± 0.04 for waiting at both the car park and T5, compared with 3.61 ± 0.07 and 3.41 ± 0.07 for bus. Mean waiting time for the bus was 5.2 minutes, compared with an average 0.3 minutes for PRT. 70% or more of PRT passengers did not have to wait at all. Only 6% of PRT passengers had to wait more than a minute.

Passengers have more **confidence** in the PRT service than in bus (4.45 ± 0.04 cf 3.98 ± 0.05), but this is a fairly general attribute of rail services, where the rails or guideway seem to offer a guarantee of service, while there is no perceived guarantee that a bus will arrive. However, PRT has the added advantage that, for most passengers, a vehicle is already waiting in the station. Moreover, service reliability has been 99.7%

This is all summarised in the **overall experience**, where PRT is marked substantially better than bus (4.50 ± 0.04 cf 3.81 ± 0.05), though the latter is still a good score for bus. This is reinforced by the first of the two additional questions asked at the end of the PRT passenger survey. This asked those passengers who had experienced both the transfer bus service and the PRT service which they preferred. Nobody thought that the bus service was better than PRT, and 94% preferred PRT to bus, while 6% thought they were much the same.

The second additional question was an attempt to establish a **willingness-to-pay for PRT**, though it had to be framed in the hypothetical context of a PRT service available to carry the passenger from near home to their local town centre, to avoid biasing the result because of considerations that the Heathrow car park might wish to charge for the service (at present transfer services from car parks are included in the car park charge). Even so, it seems that the responses were affected by such considerations, since 28 passengers said they were willing to pay less for PRT than for the bus, even though they had said PRT was better than the bus. 10% of those responding were not willing to pay as much as for bus, 41% were willing to pay much the same as bus, 36% were willing to pay more than the bus fare but less than taxi, 7% would pay as much as a taxi, and 7% more than a taxi. Thus 50% were willing to pay more than for bus, but this seems likely to underestimate true willingness-to-pay. We will return to this question in the following Sections.

4 The economic case

Clearly, passengers like PRT. But that is not sufficient to justify it. In order to justify the considerable investment required to build a PRT system there must be sufficient quantifiable, and preferably monetarized, benefits. This section considers the likely financial benefits to the operators, and the wider social benefits.

4.1 The Heathrow Pilot

The Heathrow system has been built by BAA to prove and refine the concept, to assess passenger acceptability, and to provide evidence for the value of extending the system more widely across the airport. It is a very small network, and it was never intended that it would be economically justified.

The strength of PRT is that it provides instant non-stop anywhere-to-anywhere travel across a network of routes. The PRT system at T5 demonstrates only limited aspects of this potential, providing no more than a shuttle between the Business Car Park and the Terminal. The route taken by PRT parallels that used by the previous transfer buses but only takes about 5 minutes, compared with a typical 5-8 minutes for the bus (which has to stop at two stops and then negotiate several busy roads). In addition, the return bus journey detours around the multi-storey car park, adding a further minute to that journey, and bus passengers had a mean waiting time of 5.2 minutes, compared with only 0.3 minutes for PRT.

Passenger Benefits: In transport assessment, waiting time is considered more onerous than time spent in a vehicle, and is costed at a higher rate, typically twice as much. Therefore (even ignoring any differences in trip time) PRT saves each passenger, on a round trip from and back to the car park, the weighted equivalent of 10.8 minutes. 98% of passengers are travelling on business, and the appropriate Value of Time (VOT) used in economic assessment, as recommended by the UK Department for Transport, for travel in course of work is 37 pence (0.41€) per minute for a car driver. The economic benefit from time saved per passenger round trip is £4.00 (4.48€). With an estimated 180,000 passengers per year, this equates to a total time benefit of some £717,000 (803,000€) per year.

System costs: The Heathrow system is the first publicly operating PRT system in the world. Its design and construction has been monitored closely by BAA, which has been involved at all stages of construction and testing, and several changes in specification, some major, have been made along the way. There has been extended testing, and high start-up costs in aspects such as tooling up for very small volume vehicle production in the first instance. The project has also been complicated by a change of ownership of the airport and company, which necessitated reviews and a postponement of the project. This has been far from a "turnkey" project.

It is not possible to assess all the costs of this project, since some are known only to BAA and will not be made available because of commercial confidentiality, but nor is it relevant in relation to further application of PRT. What is required here is a realistic assessment of the likely cost of installing PRT in future on a "routine" basis now that the fundamental details of the design and operation have been established.

Nevertheless, the Heathrow project has provided a much clearer experience of the details and costs of construction, and a very detailed costing methodology has been developed and tested in the light of this experience. We will consider the issue of costing PRT in Section 5.3, but here it is sufficient to note that applying the cost estimating equations described in that Section to the specification of the Heathrow pilot scheme returns an estimated capital cost, including an 18% contingency, of 24M€¹, and an annual operating cost of 1.33M€.

The costing equations used here and later reflect the best estimate of what PRT would cost if constructed and operated on a more extensive network and in a more routine way. The experience has provided sufficient cost information to ULTra PRT Ltd, together with knowledge of the costs incurred within their own areas of responsibility and sub-contracting, to review and update their costing methodology. Indeed, although the details are not

¹ UK money values originally in £ sterling have been converted to euros at the rate of 1.12€/£ throughout this report

available, apparently BAA's own estimate for the total cost of extending the system across the airport is very close to the cost obtained from the ULTra costing methodology. Small PRT systems are relatively expensive because there is a large fixed cost associated with the control system no matter how small the system is; more extensive networks return much smaller costs per passenger carried for both capital and operating cost. If the capital cost is discounted at 6% p.a, a common discount rate for public investment in the UK, the annual amortized and operating cost is 2.9M€ p.a. Other European countries use 4%, when the combined cost would be 2.3M€.

Cost/Benefit: Comparing the costs with the monetarized time savings for passengers shows that this small system cannot be justified financially. Of course, there are additional benefits which cannot be monetarized. PRT saves on emissions of polluting chemicals and greenhouse gases, and uses energy very sparingly. For BAA, the question of image matters greatly. The PRT system appears futuristic, even though the component technologies are relatively simple and cheap. Many airports have invested in much more expensive "high tech" rail systems, whether underground, monorail or mag-lev, in applications which are far from being justified in normal cost-benefit terms. PRT can illustrate an airport's commitment to technological progress and customer service and, as we saw from the passenger survey, its image is rated highly.

But the T5 Heathrow system was never intended to be justified economically. It was built to demonstrate that PRT actually works reliably, so that it might be extended to a system which could be justified economically.

Consequently, comparison of benefits and costs is not relevant here. In any case, the larger value of PRT lies in the benefits available when it offers on-demand, non-stop, no-waiting transport across a wide network, aspects which cannot be tested in this limited system. At the airport, it could serve stations within buildings, adding further to passenger convenience. Its use here in a shuttle operation makes little use of PRT's main attributes.

We need to consider what the justification can be for applying PRT on this larger scale to a range of situations. At present, this can only be done via desk studies. ULTra PRT Ltd have made a number of very detailed desk studies of PRT over the past several years, and four of these will be considered next.

4.2 The Case studies

Sections 4.3 to 4.6 below contain descriptions of detailed case studies of ULTra PRT networks designed for four very different environments. Section 4.7 summarises briefly several other case studies which have not been able to use the detailed costing information available to ULTra PRT Ltd, and which have relied on a broad average cost per km of guideway. These case studies are more generic, though they tend to rely on the characteristics of ULTra for their description of PRT because other PRT developers have not published system costs or performance data in as much detail as ULTra. Thus the case studies summarised in Section 4.7 are of necessity less realistic than those made by ULTra PRT Ltd, though they have the virtue of independence. It should be noted that the ULTra case studies were estimated in a UK context, using a discount rate of 6%. Where other countries use a lower rate (4% is common) the economic case will be substantially stronger.

All the case studies are consistent in their main findings however. They find that:

- ❖ **PRT attracts a larger share of total demand than can conventional public transport**, whether bus, LRT or urban rail, because it is able to offer a superior level of service, with much less waiting than mass transit, non-stop travel from anywhere to anywhere on the network, and no interchange required. These aspects can be accounted for in the conventional mode-split models used to predict demand for PRT. There are other attributes of PRT such as privacy and the ability to travel alone or in a personal group, and perceived reliability in that mostly the vehicle is present when the passenger arrives, which are not accounted for in modelling the mode choice, and which are likely to increase the attraction of PRT.
- ❖ **PRT seems capable of being constructed at a cost which is no greater than, and probably less than, current LRT systems.** At the same average fare it will generate more revenue. Experience has shown that advanced conventional transit systems often struggle to cover their operating costs, let alone paying off their capital investment. PRT, by contrast, easily covers its operating costs and seems capable of repaying its investment costs at the standard public investment discount or amortisation rate of 6% p.a, even at the same fare rates as for conventional public transport. The public attitude studies suggest that passengers are prepared to pay higher fares for PRT than for buses and, by extension given the higher level of service, this seems likely to provide a premium over LRT too. This aspect gives a buffer against financial shortfall with PRT. Even where covering costs is not a prime requirement of public policy, PRT will give better value for money.
- ❖ **PRT attracts a much larger share of potential car users** than does conventional public transport, by a factor of two or more. This has obvious benefits for the environment and road congestion, with worthwhile reductions in regulated air pollutants and greenhouse gas emissions.

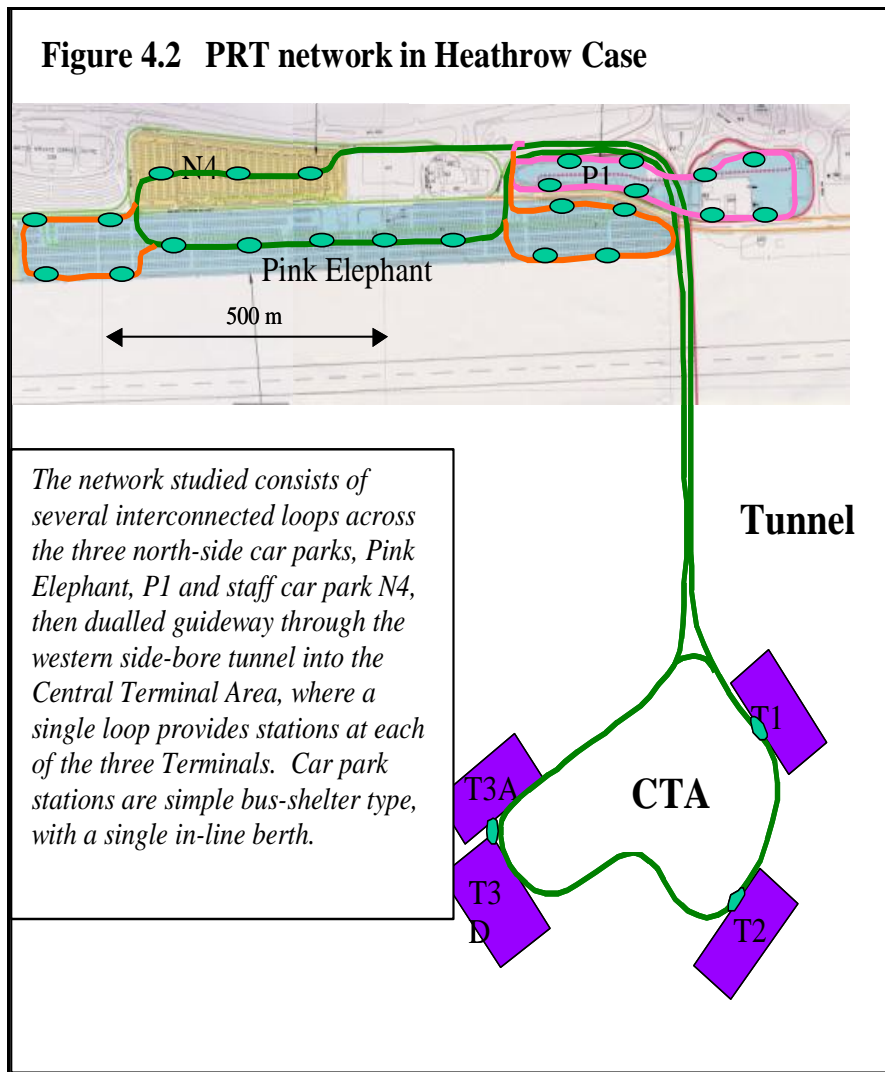
Readers who are content to take these findings on trust can proceed to Section 5, or merely skim the figures and tables in the following sections. These sections do, however, provide a substantial body of evidence that PRT would radically change both the performance and the image of urban public transport, and that it is practicable to apply PRT in a wide range of urban situations.

4.3 CASE STUDY 1: A wider Heathrow network

Prior to BAA's decision to construct the Terminal 5 PRT system, Advanced Transport Systems (ATS – now ULTra PRT Ltd) had made a detailed desk study of the effects of PRT in Heathrow for the UK Department for Transport (ATS, 2002). This was before the opening of Terminal 5, and focussed on linking three car parks on the north side of the airport with the central Terminals 1, 2 and 3. Although the study was not made on behalf of BAA, BAA provided the necessary data for the study. Note that this is an entirely hypothetical study.

A 7.6 km network was designed connecting two business car parks (Pink Elephant and P1) and a staff car park (N4) with the Central Terminal Area (CTA), as shown in Figure 4.2. BAA had plans to redevelop the CTA, but was concerned that access to the CTA was via a road tunnel underneath the main runway, and at peak times the tunnel, with two road lanes in each direction plus two small sidebore tunnels used mainly by taxis, was running over capacity and delays were frequent. It had commissioned a study from an engineering

consultancy to examine ways of improving the airport's internal transport systems, and a light rail system and a guided bus system were examined, but neither seemed fully satisfactory. An interesting aspect of the PRT design was that the small ULTra vehicles would be able to use the tunnel sidebores: indeed, two guideways could be placed within a single sidebore tunnel, and for a more comprehensive airport PRT it would be possible to use an undercroft to the tunnel which ran most of the way below the sidebores to provide four PRT lanes, two above and two below. This arrangement could in principle provide sufficient capacity to carry the entire passenger demand into the CTA.



