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**Towards advanced transport for the urban environment**

**Estimating Demand for a New Mode**

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## Executive Summary

This report discusses the problems of estimating demand for a wholly new mode, with particular reference to Personal Rapid Transit. The world's first publicly-operating PRT system has recently opened at London's Heathrow Airport, but there it serves a car park where demand is determined by the number of people who use the car park. When PRT is in competition with other urban transport modes it is necessary to know how passengers view the mode in comparison with other available modes in order to predict likely demand. For the ULTra PRT system, the initial demand predictions were obtained by making an extensive Stated Preference study of travellers in Cardiff city centre, who were given a set of pairwise comparisons of relevant trips by two modes, stating the walk time, waiting time, in-vehicle time, and cost, choosing between walk and bus, bus and PRT, and rail commute plus bus versus rail commute plus PRT. The survey worked well and gave credible Values of Time and demand predictions. However, in applying the results to other situations the problem of assigning a Mode Specific Constant (MSC) to the PRT generalised cost of travel remains. In general, it seems logical to apply a MSC somewhere between the value for car travel and that for bus or rail travel, and given the attributes of PRT probably closer to car than to conventional public transport.

One interesting result of the Cardiff study was the prediction that availability of even a short a PRT distributor at the city centre end of a rail commute would double the proportion of commuters who chose rail plus PRT over car, compared with the present situation of rail plus bus versus car. Although PRT would compete very well with conventional public transport modes in its own right, it should be used as part of a fully-integrated urban public transport system. In this way it will work to increase public transport's share overall, since it can act very effectively as a distributor from transport interchanges, and it is likely to be especially acceptable to car users as Park and Ride transport.

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## Estimating Demand for a New Mode

### 1 Introduction

Personal Rapid Transit (PRT) is a wholly new concept in public transport. The world's first publicly operating system began serving business car park users at Heathrow's Terminal 5 recently, but although passenger surveys show that the users are very keen on it (Bly, 2011a and 2011b), it does not have to attract demand. The demand is determined by how many people use the car park, and can be readily predicted in advance.

Installing PRT in a situation where it has to compete for custom with existing transport modes makes predicting demand much more difficult. Adding a new bus service, or rail service, to existing networks is straightforward, because in a transport model it can be assigned the same coefficients as the existing mode. Predicting the effect of a new mode to the area, such as LRT, is more problematic, but it is possible to import the parameters applicable to LRT from a system somewhere else. Modelling the effects of a wholly new mode such as PRT requires a different approach.

This paper discusses the methods used to estimate a demand model for the proposed ULTra PRT network in Cardiff and the likely effects of the mode on the existing public transport services

### 2 Conventional transport modelling

Transport modelling is not an exact science. The conventional, and widely used, approach is via a so-called **four-step model**, which:

1. first estimates the total travel pattern across the area modelled
2. then distributes the total demand from each zone to all the other zones according to the attractiveness of the various destinations within each zone
3. then splits the total zone-to-zone travel between the available modes (though this and the previous step can be made in the reverse order, or in combination), and
4. finally allocates the travel on each mode to a specific route, taking account of congestion where appropriate.

In many cases demand predictions may include only a subset of these steps, since often the total travel demand and its distribution is taken as a given, and the detailed routing for some modes may be of little interest. Thus the central core of many demand models is often the *modal split* step.

This works reasonably well in situations where the model can be calibrated against the existing behaviour (or, at least, it has become accepted as the standard approach because other approaches are more complicated and have not, overall, been found to be consistently superior). The model is then used to predict into the future or against proposed changes to the existing modes. With PRT, however, there is at present no real-life data describing how travellers will react to the new mode.

Conventional mode split modelling compares the travellers' perceptions of each mode available for travel by combining the time and money costs of travel into a "generalised cost" or disutility of travel, and allocating more travellers to the cheaper mode in terms of "utility". One mode may be much quicker than another, but it may cost more, and