The system was designed to carry the existing 8,300 passengers per day, and could carry 1,900 passengers per hour if required. For this, it required 78 vehicles. There were 24 simple stations in the car parks, and one station at each Terminal, with 5 berths for Terminal 1 and three each at Terminals 2 and 3. Except in the CTA most of the guideway could be at grade (only 32% of the network need be elevated, reducing costs considerably). Table 4.1 summarises the network.

Length, kms of single guideway	7.6
Proportion elevated	32%
Number of stations	27
Number of vehicles	78
Passengers/day	8,300
Passengers in peak hour	411

Table 4.1 The hypothetical Heathrow network

The PRT system was assessed in comparison with the existing shuttle bus services. The Pink Elephant business car park is served by midibuses, the N4 staff park by full-size single-decker buses, and the P1 premium business park by van-type “limousines” running to Terminal 1 only. Staff buses ran to the bus terminus within the CTA, while the Pink Elephant buses stopped sequentially at T1, T2 and T3 to drop off passengers, and then returned via T1, T2 and T3 in turn picking up passengers.

The journey

A passenger journey from car park to Terminus is made up of walking, waiting and in-vehicle time components:

Mean walking time to/from stations:

There were more PRT stations in the Pink Elephant and N4 car parks than there were bus stops, especially in N4, so there was a modest saving in mean walking time to the stops. The mean walking time saved, relative to bus, was for Pink Elephant users 0.4 minute; for N4 2.4 minutes (there is a substantially longer walk for staff bus users within the CTA); P1 users would have to walk for 0.1 minute longer than to the present limousine pick-up.

Mean waiting time for service:

PRT: Micro-simulation of the PRT network showed that it could achieve a mean passenger waiting time of only 0.2 minutes, because most passengers did not have to wait at all.

Bus: The P1 limousines operated on demand, with a mean waiting time of 1.5 minutes, while the other car parks were served at a nominal frequency of 5 minutes, though irregularity raised the mean waiting time to about 3 minutes.

Mean ride time to/from CTA:

PRT: travels direct to the required terminal, taking an average of 5.3 minutes each way (averaged across the Terminals in proportion to passenger demand).

Bus: Buses use the general airport road system, with delays at traffic signals and in congestion. The Pink Elephant bus has an average journey time per passenger of 12 minutes because it serves the three terminals sequentially. The N4 bus has a travel time of 8 minutes, and P1 limousines take 7 minutes to Terminal 1 only. Consequently, PRT would save Pink Elephant passengers 6.7 minutes on average, N4 staff some 2.7 minutes, and P1 users 1.7 minutes.

Overall, PRT reduces average journey generalised cost by 65%

To make a socio-economic assessment of the PRT system, the savings in passenger time were costed at the DfT recommended Value of Time, as discussed in Section 4.1. It was estimated that 75% of Pink Elephant users were on business, while all P1 users are on business. Staff time was valued at the standard non-business rate. As is conventional in

transport assessment, time spent walking and waiting is costed at twice the time spent in the vehicle, because it is more onerous.

This valued the **total passenger time savings at 5.67M€ per year**, a benefit which was estimated to increase over time as the number of car park users grew, and also as the Values of Time increased in line with real earnings (ie corrected for price inflation).

Against this has to be set the cost of the PRT system, and its annual operating cost, which were estimated at 25.9M€ and 1.21M€ respectively (in 2002). However, these PRT costs replace the transfer bus costs, and the bus services were estimated to cost a total of 2.81M€ per year, so there is a net saving in transport service operating cost of 1.60M€ per year. There is also a capital cost associated with the bus services over time, since the vehicles have to be replaced periodically. The 29 buses and limousines used were estimated to have a replacement cost of 2.3M€, and it was assumed they would be replaced every 11 years. The PRT vehicles, by contrast, were to be replaced every 8 years at a cost of 2.0M€. It should be noted that there is also an infrastructure cost of the bus services in roadway repairs, since roadwear depends on the fifth power of axle weight and so the buses cause roadwear disproportionately to their proportion of traffic, but this is ignored in the assessment.

Taking all this into account, the study estimated the Net Present Value of costs and benefits over 30 years, using a discount rate of 6%, which is typical of public investment economic assessment (though not of private capital calculations).

The **30-year Present Value of the user benefits and saving in bus costs was 142M€**, to be set against the negative PV of **PRT infrastructure and operating costs of 48M€**, giving a positive overall **NPV of 94M€**.

To express this another way, the 30-year Benefit/Cost ratio (taking benefits as user benefits plus bus costs avoided, and costs as capital plus operating costs – the BCR can be calculated in a variety of ways) was 298%, and the notional “first year rate of return” (ie total benefits expressed as a percentage of operating costs plus 6% of capital costs) was 470%. **That is to say, the benefits greatly outweighed the costs, to an extent that is unheard of in conventional public transport investments.**

Table 4.2 summarizes the details of the assessment. It also estimates the result of the assessment after updating the costs and Values of Time to present values. The basic demand data has not been updated, because the airport has changed substantially since the study was made, with the opening of Terminal 5 especially, and current data are no longer relevant to the assumptions of the study. Consequently this updating is only partial. Costs have inevitably inflated as engineering and component costs have risen over the eight-year interval, but experience with the construction of the Terminal 5 system has also required a re-appraisal of the costs of PRT, showing that some items of cost had been under-estimated in the original desk study, though in partial compensation others are now estimated to cost less. Originally, vehicle costs were estimated at 26,000€ if they were mass-produced, but experience suggests a likely current cost, again under large-volume production assuming PRT becomes widespread, of about 50,000€.

Operating costs for the bus services have been upgraded according to cost indices in Transport Statistics GB, and Values of Time according to the values recommended by the UK

Department for Transport in WebTag Unit 3.5². Despite some increase in cost overall, the adjusted cost appraisal still returned very positive PVs and rates of return, as shown in the right-hand column of Table 4.2. Indeed, both costs and benefits have been increased (benefits because of the higher VOT), and the overall NPV remains at 94M€.

	Original study 2002	Updated costs 2010
Capital cost	25.9M€ [#]	42.0 M€
Operating cost pa	1.21 M€	1.70 M€
Total cost per passenger⁺	0.89€	1.38€
NPV Passenger benefits	99M€	125 M€
Net NPV	94 M€	94 M€
Benefit/cost ratio[*]	298%	223%
First year rate of return[†]	470%	332%

Table 4.2 Summary of the Heathrow PRT network and assessment study

[#]UK money in £ sterling has been converted to euros at the rate of 1.12€/£ in all Tables

⁺defined as (annual operating cost + 6% of capital investment)/annual passengers

^{*}defined as NPV of (total passenger time savings relative to transfer bus + saving in bus operating cost)/(capital costs incl vehicle replacement + operating cost)

[†] defined as (first year passenger benefit + saving in bus operating cost)/(first year PRT operating cost + 6% of capital investment)

There is a case for arguing that, where PRT is installed in an airport, **the economic case is actually stronger than this assessment suggests**, because there is evidence that traveller's perceived Value of Time when travelling by air is substantially higher than the standard land transport VOTs, whether for business or leisure. A study of the charges made for car parking at UK airports has been made by Bly and Lawson (2010), who examined the extent to which charges increased as access time from car park to Terminal decreased, across 171 airports. This is not quite the same as measuring VOT, but gives a "Cost of Time" offering maximum explanation as £50±6 (€54±7) per hour (t=8.8 and R²=0.35), and this will be close to the perceived VOT itself. This is about twice the maximum standard DfT VOT for business travel, but it is worth noting that US guidance on valuing air passenger access time also suggests using twice the standard surface transport rate. It is also common experience that air passengers are particularly sensitive to access time (and reliability), and generally willing to pay more than in their usual travel behaviour. In general the parking cost is a small proportion of the total cost of the air journey, so a higher Value of Time found in accessing airports is not unexpected. Clearly, if passengers' time was to be valued at such a high rate the economic returns from an airport PRT would be much higher than found here.

The study also estimated the net saving in emissions at Heathrow. Of course, since the vehicles are battery-electric there are no tailpipe emissions from the system itself, but the power stations which generate the electricity produce emissions, and these are deducted from the annual saving in transfer bus emissions, estimated at the current national mix of

² These references are available at <http://www.dft.gov.uk/pgr/statistics/datatablespublications/tsgb/> and <http://www.dft.gov.uk/webtag/documents/expert/unit3.5.6.php> respectively.

power station fuels. These reductions are given in Table 4.3, but they refer to the ULTra prototype vehicles rather than the larger and heavier Heathrow vehicles, so the current system will have rather larger emissions. The absence of regulated and potentially harmful local emissions is of value in an urban area even if there is some offset from the more rural power stations, but greenhouse emissions such as CO₂ and NO_x are global pollutants and here the net saving is the required indicator. Of course, in terms of total emissions in the area these reductions are small, but any reductions in urban air pollution and greenhouse gases are to be welcomed.

Net reduction in emissions	Tonnes/year
CO	2.9
VOC	0.9
NOx	12.9
Particulates	1.7
CO₂	311

Table 4.3 Estimated annual reductions in emissions

4.4 CASE STUDY 2: Cardiff

This case study was originally made under contract to the UK Department for Transport, but in close collaboration with Cardiff City Council. However, it was later elaborated as a case study for the EU Fifth Framework EDICT project (EDICT, 2004 - Cardiff Site Assessment Report). The network studied linked the centre of Cardiff, capital city of Wales, with Cardiff Bay, a previously derelict area of docks and maritime buildings subsequently redeveloped into a recreational, residential and commercial and office centre, and containing the Welsh National Assembly parliament building, Cardiff County Hall and the Millennium concert hall for the Welsh National Opera. Figure 4.2 shows the layout, which is a network of interconnected one-way loops, as is appropriate to PRT. The red routes refer to Stage 1 of a possible PRT installation, and is the network studied here, while the blue routes refer to a possible later Stage 2. The main parameters of the network are listed in Table 4.4.

Length, kms of single guideway	7.7
Proportion elevated	80
Number of stations	12
Number of vehicles	134
Passengers/day	13,900
Passengers in peak hour	1,346

Table 4.4 The Cardiff Stage 1 network

In the Heathrow study the demand for service was given, since it was the estimated demand for the car parks, whether from business car parks users or from airport staff, estimated by BAA into the future. It was assumed that this would be the same whether the car parks were

served by PRT or by transfer buses. In Cardiff, use of PRT had to be estimated from knowledge of the existing travel patterns by car, rail and bus, and forecast changes in these into the future.

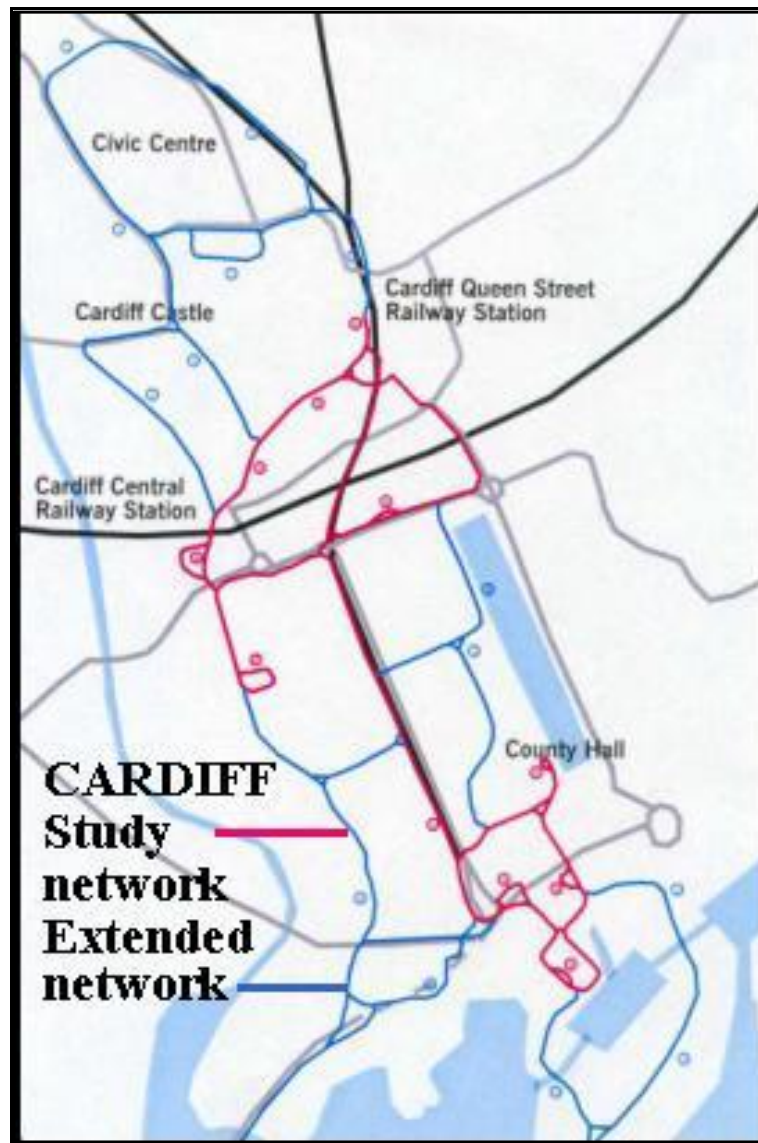


Figure 4.3 The PRT network in Cardiff examined for the EDICT project

Consequently a mode-split model had to be constructed to predict what proportions of trips by the existing modes would transfer to PRT if it were available. The approach adopted was of conventional logit modal-split modelling but, because PRT is innovative and has no historical data base from which to extrapolate, the modelling was based on a Stated Preference (SP) survey carried out in 2002 (Ove Arup, 2002). First, a sample of 358 respondents had the PRT system explained to them, and they had the opportunity to see and sit in a dummy ULTra vehicle. They were then asked to choose between various pairs of travel options, one journey made without ULTra and one with, in which the various travel times and costs were quantified. The sample was reasonably representative of travellers within the central area of Cardiff, and respondents were given details of a journey in the area which was relevant to them, and which could be made by two different modes, which might be car, rail plus bus, bus, rail plus PRT, and PRT. The choices of journey offered included a

range of different travel times, waiting times, walking distances, fares and parking charges, so that as people's choices varied according to the particular combinations of these times and costs a modal-split model could be calibrated for each choice of mode or mode combination. Each respondent was asked to make this binary choice for several hypothetical journeys, but each was given a different set of journeys and all journeys were realistic within the study area. The parameters calibrated could be interpreted in terms of the respondents' Values of Time, with different rates perceived for time spent in the vehicle, or walking or waiting. These values of time were similar to values estimated in many other mode-choice studies and widely used in transport demand modelling, which gave confidence in the demand estimates.

The Journey

The travel choices were between walk, bus and PRT for travel between the City centre and the Bay, a crow-fly distance of 1.8km. For this journey, even on the most direct bus service, the mean in-vehicle time is 9.2 minutes, and passengers have to wait, on average, for 7.5 minutes, and the State Preference study suggested that wait time was perceived to cost 2.8 times as much as in-vehicle time. Walkers will take half an hour, and the SP study suggested time spent walking was perceived to cost 2.3 times as much as in-vehicle time. Consequently, the generalised cost of travel between centre and the Bay were walk 6.66€, bus 5.23€ and ULTra 2.47€.

However, for many commuters the competition would not be between PRT, bus or walk between city centre and the Bay, but between driving by car from the suburbs directly to the Bay, or taking a train into Central Station, or bus to the central bus station, and then onward by public transport to the Bay. The availability of an onward link by PRT, with little or no waiting, is predicted to affect this choice radically. The model predicts that 8% of current car commuters would shift to rail plus PRT, and to a lesser extent bus plus PRT (see Deliverable 1.2.5.2). Given that at present only 5% of commuters with a car available opt for public transport this would be a very significant gain by the Cardiff public transport system.

***Overall, the average generalised cost of travel by PRT
is less than that by bus by 53%***

The parameters extracted from the Stated Preference survey were used to construct a logit modal-split model of travel between the city centre and the Bay. Overall, the model predicted a shift in modal shares as indicated in Table 4.5, with PRT attracting some 14,000 person-trips per day.

The EDICT study was also novel in that it surveyed the attitudes of a sample of people after they had ridden the prototype PRT system at ULTra's Cardiff test track. As Figure 4.3 indicates, their perceptions of various aspects of the system were uniformly favourable, even though many respondents had doubts about the practicality of building segregated guideways through the already built-up areas of the city centre. These positive views on PRT have of course been verified by the results of the Heathrow surveys. This survey also showed that about 80% of respondents felt "secure" or "very secure" on the system, and no-one felt insecure, while when asked how much they were willing to pay to use such a system 70% of respondents indicated that they would pay more than for a bus, though less than for a taxi.

	Before		After	
	Demand	Share	Demand	Share
Car Daily	69,990	48%	64,800	45%
Taxi	600	<1%	300	<1%
Walk from station	38,204	26%	34,555	24%
Bus from station	1,745	1%	678	<1%
Other Walk	34,766	24%	31,041	22%
ULTra	0	0%	13,931	9%
Total	145,305	100%	145,305	100%

Table 4.5 Modal shares and numbers of trips by mode (12-hour day)

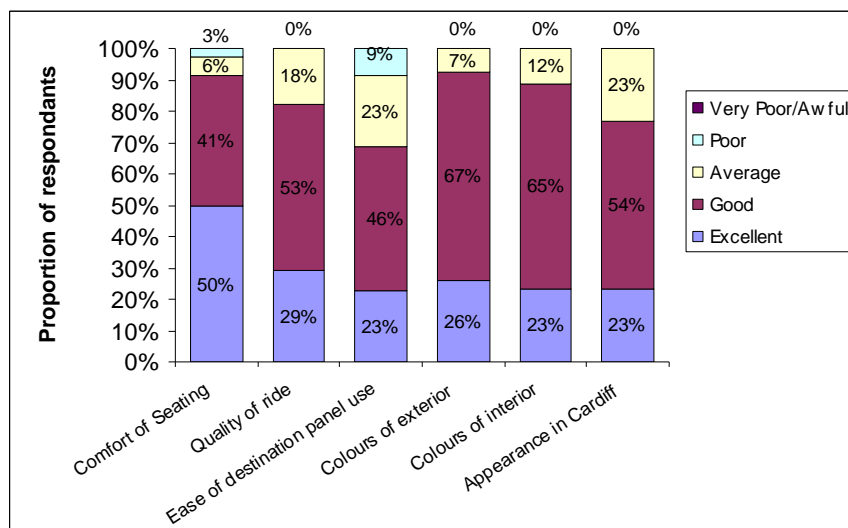


Figure 4.3 Opinions on the design of the ULTra system

The socio-economic assessment of the Cardiff network was very comprehensive, considering not simply the financial case for such a system, or the time saved by the PRT users, but also the wider issues of the effect on traffic congestion in the city, and the knock-on effects of reductions in traffic accidents, emissions and energy use. The effects were estimated via a detailed SATURN traffic model, and although they are proportionately small they affect a widespread part of the road network. Unlike Heathrow, passengers paid directly for travel by PRT, at a flat charge of £1 per vehicle, or £0.70 (0.79€) per passenger at average occupancy - though, of course, people travelling on their own would pay the full £1 while in a group of four they would pay only £0.25 each. This provides an annual revenue to the operating company of 4.8M€, which easily covers operating costs of 2.3M€ per year, and also the capital costs at a 6% amortized rate, to give a small positive annual profit, as Table 4.6 shows. However, over a 30-year operating period this is outweighed by the need to replace the vehicles every 8 years, and the 30-year NPV is negative but small. When costs have been updated using a costing estimate based on Heathrow experience, the negative

financial NPV is still only 8% of the total cost NPV - a relatively modest subsidy. This financial result refers to a fare of £1.26 (1.41€), which is equivalent to the original £1 fare updated in line with the change in Value of Time, to keep the modal split calculations unchanged, and this is much the same as the bus fare. The attitude survey (Section 3) makes it clear that most passengers are willing to pay more than this. This would reduce demand, of course, but the net gain in revenue would readily cover both operating and amortized capital costs, a result which is rarely seen with conventional public transport proposals, and still less in their out-turns.

In terms of net social benefit, as Table 4.6 shows, the large savings in passenger time, car operating costs as people reduce their car use, and in reductions in general traffic congestion and accidents, give a large positive net NPV over thirty years, and in annual rates of return and benefit/cost ratios. Environmental benefits are not costed here, but Table 4.7 shows that reductions in emissions are substantial, even after emissions from the electricity generating stations have been accounted for. However, these reductions will be smaller with the present BAA vehicles, which are heavier and more powerful than the prototype ULTra vehicles.

	Original study 2002	Updated costs 2010
Capital cost[§]	38M€	57M€
Operating cost pa	2.4M€	2.7M€
<u>Financial analysis</u>		
Total cost per passenger⁺	0.98€	1.30€
Annual revenue[¶]	4.8M€	6.1M€
Annual profit after costs	+210K€	-67K€
Financial 30-year NPV	-3.9M€	-9.1M€
<u>Socio-economic analysis</u>		
Value of annual passenger time savings	1.4M€	1.8M€
NPV Passenger benefits[#]	+158M€	+182M€
Net 30-year NPV	+149M€	+173M€
Benefit/cost ratio[*]	270%	248%
First year rate of return[†]	277%	254%

Table 4.6 Summary of the Cardiff network and assessment study

§ includes 16% increase in fleet size in update

+ defined as (annual operating cost + 6% of capital investment)/annual passengers

¶ at £1 fare, updated to £1.26

not discounted by fare paid, and also including wider benefits to community in terms of reduced congestion and accidents

** defined as NPV of (total passenger benefits+revenue)/(capital costs incl vehicle replacement + operating cost)*

† defined as (first year passenger benefit + revenue)/(first year PRT operating cost +6% of capital investment)

Net reduction in emissions	Tonnes/year
CO	45
VOC	3.6
NOx	5.7
Particulates	0.30
CO₂	3,552

Table 4.7 Annual savings in emitted pollutants

4.5 CASE STUDY 3: Corby

Corby is a post-industrial steel-making town with a population of some 50,000 in the English midlands, where most of the heavy industry has disappeared and the town has had to renew itself by attracting new and lighter industries. It has been successful in this and has ambitious plans for expansion. The PRT assessment study here was again part of a DfT contract, and Corby was chosen as a case study because it permitted study of public transport services connecting the existing town centre, which itself deserved extensive renewal, with new residential and commercial development planned for greenfield development surrounding the town.

Corby had already commissioned from Colin Buchanan and Partners (CBP) a study of a proposed Light Rapid Transit (LRT) system to serve the same purpose. CBP were interested in PRT, and supported ULTra Ltd by providing their data and the CBP modal split model to assess a PRT system. This was an opportunity to compare PRT and LRT on exactly the same basis.

The LRT system used two-car tram sets running on double rail lines at grade, mostly alongside existing roads. Because the new development around Corby was to be phased, the LRT system was to be constructed in two phases, starting in 2008. Phase 1 was to be a line from SW to NE of the town, penetrating extensive new development in both SW and NE areas and passing through the town centre. Eight years later, in 2016, a second line from the town centre to Stage 2 development in the SE was proposed.

A PRT network was designed to cover the same general area and service the same new Greenfield developments, as shown in Figure 4.5 (ATS, 2004). This would also be constructed in two phases, with the large loop in the SE constituting Phase 2. Because the ULTra system uses interconnected one-way loops, as can be seen in the diagram, it services a larger area than the LRT routes, though for some passengers the route may be less direct. The intention was to construct a PRT system which was similar in total investment cost to the LRT system. Table 4.8 compares the two systems.

	PRT	LRT
Length, kms	30.1 one-way	14.2 two-way
Proportion elevated	44%	none
Number of stations	30	17 (two way)
Number of vehicles	895	14
Passengers/day	38,000	23,000
Passengers in peak hour	3640	2200

Table 4.8 The Corby network

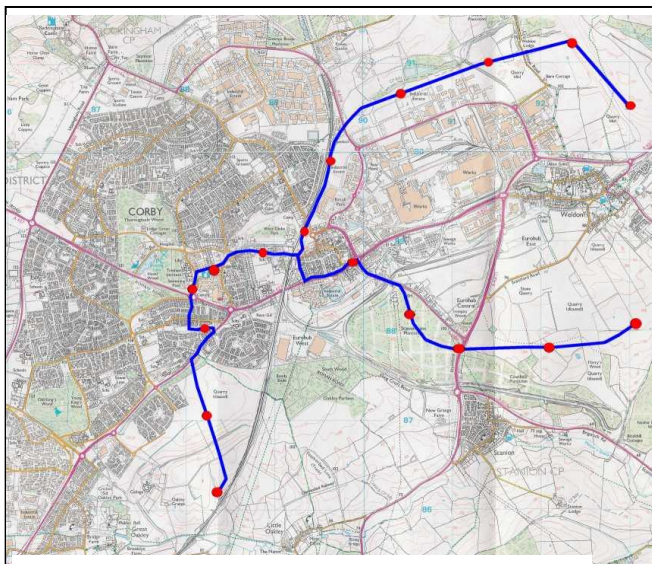


Figure 4.4 The Corby LRT network

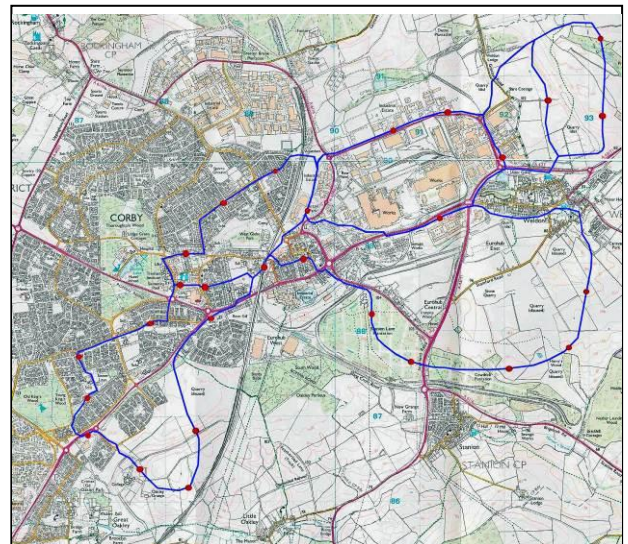


Figure 4.5 The Corby PRT network

The modal split model used by CBP (CBP, 2002) was a conventional logit modal split model which divided the area into seven large zones, and split the estimated demand between each pair of zones into travel by walk, bus, taxi and car. Taxi is important in Corby because 16% of trips are made by taxi, largely on a shared basis, compared with only 10% by bus. Indeed, across the zones modelled, bus accounts for just 1.4% of trips, compared with 6.9% by taxi, 2.5% walked, 4% as a car passenger, and 85% as a car driver. The various components of generalised cost - walk, wait, in-vehicle time, fare, car operating cost and parking costs - of a journey from each zone to each other zone were estimated. The model was calibrated by adjusting mode specific constants added to the generalised cost of each journey to reproduce the observed modal split.

The journey

The LRT and PRT services were designed to serve new development on the edge of town, and the existing bus services did not serve these areas. However, to take as a sample journeys between the town centre and Kingswood, an existing housing area in the west:

A **walk journey** would take 21 minutes

A **bus journey** would involve 10 minutes' walking to and from the bus stops, 4.5 minutes waiting at the stop, 5 minutes in the bus, and a fare of £0.70

A **car journey** would require 5 minutes walking to the town centre car park, 2.25 minutes in the car, and £0.19 operating costs and half the parking costs

A **taxi journey** would require 8 minutes' waiting/walking time, 2.25 minutes in the vehicle, and a fare of £1.31

On the proposed **LRT service**, there would be 10 minutes' walking, 3.5 minutes waiting, 4.45 minutes in the vehicle, and a fare of £1

With the proposed **PRT service** there would be 5.6 minutes of walking, 0.2 minutes waiting on average, 6.8 minutes in the vehicle (though for most other journeys PRT would be quicker than LRT or bus), and a fare of £1.12 per passenger, or £1.50 per vehicle.

For this particular journey the model predicts that LRT would gain a 17.5% share of journeys, with the other modes at walk 3%, bus 7%, car 64%, and taxi 8%. By contrast, PRT would gain 25%, bus 6%, walk 3%, car 58% and taxi 7%.

Overall, PRT reduces average bus journey generalised cost by 23%

When the full Phase 2 system is in operation, the model predicts that LRT would attract 11% of all trips, whereas PRT takes 19%, as Figure 4.6 shows. LRT reduces car trips in the area modelled by 9%, but PRT reduces car use by 18% at a similar fare per passenger. **Thus PRT achieves about twice as much modal shift from car.**

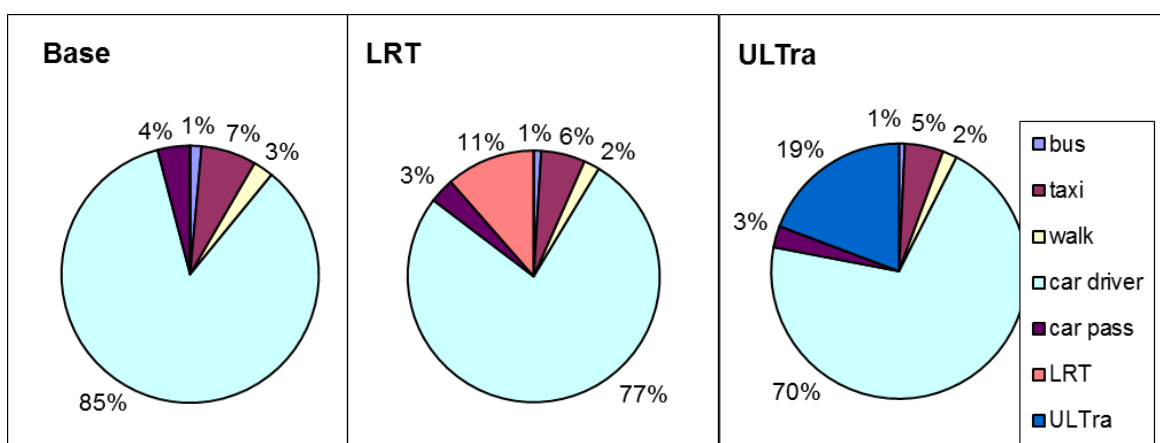


Figure 4.6 Modal shares in base, and with LRT and ULTra, 2027

Model calibration: The modal split model used here is exactly the same for both modes, but because it relies on generic VOTs and logit parameters the calibration is necessarily rather crude. It obtains the observed mode split by adding Mode Specific Constants (MSCs) to the generalised travel costs for walk, taxi and bus, taking the MSC for car as zero. There

is no way of knowing what the appropriate modal constants should be for the new modes, LRT or PRT. In the LRT study it was assumed that the constant for LRT should be zero, the same as for car, whereas the other modes carried substantial additional constants to their generalised costs. These mode specific constants represent perceived costs which are not included in the measured travel times or money costs, such as comfort, convenience, reliability, etc, but no matter how good the new modes might be they are not likely to as attractive as the car. Arguably in both cases their constants should lie somewhere between the reference zero of car travel and the MSC of bus travel (which was an extra 35 minutes of in-vehicle time at calibration). Increasing the assumed constant for the new modes will depress their predicted modal shares, but this will not change the relative performance of PRT and LRT. Indeed, PRT is closer to car in its performance than is LRT, so it would be likely to gain in the comparison.

Table 4.9 summarises the economic assessment of both PRT and LRT. Updated PRT costs refer to the post-Heathrow costings, using also updated values of VOT and, by the same proportion, fare to keep the modal split model in balance, but the base demand data remain unchanged.

LRT		PRT	
CBP study 2002		Original study 2004	Updated costs 2010
105M€	Capital cost[§]	110M€	188M€
6.5M€	Operating cost pa	5.7M€	8.0M€
	<u>Financial assessment</u>		
1.64€	Total cost per passenger⁺	0.983€	1.50€
9.5M€	Annual revenue	18.6M€	26.2M€
-3.2M€	Annual "profit"	+6.3M€	+6.9M€
-91M€	Financial NPV	+4.3M€	-22M€
	<u>Socio-economic assessment</u>		
57M€ [¶]	NPV Passenger benefits[#]	2012M€	291M€
-35M€	Net NPV	+206M€	+270M€
89%	Benefit/cost ratio[*]	201%	184%
2.9%	First year rate of return[†]	480%	430%

Table 4.9 Summary of the Corby PRT and LRT assessment study

§ includes 18% increase in fleet size in update

+ defined as (annual operating cost + 6% of capital investment)/annual passengers

total user benefits, not discounted by fare paid

¶ LRT attracts 45% of PRT pass-kms, but reduction in passenger generalised cost is only 21% of that for PRT, because LRT still involves substantial waiting time

** defined as NPV of (total passenger benefits + revenue)/(capital costs incl vehicle replacement + operating cost)*

† defined as (first year passenger benefit + revenue)/(first year PRT operating cost +6% of capital investment)

The capital costs as originally estimated were very similar. At the time, the CPB estimated costs for LRT were below the outturn costs for LRT systems recently constructed, and they will in any case have increased with time. Similarly, however, the PRT costs have increased when updated, in the light of the Heathrow experience. Operating costs were also fairly similar. But PRT will certainly attract greater demand, both because it offers little or no waiting and a direct non-stop journey to anywhere on the network, and because the loop network brings the system closer to a larger population than can LRT. In both cases revenue easily covers operating costs, but LRT revenue offers only a small contribution towards the capital cost, whereas PRT covers capital discounted at 6%. This remains true for PRT with updated costs, yet the 30-year NPV becomes negative, whereas in the original assessment it was positive, because renewal of the vehicles every 8 years adds to the capital cost. It is not clear whether the LRT assessment includes vehicle renewal, and although there are only 14 train sets operating their total cost was £21.3M. In any case the 30-year NPV for LRT is large and negative. In the Table annual indicators are taken at year 9, the first year with both Phase 1 and Phase 2 operating. This depresses the 30-year NPV, because although the whole system operates at a substantial annual profit, this is discounted over the first 8 years, when in the early years both PRT and LRT made a loss because population growth had still to occur. Again, the financial results refer to a PRT fare set to be similar to the LRT fare, but there is scope for increasing it and reducing subsidy, since passengers are likely to be willing to pay more.

Both systems save passengers considerable travel time, giving substantial benefit/cost ratios and rates of return, but PRT both saves more passenger time and attracts more passengers, so the socio-economic case for PRT is much stronger than for LRT. As noted above, setting the mode-specific constants (MSC) to zero for both LRT and PRT keeps the comparison equitable, but this will almost certainly over-estimate the demand. The original Corby PRT study made sensitivity tests on the effects of increasing these costs, and also made an assessment based on a model which used the Stated Preference parameters as obtained for the EDICT study. Increasing the MSCs to halfway between car and bus reduced PRT demand by 15%, whereas using the EDICT parameters gave demand only 1.5% lower.

There is relatively little traffic congestion in Corby, so there is little wider benefit to add to the passenger benefits. Nevertheless, PRT was predicted to capture 17% of existing car trips, compared with only 10% by LRT, and this adds substantially to the reductions in total exhaust pollutants and greenhouse gases achieved by PRT, as Table 4.10 shows though, again, with the heavier Heathrow vehicles the reductions would be smaller.

Net reduction in emissions	Tonnes/year
CO	62
VOC	4.7
NOx	10
Particulates	0.7
CO₂	3600

Table 4.10 Annual savings in emitted pollutants

4.6 CASE STUDY 4: Bath

The fourth comprehensive case study of ULTra has been made very recently as a contribution to the CIVITAS Renaissance project (<http://www.civitas-initiative.org/>). CIVITAS is an EU initiative which aims to help cities to achieve a more sustainable, clean and energy efficient urban transport system via ambitious technology and policy based measures. Within this wider collaboration, five European cities are examining technologies and policies which could be adopted in their historic and tourist-attracting old towns. One of these is Bath, a fine and homogeneous Georgian city in the west of England. The main interest here lies in deciding how far it might be possible to construct such a modern and apparently high-tech system as PRT in an architecturally-sensitive area. The project invited architectural practices and engineering consultancies to make suggestions as to how stations and vehicles might be designed to fit into Bath's historic environment, and exhibitions and workshops were held to consult with interested residents and collect their reactions, ideas and suggestions. Participants were self-selected in terms of interest, of course, but they were overwhelmingly supportive of the concept of PRT. The question of acceptable design remained unresolved, since many of the entries in the design competition were conceptual and rather abstract: one of the most popular designs was, perhaps predictably, a retro-design (Figure 4.7), though a very modern design for a station near a new hypermarket development was also marked highly. Stations can be designed to suit their environment, but the vehicles would have to be acceptable in any part of the town.

The study (Hammersley, 2010) identified a practical network of PRT routes which could penetrate closely into the historic center, though there was one place where a desirable link would probably have to be placed underground for aesthetic reasons.

Detailed demand data by existing modes was available from the local authority, and enabled the construction of a modal split model with 39 zones. The model was a conventional logit model, but a specific feature of interest is that it permitted car users coming into the city from outside the area served by the PRT network to choose to Park and Ride. PRT is well suited to P&R because car parkers can transfer directly to PRT with little or no waiting, and in the same groupings in which they travelled by car.

Figure 4.8 shows the fairly extensive network designed for Bath, with the central loops running around and through the historic center, and the western loop servicing a large hospital and the eastern loop to the University of Bath. Table 4.11 lists the main characteristics.

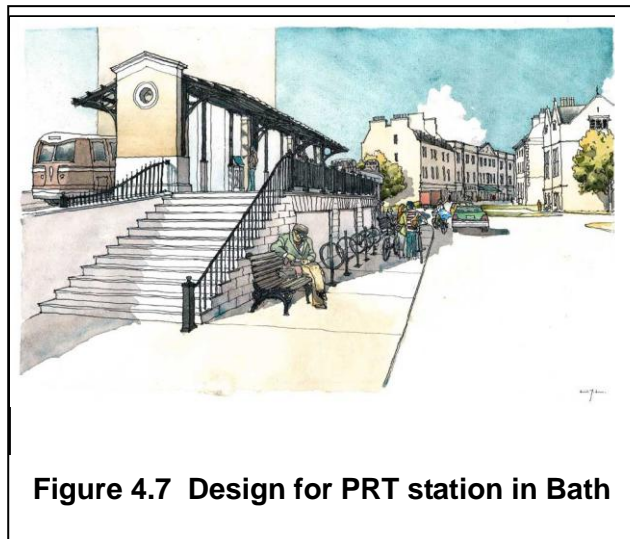


Figure 4.7 Design for PRT station in Bath

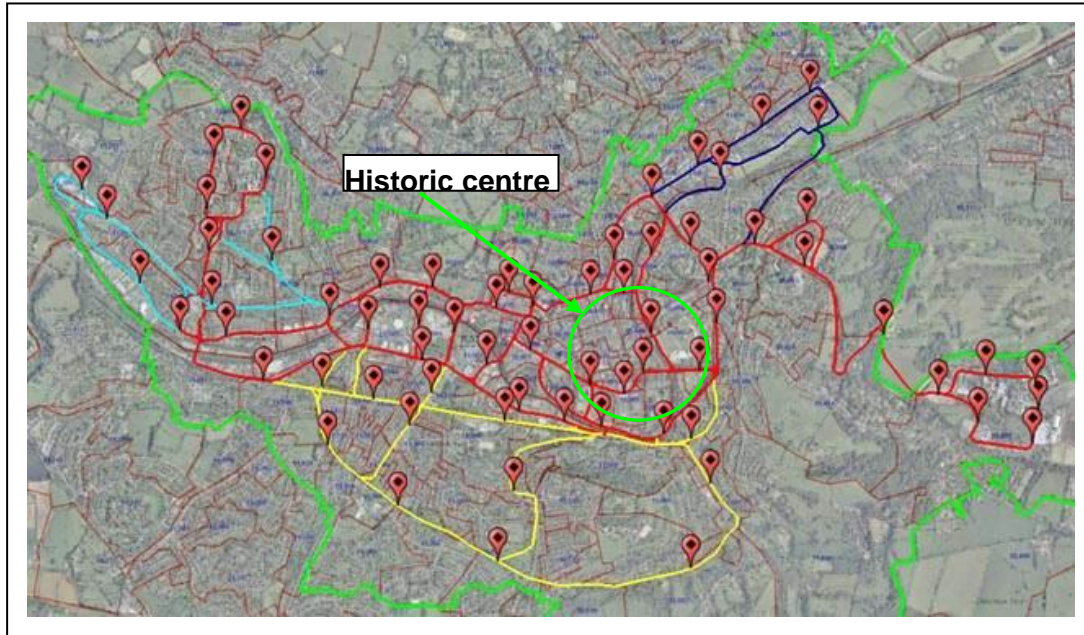


Figure 4.8 The Bath network as evaluated for the RENAISSANCE project

Length, kms	45
Proportion elevated	88%
Number of stations	69
Number of vehicles	1310
Passengers/day	61,850
Passengers in peak hour	5,700

Table 4.11 The Bath network

The journey

The model splits the total demand between walk, car, bus and PRT, though it allows trips coming into the town from outside the area covered by the PRT network, whether by car or by bus, to interchange with PRT at several P&R stations, with a transfer penalty of 3 minutes. There is a small amount of rail travel, but this is mainly commuter travel into Bath Spa station, and this is treated as a central generator.

For example, for a journey from the Newbridge Park and Ride station, which is in a residential area west of the centre, into the city centre, a crowfly distance of 3.4km:

By **walking**: 60 minutes

By **car**: 17 minutes travel time, £0.44 operating cost, 8 minutes walk access from the city centre car park, £1.40 parking cost (actual cost of £2.80 split between the two legs of the journey)

By **bus**: 10 minutes walk to and from the stops, 5 minutes wait, 24 minutes ride, fare £1.50

By **PRT**: 10 minutes walk to and from the stations, 0.5 minutes wait, 13 minutes ride, fare £1.50

For trips starting in this zone the predicted modal split is 4/45/13/38% walk/car/bus/PRT. For trips travelling in from further out by car or bus, travellers may elect to interchange to bus or PRT, but this adds an interchange penalty of 3 minutes to the journey cost, and the predicted modal split becomes 0/53/12/36%.

Overall, PRT reduces average bus journey generalised cost by 30%

Overall, the model predicts modal shares of:

	AM peak	Interpeak	PM peak	All day
walk	14%	13%	14%	14%
car	52%	54%	54%	54%
bus	10%	10%	9%	10%
PRT	24%	22%	23%	23%

As with the other case studies, PRT out-competes bus easily because it has very little waiting and a lower journey time without any intermediate stops, either at stops or junctions. The model also suggests that PRT would achieve a **net reduction of 17% in total car travel**.

Table 4.12 summarises the economic assessment. There was no time-trend data available, so only a one year assessment was made, rather than calculation of an NPV. This is a large network and the capital cost is large, but the predicted revenue covers not only the operating cost but also the capital cost discounted 6%. As in the other studies, the annual surplus is modest compared with the operating cost, suggesting that in practice the system may be on the margin of covering full costs, but there is scope for ensuring a robust financial case because passengers will be willing to pay a higher fare - the assumed fare here is the same as for buses, and passenger assessments show that their willingness-to-pay lies between bus and taxi.

Capital cost	326M€
Operating cost pa	11.3M€
<u>Financial assessment</u>	
Total cost per passenger⁺	1.48€
Annual revenue	35.1M€
Annual "profit"	4.3M€
<u>Socio-economic assessment</u>	
Annual passenger time saving	48.6M€
First year rate of return[†]	271%

Table 4.12 Summary of the Bath PRT assessment study

+ defined as (annual operating cost + 6% of capital investment)/annual passengers

† defined as (first year passenger benefit +revenue)/(first year PRT operating cost +6% of capital investment)

Assessments were also made of the benefits due to:

- Savings in energy use (environmental/social benefit)
- Reduction in emissions (environmental/social benefit)
- Savings in travel time (economic benefit)
- Reduction in congestion (economic benefit)
- Reduction in accidents (safety & security improvement)

The net overall saving in traveller time is large, and provides a high social rate of return, as shown above.

Table 4.13 gives the net reductions in air pollutants and greenhouse gases due to the substantial transfer from car. This assumes no change in total bus-km, but in practice if demand transfers from bus to PRT subsequent rationalisation of the bus services would also save some bus emissions. But as for the other case studies, these estimates are based on the prototype ULTra vehicle, and the larger vehicle as used at Heathrow will use more energy and have higher emissions. Even so, there will be a substantial net saving here.

Net reduction in emissions	Tonnes/year
CO	38
VOC	3.1
NOx	21
Particulates	0.83
CO₂	8100

Table 4.13 Annual savings in emitted pollutants

4.7 Other relevant studies

The case studies described so far are very detailed because they have been undertaken by ULTra PRT Ltd (formerly ATS), and can therefore be given a comprehensive treatment in terms of design and engineering, microscopic simulation of the control strategies, and detailed costings of each system, together with relatively detailed modal split models to estimate demand. No such studies have been published by other PRT manufacturers, and where other groups have made case studies of PRT they have mostly had to use the ULTra characteristics and published data on costs. In the previous case studies, cost estimates have been derived from a complex costing spreadsheet, covering very many individual cost components, and these details are not available for reasons of commercial confidentiality. The following studies are based on average costs per guideway-km, or on an approximate costing formula published in EDICT.

In addition to the Cardiff study, The EDICT project included three other "demonstration" studies aimed at showing how practical and effective PRT might be in different locations:

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One study was of a notional PRT network connecting **Ciampino Airport outside Rome** with the town and railway station (EDICT 2004). However, the layout consisted primarily of one large loop, and did not make use of the routing possibilities of a PRT network with interconnected routes. The PRT characteristics assumed were those of ULTra, and the study developed a microsimulation model, based on the ideas of Andreasson (1994), and used it to examine a range of different control strategies. The simulation indicated mean waiting times of about half a minute, and validated a number of aspects of synchronous control, as used in ULTra. It also interviewed travellers to the airport to identify their travel patterns and characteristics, and found a good degree of openness to the concept of PRT, but these people could only view pictures of PRT without necessarily having a realistic context. The available demand matrices were notional, and no attempt was made at economic assessment.

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A second study was based on **Almelo, Netherlands** (van Zuylen, 2004), and examined the practicality of 9.8km of guideway, mostly elevated, arranged in four interconnected loops. Again, a microsimulation model was developed to investigate the system's performance, but there was also a relatively detailed demand matrix drawn from existing use of car, bus, rail, walk and cycle, from which it was estimated that about 6,000 passengers per day would use PRT, a modal share of between 10% and 20% of all trips. This is in line with the ULTra case studies. This would require a fleet of 45 PRT vehicles based on ULTra characteristics, which would reduce average waiting times to well below one minute. At a fare of €1 the system would cover operating costs, but could only make a small contribution towards capital costs. The prevailing social policy in the Netherlands, however, suggested that this should not be expected from public transport, and public subsidy was the norm, so the effect of higher fares on cost coverage was not examined further. Attitude surveys of the public showed, as elsewhere, that travellers stated a high willingness to use PRT.

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The third study in EDICT was of **Huddinge, a suburb of Stockholm** (Tegner and Andreasson 2004) in the Kungens Kurva retail and office development. The network studied

was one of 5.5 kms with 11 stations which acted as a distributor from the local metro station around the retail park, and the operation of the system was examined in micro-simulation. The PRT option was added to the regional four-step travel model, which predicted it would reduce total car trips to the site by 9%, and increase the total public transport mode share from 5.6%, when metro+bus was the only public access mode, to 15.2%, as the availability of PRT persuaded car user to come by metro and PRT instead. This is similar to the predicted effect in Cardiff (Section 4.3) of providing the relatively small PRT service as a final link in a rail+PRT commuting journey, where the addition of PRT reduced car commuting by 8%. In Kungens Kurva the mean journey time was reduced by 26%. Over 13 year's growth, the presence of PRT was predicted to increase the total number of visitors to Kungens Kurva by 3% over the number if only bus were available as the local distributor, and there would be a doubling of total public transport use.

This latter finding is an important one, and an aspect not investigated in the ULTra studies, which considered only changes in modal shares. The Distributive stage of a transport model examines the extent to which transport changes can change people's activity patterns, as they decide to shop in a different place, for example, because it has become more accessible to them. **In this way PRT can help to support commercial and retail activity in the areas it serves.**

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Tegner has also estimated the **likely benefits of introducing PRT into 59 Swedish cities**, albeit at a very broad brush level (Tegner, 2009). In each city, data on bus use, operational performance and revenues were collected, and a notional PRT network described, so that journey times by bus and PRT could be compared and demand predicted using an elasticity-based modal split model. Overall, this predicted that public transport's share of total city travel would increase from the present average of 17% to between 23% and 32%, depending on whether the mode-specific constant is set to be the same as bus or half way between bus and car (see the discussion of mode-specific constants in connection with Corby, Section 4.5). The second approach seems more realistic, and consequently PRT would almost double public transport use. The overall benefits were estimated at 2.85 billion €, while the total costs amount to 2.24 billion € in present value. The net benefits amount to 0.61 billion € and the benefit-cost ratio is 1.27. This means that one € spent on PRT yields 1.27 € in return in terms of benefits to society.

The study also examined the **minimum size of town** in which PRT could provide a net benefit, as shown in Figure 4.9, where the minimum size increases as the mean unit capital cost increases. Updated ULTra costs suggest an all-up unit cost (including vehicles and control system) towards the higher end of the cost scale, so that towns would have to have populations of at least 50,000 to satisfy this criterion. This would mean that some 20 out of the 59 Swedish cities would benefit from PRT, though Tegner notes that at a more severe costing of 8 M€/km PRT would benefit 10 of the cities. Tegner and Angelov (2009) also examined the problem of financing PRT in the cities, and noted that the cost per passenger trip was lower by PRT than by LRT, and in some cases even lower than by bus.

However, the Heathrow study suggests that PRT could be economically justified for smaller systems, and much would depend upon the density of the demand flows along particular corridors.

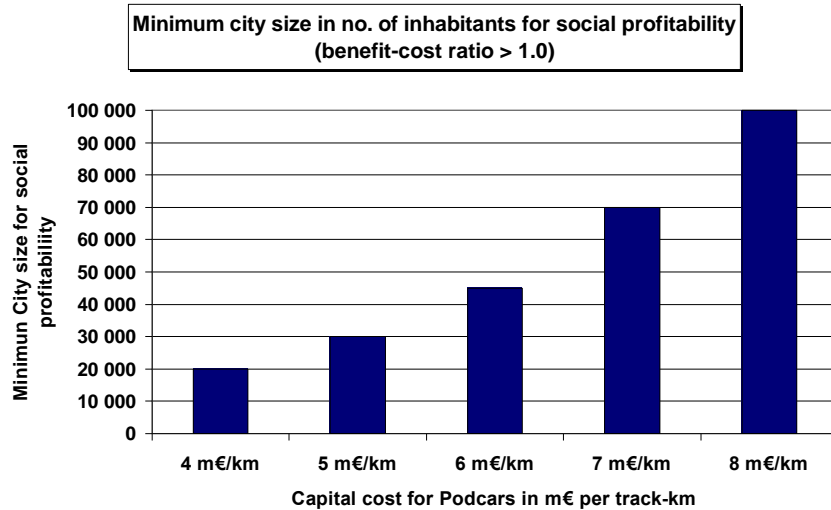


Figure 4.9 Relationship between City size and Social profitability (ie B/C ratio > 1.0) (Tegner, 2009)

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Colin Buchanan and Partners have examined how public transport services in **Daventry**, a medium-sized town in the English midlands, might be improved either by investing in a reorganized bus network, or in PRT (Colin Buchanan & Partners 2007). The bus improvements were either a modest enhancement of the existing services, or a radical reorganization of the services with substantially increased service frequencies. Sections of **automatically guided bus** were also considered, but these were found to add no value to the level of service seen by passengers. Once the likely journey time components had been established, modal shares were estimated by Northampton County Council's transport model of Daventry. The base travel pattern showed only 4% of trips were by bus, but the CBP enhancements to the existing bus network were estimated to increase this share to 14%, while the entirely reorganized network achieved 17%. The predicted PRT share depended on the assumed Mode Specific Constant, as discussed in Section 4.5 and in connection with the Swedish cities study. If the MSC was assumed to be the same as for bus PRT would take 22% of total trips, but if it was assumed to be the same as car it would achieve 33%. As Section 4.4 suggested, in reality the MSC can be expected to lie somewhere between the two, since the passenger attitude surveys show that people prefer PRT over bus, and PRT has attributes more similar to car than bus. In the absence of other evidence one might prefer to assume an MSC half way between car and bus, as in the Swedish towns study.

Table 4.13 summarises the CBP findings, but note that the PRT results here refer to use of an MSC equal to car, and to this extent they will flatter the performance of PRT. The Table shows that the enhanced present bus network can just about cover its operating costs, but neither the new bus network nor PRT at a flat fare of £0.80 (0.90€ - similar to the existing average bus fare) can do so. However, PRT with a fare of £1.60 (1.80€), though it has substantially fewer passengers, easily covers operating costs and comes close to covering capital costs discounted at 3.5% as advised by the UK Department for Transport for technologically innovative transport projects. When social benefits of reduced passenger waiting and journey times, and reduced congestion, are taken into account then all the options show a positive NPV over 60 years, and a good benefit/cost ratio, but the returns from PRT are much larger than for bus. It might be noted that Daventry with a population of 23,000 lies at the smaller end of Tegner's size range and below the threshold suggested as suitable for PRT, but the CBP study suggests that nevertheless PRT would be a good public transport option.

| Scheme option               | Capital costs PV* | Operating costs PV | NPV Net Financial Impact (revenue - costs) M€ | NPV Net Financial Impact excl. capital costs M€ | NPV incl. Social benefits M€ | Benefit/cost ratio |
|-----------------------------|-------------------|--------------------|-----------------------------------------------|-------------------------------------------------|------------------------------|--------------------|
| Enhance present bus network | -2.6              | -49.9              | -1.1                                          | +1.4                                            | +44.1                        | 250%               |
| New bus network             | -4.4              | -73.3              | -13.0                                         | -8.6                                            | +131                         | 410%               |
| PRT fare £0.80              | -79.2             | -169               | -119                                          | -39.1                                           | +578                         | 530%               |
| PRT fare £1.60              | -74.6             | -108               | -15.4                                         | +59.2                                           | +218                         | 760%               |

\* Present Values are estimated with a discount factor of 3.5% for 30 years, and then 3% for another 30 years

**Table 4.13 Summary of the CBP findings for Daventry**

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Young et al (2009) examined the viability of a PRT network serving a popular commercial, retail and entertainment development at Village West on the outskirts of **Kansas City**. The network studied had 16kms of guideway and 26 stations, carrying 15,500 passengers daily. Overall financial and societal benefits outweighed the costs by some two-and-a-half times, and a fare of \$1 per trip would cover operating costs, though higher fares and tax charges would be required to recoup capital costs over the first ten years. The study concluded that PRT looked attractive in relation to other rail-based systems, that it was viable and financially feasible, and, importantly, that quite significant land redevelopment options would become available through installing a PRT system. The enhance accessibility provided by PRT would generate considerable gains in terms of land prices and development opportunities, an aspect which is ignored in many transport studies because of the difficulty of quantifying the benefits, though this is an aspect discussed in the CBP study of LRT in Corby, and which would apply with greater strength to the PRT network.

5 Where Is PRT appropriate?

Sections 3 and 4 have demonstrated that:

- i) *People prefer PRT to conventional urban public transport and are willing to pay more for it*
- ii) *PRT can attract substantially more passengers than conventional public transport*
- iii) *PRT can persuade more people to transfer from car than can conventional public transport*
- iv) *PRT can be cheaper than conventional LRT systems, certainly in terms of cost per passenger*
- v) *PRT can cover its operating cost and is much more likely than LRT to cover both operating and capital costs.*

These potential benefits suggest that any organisation or authority contemplating installing a new public transport system to carry passengers over an extended area should consider the

possibility of PRT in comparison with conventional public transport modes. In doing this, there are a number of issues to be resolved.

5.1 The practicality of constructing PRT guideways

Against PRT's benefits must be set a societal cost which has not been quantified. It cannot be included in the socio-economic assessments because it cannot be readily monetarized, and it is likely to vary enormously from one location to another. This is the matter of **visual intrusion and community severance**.

The acceptability and practicality of routeing PRT through a given area can only be judged on site. It is obviously cheaper to construct the guideway at grade, and there is less visual intrusion, but it is necessary to provide passageway for both pedestrians and road vehicles if the system is not to cause unacceptable severance. Consequently, as the ULtra case studies show, much of the guideway will need to be elevated. Moreover, where it is at grade guideway must be segregated from other traffic using some form of fence or barrier, and elevation in itself will provide the necessary segregation, and also some protection from vandalism and graffiti in areas where this could be a problem. In residential areas problems of privacy may arise, however.

To offset this, PRT vehicles are small, and the guideway can be slim and lightweight. The ULtra vehicle weighs 850kg, with a maximum payload of 450kg. The guideway is 2m wide, and can be made of steel or concrete, since it is passive and merely provides a smooth running surface. Elevated sections are just 0.45m high on the sides, and steel sections can be supported on slim columns (0.5m diameter) at 18m intervals. The guideway has a smaller loading than a pedestrian bridge, and hence the low cost and low visual intrusion. Figures 5.1 and 5.2 show an architect's suggestion for PRT in the Bath Renaissance study, in both modern and historic settings.

Moreover, the vehicles are silent and have no exhaust emissions, so that they can be run through buildings where appropriate. All this minimises the problems of elevated structures. Even so, this is a non-quantifiable cost of a PRT system which will weigh more or less heavily depending on the location. It will be offset to some extent by non-quantifiable or non-monetarizable benefits, such as the environmental advantages, passenger comfort and convenience, privacy, and reliability (the Heathrow service has scored 99.7% reliability, measured as the percentage of the time when all stations are available as destinations (to request to and from), whereas many conventional public transport services struggle to achieve 90%).



Figure 5.1 Architect's drawing of PRT in Bath



Figure 5.2 Architect's drawing of PRT in Bath (Arup)

The various ULTra case studies (and there have been several unpublished additional studies) have examined in detail the routes to be used by the guideways. It is not clear to what extent studies by others have judged the practicality of routing PRT through built-up areas, but the ULTra studies have found a surprisingly large number of potential options for their routes, even where the existing roads are relatively narrow. Disused railway rights-of-way, rivers, drains and canals, existing pedestrian short-cuts and alleyways where PRT could be constructed above the pathways, all offer opportunities. As the Bath study showed, even where the architecture is very sensitive it is still feasible to identify routes which penetrate sufficiently close to the desired destinations, though there are clearly locations which must be avoided altogether for aesthetic reasons.

5.2 The appropriateness of PRT

The NICHES+ Consortium www.niches-transport.org (which contains Daventry as its "Champion City") has published a set of guidelines for PRT (NICHES+ 2010). It provides as a "check list":

City size Initially [use PRT] for widening catchment areas e.g. for stations etc. and serving dispersed sites, but city sized networks are possible.

Costs [operating costs are] Less than for an equivalent bus scheme using drivers, and less than for a tram. Capital costs are needed to procure the podcars; provide the control system/centre and a depot for vehicle maintenance/charging; and also to provide and equip the guideway, stations and security measures.

Implementation time Medium term, 5 years or more may be needed to plan and implement a scheme in a city environment.

Stakeholders involved Operating company, local authority as the infrastructure owner, national government for safety certification. Local community and users.

Undesirable secondary effects Possible visual intrusion caused by elevated sections of guideway, and of severance caused by sections at-grade, although these can be mitigated by using 'cut and cover' or tunnels.

The NICHES+ guideline goes on to consider the steps required in preparation, procurement and funding.

We have seen above in Section 4.7 that Tegner et al in their assessment of the potential application of PRT in 59 Swedish cities find an increasing net benefit as city size increases, and they consider towns would have to have populations of fifty to a hundred thousand to justify PRT if guideway costs were at the higher end of the spectrum they considered. However, the Buchanan study of Daventry suggests that PRT is likely to be beneficial in a town below this size, and Corby only just reaches this threshold, so in practice, and in the right context, PRT may be valuable also in smaller towns. In terms of activity, Heathrow is equivalent to quite a sizeable city, but it seems likely that PRT could be cost-effective if applied to only a part of the overall transport pattern, provided the density of demand along the corridors served justifies it. PRT has also been suggested as the appropriate solution to university or commercial campuses, where there is value in saving travel time over relatively short distances, and where car use may be less than in a town.

A PRT network might form a core part of urban public transport, operating as the main carrier in a sector or across the town. In larger cities it could provide a valuable distributor of trips around major transport nodes such as railway stations or other transport hubs. It is also well-suited to Park and Ride sites, since for car drivers the need to wait for a bus is onerous, and without extensive bus priorities the bus may still be stuck in traffic. With PRT waiting is short

or non-existent, and the car occupant(s) can continue in a PRT vehicle in the same grouping as in the car, and in a vehicle which resembles a car.

5.3 PRT costs

In judging whether a PRT system would be viable in a particular location, the likely benefits, revenues and savings have to be judged against the likely costs of the system. As noted in Section 4.1, the Heathrow pilot has provided a great deal of practical experience of constructing a small PRT system, but because of its nature as a first application in a prestige environment, and because of its very small size and volume, its detailed costing is not very relevant to the construction costs of a larger PRT network. Moreover, many aspects of the expenditure will not be released by BAA for reasons of commercial confidentiality. ULTra have applied the lessons learned to their own costing methodology to provide as realistic an estimate as possible of the costs of providing a PRT system of useful size, in a situation where the vehicles can be produced in modest volume, as compared with the small number of bespoke hand-built vehicles used at Heathrow. In terms of total cost, it gives confidence that BAA's own estimate for the Heathrow expansion is very close to ULTra PRT Ltd's own estimate, as noted in Section 4.1.

Detailed estimation of both demand and costs is a complex and time-consuming process, and it will be as well to start with short-cut procedures to gauge the likelihood of success. The costing equations given in the box below have been derived from applying ULTra's detailed costing methodology to a number of case studies and fitting the equations to the resultant costs. They give cost estimates within 10% across a wide range of configurations. However, it is important to understand that a PRT network is an integrated system, and each aspect is inter-dependent on others. It is not simply a question of taking a unit cost per km of guideway and adding the vehicle fleet costs, because adding a length of guideway affects the number of vehicles required, running costs and maintenance costs, etc.

In the EDICT case study of Huddinge, Tegner and Andreasson (2004) compared the investment costs per track-km of advanced transport systems, including PRT and LRT, as noted in Section 4.6. Figure 5.3 shows costs per km for five LRT systems which were recent at that time, with costs ranging from 14 to 22 M€ per km. The updated ULTra costs have an average across the four case studies of 6.5M€ per km. This is an increase from the 5.6M€ assumed for ULTra at the time of EDICT, but the LRT costs are also out of date, and are likely to have increased by well over 10% since then, giving a likely range of 15 to 23M€ per km at best. It is clear that ULTra costs compare favourable with LRT costs, and the Corby study showed the same, especially since the LRT costs assumed by Buchanans seemed optimistic.

COSTS : A preliminary calculation

A possible check of suitability may lie in checking the cost per passenger seen in viable networks against an outline costing of the network proposed. With the updated **ULTra costing** of the case studies, the mean cost per passenger lies within a fairly narrow range.

This is 1.38, 1.30, 1.50 and 1.48€ for Heathrow, Cardiff, Corby and Bath respectively.

If a preliminary estimate can be made of the likely number of passengers, then multiplying it by, say, 1.40€ gives a measure of the revenue which would have to be earned to cover costs.

The proposed network can be characterised by:

L = its total length in kms of one-way guideway

E = the number of kms of elevated guideway

S = the number of stations

U = the estimated annual number of passenger-kms
(passengers * average trip length)

P = the proportion of passengers travelling in the peak hour

Then the **costs** of the system can be estimated, very crudely, as:

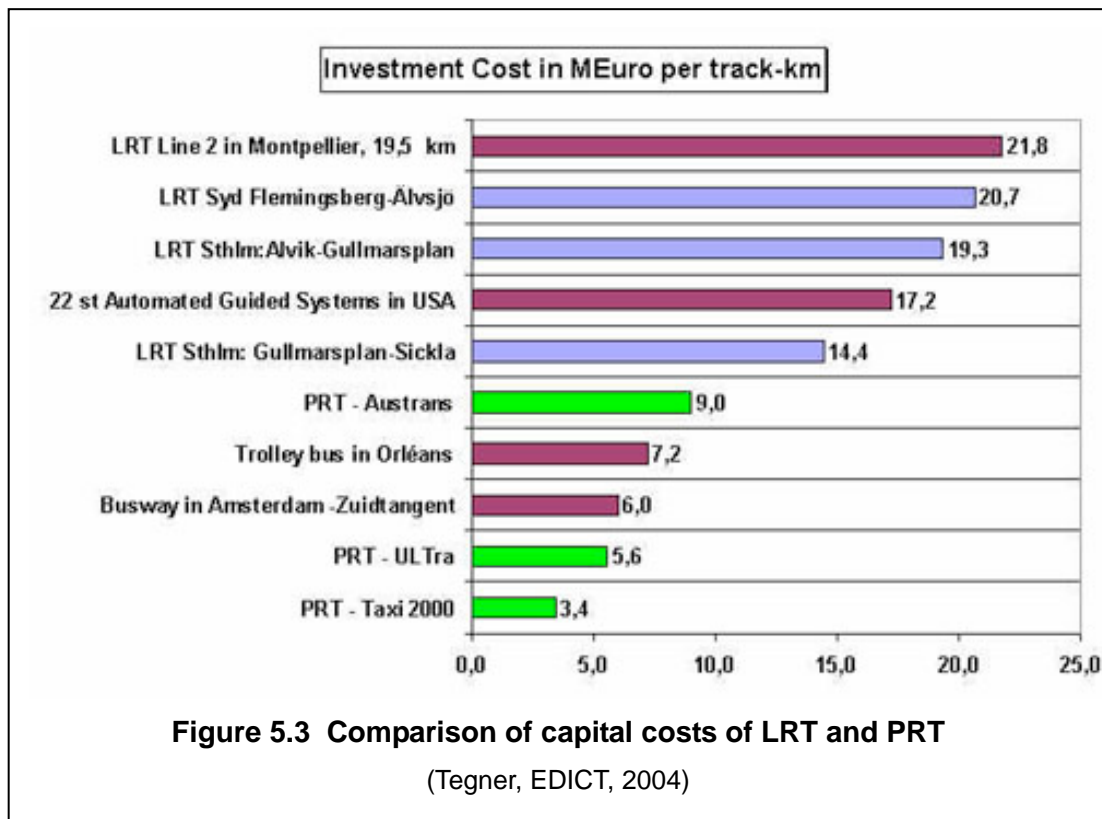
Capital cost in '000€ = $9700 - 78*L + 2700*E + 0.00164*U + 16500*P*L + 507*S$

Operating cost in '000€ = $1200 - 107*L + 0.00013*U + 920*P*L + 34*S$

and the annual "break even cost" = Operating cost + 6%*Capital cost

Then if the "break even revenue" lies much below the "break even cost" the system is likely to require considerable subsidy. However, it is also the case that social benefits are roughly twice as much as the break-even revenue in the ULTra case studies, which could justify substantial subsidy if the socio-economic case is to be made.

Another approach might be to estimate the journey time savings which could be achieved by PRT over existing transport systems, then calculate the total Value of Time saved by the total estimated demand, weighting waiting and walking time at twice in-vehicle time. This total benefit can then be compared with the total estimated cost of PRT, less the saving in operating costs where existing services are no longer required.



Other PRT systems will, of course, have different costs. Unfortunately, Austrans and Taxi2000 which were included in Tegner's comparison are not consistently in active development, and no costs are given for the currently active systems. At present only three systems are in active development. These are ULTra, 2getthere, and Vectus, though Taxi2000 moves through periods of activity and its present status is unknown. PRT websites are often short on detail, and it is sometimes hard to distinguish activity from optimism.

2getthere (www.2getthere.eu/) is a Netherlands company presently constructing a PRT system in the basement of a huge retail and commercial development in Masdar City, Abu Dhabi. The global financial difficulties have caused this extensive projected system to be cut back to a more modest pilot system, at least for the present, and this pilot system is now in operation. The 2getthere PRT system is very similar to ULTra, in that the vehicles are battery operated and autonomously guided on a flat passive surface.



Vectus (www.vectusprt.com/) is owned by the large Korean industrial company Posco, and is being developed in Sweden at a test ground in Uppsala. It is very different in concept from ULTra and 2getthere, in that its vehicles are driven by linear motors, so the guideway is relatively complicated, but the system is capable of higher speeds. It has signed a contract to construct a system at Suncheon City in South Korea, and recently (June 2011) announced the groundbreaking ceremony.



Skyweb Express (www.taxi2000.com/) is the name now given to the revamped Taxi2000 system, which has been in development, on and off, for thirty years or so. It has a working prototype on a 60m test guideway in Minnesota, USA. The three-seater vehicle sits atop a chassis which runs within a U-shaped guideway, from which it draws power, so the guideway is relatively deep.



Critical Move (www.critical-move.com/) is a recent Portuguese entry to PRT development, formed in 2009 as a spin-off company from the University of Coimbra in collaboration with Siemens. It seems to be another battery-powered, autonomously navigated four-seater, along the lines of ULTra and 2getthere, but it is not clear from the website what technology exists in reality.

Austrans (www.austrans.com/) was a system considered in the EDICT assessment of Kungens Kurva, but this now seems to be defunct, and was in any case a mass people mover with a vehicle seating 8 or 9 people, rather than a true PRT.

As PRT becomes more widely installed, more suppliers can be expected to start up.



Figure 5.4 Heathrow car park station

shelter-like stations would be adequate, at a unit cost below that assumed in the cost estimator.

Of these companies only ULTra reports quantitative cost data, and for obvious reasons of commercial confidentiality, not at a fully detailed level. However, ULTra has reported system costs in the various case studies it has published for DfT, EDICT and Renaissance, albeit at the level of average unit costs. The costing equation given above enables a good estimate to be made of the costs of any configuration, although some aspects of cost will obviously vary - the car park stations at Heathrow, for example (Figure 5.4), are designed as architectural statements to reflect the advanced image of the system, whereas in a car park simple bus-

5.4 Safety

With any new transport system where the whole system is automatic, and especially with one as innovative and technologically advanced as PRT, safety registers high on the users' list of concerns. Automated rail systems have been around for decades, but for a long time the public insisted that there had to be a human driver in the cab as a safeguard; indeed, in some systems this is still the case. This is obviously a less reasonable request in a vehicle which carries only four people, but nevertheless passengers need reassurance that there is no risk of injury, and certainly ULTra has given a great deal of effort to safety design. Worldwide, there are 144 automated fixed guideway transit systems operating, carrying more than 4.6 million passengers per day (source: Planners Guide to Automated People Movers,

2006/7). These systems have operated with 100 times fewer accidents per passenger km than have either non-grade separated transit such as Commuter Rail and LRT or private automobile travel. The Morgantown advanced transport system serving the campus of the University of West Virginia is sometimes described as the world's first PRT system. It is not, because although it was initially designed in 1970 as a PRT system, finances caused it to be adapted as a mass people mover, with vehicles designed for eight seated passengers and 12 standing (though they often carry far more) and intermediate stops (Morgantown, 1975). Nevertheless, Morgantown is a fully-automated system of a similar design to true PRT, and it has been operating now for 35 years without fatality or serious injury.

Throughout its development, ULTra gained the appropriate regulatory approval at each key milestone, and assessment of the safety case at Heathrow is provided by an independent Safety Verification Team. The safety targets are achieved by a hierarchy of control levels:

- ❖ The central control system only allows a vehicle to begin its journey when it has been allocated a protected time slot throughout its journey into the destination station.
- ❖ As it enters the destination station, control is handed over to the local station controller, which ensures there are no conflicting movements between different vehicles.
- ❖ Each vehicle has its own precisely-detailed route map, and it regularly updates its position via laser guidance on the guideway kerb. This allows it to perform very accurately choreographed movements across any flat surface, and in an infinitely flexible way.
- ❖ An Automatic Vehicle Protection (AVP) system provides secondary protection by preventing any vehicle moving too close to another, as sensors in the guideway would detect the presence of one vehicle trying to enter a section already occupied by another and halt the following vehicle, an event which could only happen if a fault occurred in the higher-level control system.
- ❖ A third level of safety is provided by the kerbs on the guideway, which in extremis would physically prevent a vehicle running off the guideway.
- ❖ Vehicles have been subjected to a robust level of crash testing and sustain no serious level of damage against most objects which could be placed on the track by accident or vandals. Comprehensive coverage of the network by CCTV will detect the presence of larger objects.
- ❖ Vehicles have an internal Vehicle Health Monitoring system, which senses any variation of the battery and mechanical parameters from the expected norms, and informs central control, where a decision can be made to take a vehicle out of service at the next destination, or if the problem is more urgent at the next station, or to halt the vehicle (and other operations on the line) and send a special recovery vehicle to bring the impaired vehicle in for attention.
- ❖ In extremis, if for example there were a fire (though the VHMS should have detected this at an early stage), there is an escape hatch which allows occupants to escape onto the guideway, which is passive and safe to walk on. At this point all operations would be halted, and action undertaken to recover the passengers safely.

Mechanical failures will occur, no doubt, though proper monitoring and maintenance should make failures in transit extremely infrequent, and the system should not have to move very far down this list of safeguards before the situation is recovered. In the Heathrow operation so far, none of the back-up systems have been activated, and system reliability has been 99.7%. The approach to safety listed above relates to ULTra, of course, but presumably other PRT systems which are offered commercially will have a similarly comprehensive hierarchy of protection.

Doubts are sometimes expressed about passenger security, as especially for women the idea of being isolated in a vehicle they have no control over raises the concern that an intruder might get into the vehicle with them. It is possible that, as they enter a vehicle at a station, someone else might push in. But there is an emergency button by the seat, and both audio communication and a CCTV link with central control. Since the controller can direct the vehicle to a station where police or security guards are waiting for the intruder, there is little risk that this will occur. Moreover, and especially at off-peak times in the evening or night, vehicles will be waiting at the station for each passenger, and there is no requirement to wait at a lonely station where there may be a risk of mugging.

Overall, then, both safety and security should be better with PRT than with conventional transport.

As noted in Section 3, it is extremely gratifying for ULTra that personal safety received the second highest score in the passenger survey. This indicates that passengers are comfortable with the automated vehicle and lack of driver, and with travelling on a guideway several metres above the ground.

5.5 Environmental aspects

The environmental advantages of PRT have no bearing on the level of service as seen by passengers, but many passengers like to feel that the mode they have chosen is environmentally friendly, and as the passenger survey showed in Section 3 passengers rated PRT as substantially more environmentally friendly than bus.

The ULTra case studies have estimated the reductions in air pollutants and greenhouse gases which PRT could achieve. This is both because the vehicles are electric and emit no exhaust gases, and because they are light-weight and low-powered. All PRT systems in development at present are electric, and so emit none of the pollutants which are often a problem in urban areas, such as carbon monoxide and particulates, but the electricity generating stations which power them do emit exhaust gases, albeit in more rural or peripheral areas generally. Their emissions of oxides of nitrogen, volatile hydrocarbons and greenhouse gases are important, and have to be offset against the PRT vehicles' use of energy, but these pollutants emitted at power stations per unit of primary energy used are very much less than the equivalent emitted by road vehicles.

The ULTra vehicle is low-powered and uses regenerative braking to achieve low overall energy use. For the prototype vehicle energy use was estimated at only 0.55MJ per passenger-km, less than half that of urban bus or metro, as Figure 5.5 illustrates. The Heathrow vehicles are larger than the prototype, and energy measurements show energy use some 65% higher than for the prototype, but this still makes the system substantially more energy-efficient than either bus or rail. The Heathrow PRT system emits about half the carbon dioxide emitted by the previous transfer midibuses.

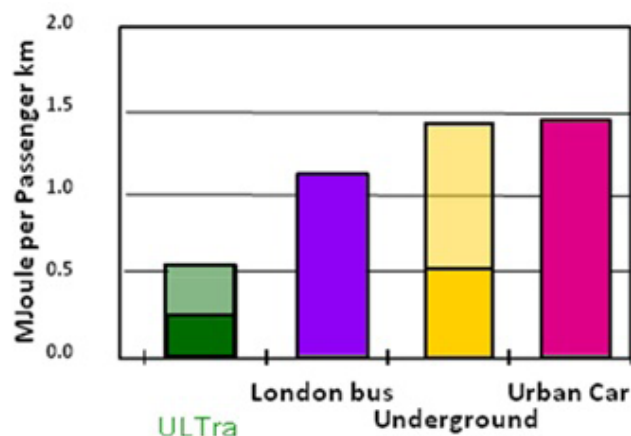


Figure 5.5 Comparative energy use MJ per passenger-km (for PRT and metro the pale colour indicates power used in generating and transmitting electricity)

Table 5.1 lists the average emission rates for cars and buses, taking rates per vehicle-km from the UK DfT Road vehicle emission factors 2009 (TRL, 2009) and dividing by mean occupancies of 1.4 for car (and PRT) and 12 for bus. The PRT emissions occur only at the power station, of course, at the UK average fuel mix. As electricity generation moves towards more sustainable energy sources in future so PRT emissions will decrease, but it is in any case clear that PRT is substantially less polluting than conventional internal-combustion-engined transport. When assessing the net environmental benefits of PRT the reduction in energy from lower use of the alternative modes can be estimated from these emission rates, though the result depends on the extent to which the reduced demand results in reduced vehicle operation. In the case of transfer from car this is straightforward, but where demand is transferred from public transport to PRT a judgement has to be made as to how much the services of the alternative public transport will be cut.

Emission	UK emission rate (g/pass-km)		
	Car	Bus	ULTra
Carbon monoxide	0.56	0.14	0.010
Hydrocarbons	0.04	0.03	0.001
Nitrogen oxides	0.19	0.68	0.06
Particulates	0.01	0.02	0.001
Carbon dioxide	110	78	25

Table 5.1 Comparative emission rates for car, bus and PRT

PRT vehicles are very quiet ($L_{eq} < 50$ dBA at 2.5 metres) as well as having no emissions, and produce a very low floor loading, so they can be routed through buildings, improving access and integrating transport more closely with other activities.

5.6 The decision to install

Once the preliminary investigations have suggested that there is a good case for PRT in a particular location, it is necessary to examine the proposal in detail and make a full business and social case. This requires a detailed prediction of likely ridership, from which the revenues, passenger benefits and wider social benefits can be calculated. Except where ridership is captive or unaffected by the transport provided, as in the case of the Heathrow car parks (though even here use of a particular car park may be encouraged by provision of a superior transfer service), it will almost certainly be necessary to undertake some form of mode choice modelling to decide how many travellers will elect to use PRT, and, importantly, where their trips have been transferred from. The Box below indicates the considerations involved.

Any model requires as its input data describing the existing trip pattern, which will have been obtained by traffic and travel surveys. A mode choice model may be constructed, or a consultant's package may suffice, or in many areas local authorities maintain a full four-step area or regional model which can be used to test transport proposals. This latter approach can model **redistribution of trips** as well as modal shift, and in situations where PRT enables people to access destinations in places or in time which the existing transport does not serve well, there may be a redistribution of existing trips across the area in a way which strengthens demand beyond the level suggested by modal shift alone. Section 4.7 has already pointed out that this can lend substantial support to new developments.

Estimating demand

A detailed estimate of demand requires expert support, but as a preliminary examination it may be sufficient to consider existing public transport passengers who would be able to use PRT within the catchment area covered by the proposed system. It may be that the sensible policy will be to reorganise existing bus services, reducing the number of routes or frequencies where bus services would be in competition with PRT. But even in direct competition PRT is likely to capture at least two-thirds of existing bus demand. It would also compete very strongly with LRT, but generally it would not be economic to replace existing LRT with PRT and it would be better to design PRT as a distributor from major LRT or rail nodes. In addition, the case studies suggest that PRT could attract 10% to 20% of present car traffic, and as a conservative estimate perhaps 10% of car traffic could be added to the PRT demand transferred from conventional public transport. If PRT is used for Park and Ride it is likely to attract more demand than bus-based P&R, because car drivers can interchange with little waiting, and can continue to travel in their own personal groups. In the event, once PRT is in place people will find that it enables them to travel to places they would not have considered as destinations previously because access was too difficult, and in the longer-term this will increase demand further.

If appropriate, it may be desirable to take the preliminary examination a little further by making a rough calculation of modal split at an overall level. This involves calculating average generalised times for each competing mode as:

- ❖ Twice walk time
 - + twice wait time
 - + in-vehicle time
 - + fare/VOT (for public transport and PRT)
 - + operating cost /VOT (for cars - perceived cost is close to fuel cost)
 - +parking cost/VOT (half park cost and include mean time to find a place if long)

where VOT is the appropriate Value of Time for the place.

Modal shares can be calculated by a simple logit model as:

$$\text{❖ } P_{m1} = \frac{\exp(-\lambda G_{m1})}{\{\exp(-\lambda G_{m1}) + \exp(-\lambda G_{m2}) + \exp(-\lambda G_{m3}) + \dots\}}$$

Where P_{m1} is the proportion of total trips attracted by mode $m1$, and G_{mx} is the generalised time in minutes of an average journey by mode mx ., and the denominator contains all the modes to be included. Typical values of the λ coefficient for modal split are 0.03 to 0.05 when generalised time is measured in minutes.

However, the calculation is complicated by the fact that Mode Specific Constants (MSCs) are normally required to calibrate to the observed mode shares. These would be added to the time for each mode. If modal split is calculated between PRT and bus in this expression without any MSC this can be expected to underestimate the PRT mode share. Conversely, if modal split is calculated between PRT and car it will overestimate the PRT share.

This approach may give a useful first indication for purposes of discussion, but at some point a detailed and expert examination of demand, and its pattern across the area and the PRT network will be essential.

The fare charged affects both demand and the financial balance of the service. As we saw in Section 3, it is difficult to establish an unbiased estimate of willingness-to-pay, but it is fairly clear that most passengers are willing to pay more for PRT than for bus (and probably more than for urban rail or LRT) but less than for a taxi. In economics, theoretically if fares were raised by the additional value to the average passenger of the travel time saved this would reduce their net benefit (or their “consumer surplus”) to zero and bring demand back to the level of the bus service PRT replaced. In this case there would be no social value in providing the new service, but it indicates the scope for raising fares. The decision to set the fare would depend on the objective, but it inevitably involves some trade-off between achieving a required financial outcome, and raising demand with its accompanying social benefits.

Transport modelling is always of uncertain reliability, and its predictions are likely to have wide margins of error, but no better approach is available and the possibility of error must be considered in the decision making. Estimation of system costs, even via the average costing equation for ULTra, is likely to be more reliable, and on the basis of demand and cost a financial and/or socio-economic case can be made in a similar way to the previously-described case studies. For PRT suppliers other than ULTra an outline cost estimate would have to be sought from the suppliers.

If the decision is taken to pursue implementation, then it will be necessary to refine both the costing and the routing of the system in full practical detail, by involving the supplier(s) in the design study. The various steps and considerations in procurement are well described in the NICHES+ guide.

6 The future of PRT

- **PRT is not new.** It was first suggested in the 1950's, and was a very active area of development in the USA, UK, France and Germany in the late 1960's and 1970's. Various prototype systems were built (see [Wikipedia en.wikipedia.org/wiki/Personal_rapid_transit#Origins](https://en.wikipedia.org/wiki/Personal_rapid_transit#Origins)), including Morgantown which began operations in 1975, but as a mass people mover rather than as PRT. No PRT system was installed, though some were very advanced in the planning, but they were killed by cost and by public objection to visual intrusion. At that time, computers were slow and of limited capacity, and the control systems themselves were very expensive. The systems were also over-engineered: guideways were generally active and complicated, and required a large and intrusive infrastructure. It was an exciting time in the research, but in the end it came to nothing and it gave PRT a bad name.
- **Technology moves on.** Curiously, however, at least with some systems, PRT has become practicable because of a step back in technology. Certainly, computing technology has become much faster, smaller and cheaper, but a rethink of the technology has also made it possible to avoid over-complication and over-design, and this has simplified in some aspects the operation of PRT. It is the control systems which must be clever, while all that is required of the vehicle is the ability to power itself, or be powered, and steer itself along some form of guideway. In this sense, both ULTra and 2getthere opt for the simplest form of propulsion, with batteries on the vehicle which can be recharged in stations. Moreover, electric motors driving rubber-tyred wheels enable most of the components to be sourced from the automotive industry, with cheap tried-and-tested parts. Vectus has opted for a more complex power source in linear motors, to gain the advantage of range and higher speed. In comparison with conventional public

transport PRT can adopt small and lightweight vehicles, because it requires no driver, and that permits small and lightweight infrastructure and low energy requirements, especially with regenerative braking.

- **Heathrow is the first publicly-operated PRT in the world.** This report has drawn together the evidence that PRT provides greater benefits and revenues, at less cost, than conventional public transport. The performance of PRT in attracting more passengers, and greater transfer from car, has been illustrated by modelling, but it is obvious that this must be so in reality too, other things being equal, because PRT offers little or no waiting, and a direct, non-stop and faster journey time than is available from other urban transport. The remaining question is whether, in practice, PRT can provide this superior performance at acceptable cost, comparable (if not better) than for LRT, or even if it were somewhat more expensive than LRT in out-turn whether the higher demand would compensate. The Heathrow experience has shown that PRT can work reliably, and ULTra PRT Ltd still claim that it can be cheaper than LRT, and can justify very strong business cases.
- **It is no surprise that the first installation of PRT should be at an airport.** This is an application where technological innovation and advanced image is very important. It is also the case that the existing built environment offers few problems for installation of a new transport system, since development and redevelopment is continuous, and there are few concerns of visual intrusion. Many airports have installed expensive advanced mass people movers because of the technological image, some on monorail, some with linear motors, when the economic justification would have been greater with simpler, cheaper solutions. For similar reasons, construction of 2getthere at Masdar City ticks all the developer's boxes there, and other high-value campuses will value PRT for the image, in addition to its high level of service. There can be no doubt that, once the Heathrow system is seen to operate reliably, other airports and campus developments will be keen to adopt PRT. They require a transport system which can connect seamlessly anywhere to anywhere (Terminal to Terminal to car parks to car hire to staff locations to hotels), which PRT supplies, and importantly this small, quiet and non-polluting transport can run through buildings, to check-in desks and passenger concourses. PRT vehicles are lightweight and need little new infrastructure within buildings: for example, ULTra has a footprint less than the standard floor strength design of an office building, and can operate on any flat surface.
- **Nevertheless, PRT was originally envisaged as a general-purpose urban transport system.** ULTra was designed with this in mind, and the first serious application was in Cardiff, UK. This was prior to EDICT, and a PRT system was designed to connect the city centre with the rapidly developing Bay area, where the old docks were redundant and redevelopment as a leisure and residential area, together with the Welsh Parliamentary Assembly and the Millennium opera and concert hall, has been very successful. Amongst all this new building a PRT network would have been easily installed, and would have improved public access to the Bay enormously, supporting the activity there. Stated Preference modelling of ULTra suggested that even though the Cardiff Bay PRT provided a distributor from the Central Rail Station of only a couple of kilometres to the Bay it would encourage some 8% of car commuters to switch to rail and bus plus PRT, and give a substantial boost to public transport use generally (see Deliverable 1.2.5.2). Design and planning advanced to the threshold of contracting supply of the system, before falling foul of largely political considerations.
- **First adopters of new technology take a risk.** Cardiff was an ideal opportunity lost, but it illustrates the difficulty PRT faces in penetrating into existing urban areas, as opposed

to specialist applications in airports, retail parks and campuses. To become the first to implement any radically new solution involves substantial risk. It was a risk for BAA, but they took it because they judged the potential advantages to be so large as to outweigh the risk, and it showed the airport's commitment to technological progress and improving customer services.

- **The risks to adopters of an urban PRT are different from those for an airport or campus development.** The questions of rights of way, severance and visual intrusion loom much larger when PRT guideways are installed in a town, and democratic planning processes will always find opposition. Elected representatives and local authority officials are generally more risk-averse than private entrepreneurs, and to build expensive, extensive and visible infrastructure in a town for a project which might not succeed will be a step too far unless someone has the vision and persuasiveness to persist.
- **It seems likely that PRT will have to become widely accepted in specialist locations before urban authorities are willing to adopt it.** Once its value, practicality and reliability are seen in these applications, cities and towns will begin to follow, but this will place urban PRT decades in the future.
- **PRT provides a higher level of service for passengers, but it also reduces congestion and emissions.** If it proves successful as a system, we need to adopt it as early as we can. It is unreasonable to leave this responsibility to the finances and risk of individual local authorities. There needs to be partnership with national governments, or better still international governments, for example the EU, to prove the value of PRT in an urban environment. Indeed, the EU has so far taken the lead in assessing and testing PRT. Heathrow has demonstrated the practicality and reliability of PRT, but this does not demonstrate the versatility of a PRT network. A similarly small-scale pilot in a city will not advance the position appreciably, because to demonstrate the go-anywhere competence of PRT a more extensive network is needed, and it must be seen to meet a real public need.
- **To demonstrate and evaluate urban PRT, risk and funding need to be spread across and between countries.** Once the large theoretical benefits are demonstrated in practice, PRT will start to become a standard element in urban public transport. But it will take vision and leadership to achieve this.

7 In conclusion

The passenger attitude surveys and the many case studies have shown very clearly that:

- i) **Passengers prefer PRT to bus travel, and are prepared to pay more for it. Similarly, it is likely to be preferred to conventional urban rail travel**
- ii) **PRT attracts more passengers overall, and more car drivers, than conventional public transport, and is likely to provide both a much stronger financial business case and a better socio-economic case.**

So far the economic case studies are theoretical and hypothetical, though some at least are detailed and realistic. But in any case, it is obvious that for a given catchment area PRT will perform better than conventional public transport because it offers a higher level of service: travel time is reduced because there is little or no waiting, journeys are direct from point-to-point and there are no intermediate stops, and no interchange is required.

The remaining question is whether:

- ❖ **PRT can work reliably as intended, and**
- ❖ **at a cost which is competitive with conventional public transport.**

The Heathrow demonstration has shown that it can work reliably, and although the Heathrow experience has suggested some inflation in cost beyond the original cost predictions for ULTra, these are modest and still leave the economic returns looking very attractive. Other PRT systems will have different attributes and different costs, but the advantage of PRT over conventional transport is large enough that even with higher costs a strong business case can be made.

The Heathrow system is limited and does not permit the full flexibility of PRT to be seen, but more extensive networks will show the full advantages of PRT. **The case for PRT in new developments and in campus environments is very strong.** Even in systems with higher costs, PRT will look attractive for such developments, and for airports there is evidence that passengers behave as if their Value of Time were enhanced, making PRT still more attractive.

Introducing PRT into an existing urban environment is more difficult. It would be easiest and most suitable to build it in an integrated system with large-scale new development, where it could provide valuable support to encouraging demand for the new shops, offices and homes.

The potential advantages of PRT in quality of service, energy and emissions, and congestion reduction seem so large that it should not be left to the bravery of individual urban authorities, which may delay it by decades.

Some national or international initiative is needed to support both funding and risk, so that the advantages of PRT in a real and useful urban application can be demonstrated.

8 References

Advanced Transport Systems 2002. Case Study Report: Application of ULTra in Heathrow. ATS/CS/02 (Ultra PRT Ltd, Thornbury, UK)

Advanced Transport Systems 2004. The Corby New Town Case Study, Report ATS/CS/04 (Ultra PRT Ltd, Thornbury, UK)

Andréasson I 1994. Vehicle Distribution in Large Personal Rapid Transit Systems. Transportation Research Record, #1451, pp 95-99. 1994

Bly and Lowson, 2010 Analysis of Airport Car Parking Cost versus Access Time CityMobil Deliverable D1.2.4.4

CityMobil 2009 Outline Description of the Heathrow PRT Pilot Scheme. Deliverable 1.2.2.2, June 2009. <http://www.citymobil-project.eu/>

CityMobil 2009 Evaluation of passenger satisfaction levels for the existing bus service between the Business Car Park and Terminal 5 in Heathrow Airport. Deliverable 1.2.4.1, May 2009. <http://www.citymobil-project.eu/>

CityMobil 2011 Evaluation of passenger satisfaction with the Heathrow PRT system. Deliverable 1.2.4.2, June 2011. <http://www.citymobil-project.eu/>

CityMobil 2011 Comparison of the ULTra PRT system with the existing bus service from the passenger and operator viewpoints. Deliverable 1.2.4.3, June 2011. <http://www.citymobil-project.eu/>

CityMobil 2011 Estimating demand for a new mode. Deliverable 1.2.5.2, June 2011. <http://www.citymobil-project.eu/>

Colin Buchanan and Partners 2002. Corby Rapid Transit Feasibility Study. (CBP, London)

Colin Buchanan & Partners 2007 Daventry Transport Development Study (Daventry District Council, Feb 2007)

EDICT 2004. Evaluation and Demonstration of Innovative City Transport. Fifth Framework Programme Key Action "City of Tomorrow and Cultural Heritage". Site Assessment Report.

EDICT Project Deliverable 6 (Project No. EVK4-CT-2001-00058) April 2004 (European Commission, Brussels and Transport and Travel Research, (Lichfield UK)

EDICT, 2004 (Evaluation and Demonstration of Innovative City Transport) 5th Framework EU project, Site Assessment Report for Ciampino. Deliverable 6.3. (ec.europa.eu/research/environment/newsanddoc/article_2650)

Hammersley J 2010. Stimulation of Collective Transport - Personal Rapid Transit applied to the City of Bath CIVITAS RENAISSANCE – Testing Innovative Strategies For Clean Urban Transport For Historic European Cities, Measure 2.2 July 2010. (European Commission, Brussels)

Lowson M V (2002) Sustainable Personal Transport. Proceedings of the Institution of Civil Engineers, Municipal Engineer 151 March 2002 pp 73-82

NICHES+ 2010 Guidelines for Implementers of Personal Rapid Transit. NICHES+ WG4 Policy Notes 21582 (Southampton University School of Civil engineering and the Environment)

Ove Arup 2002 Cardiff ULTra Stated Preference Survey and Analysis Report, Final Report, Ove Arup & Partners Ltd

Tegnér G and I Andréasson 2004. PRT- a High-quality, Cost-efficient and Sustainable Public Transport system for Kungens Kurva. Site Assessment Report, Deliverable 6, EDICT project (EU Commission, Brussels)

Tegner 2009 Benefits and Costs of a Podcar Network in 59 Swedish Cities – The role of City Size for the Net Benefits. WSP Analysis & Strategy, Stockholm, Sweden

Tegner and Angelov 2009 Financing Transit Usage with Podcars in 59 Swedish Cities. Paper to presented at 12th International Conference on Automated People Movers, Atlanta, May 2009

TRL, 2009 Report Number PPR361 - Emissions factors 2009: Final summary report (Transport Research Laboratory, Crowthorne, UK)

van Zuylen H J et al (2004) Almelo Site Assessment Report. Deliverable 6.4, EDICT project (ec.europa.eu/research/environment/newsanddoc/article_2650)

Young S E, P Muller, M El-Aasar, D Landman and S Schrock (2009) PRT Case Study at the Village West Development in Kansas City, Kansas. Proceedings of Conference on Automated People Movers, pp190-200 2009. (American Society of Civil Engineers)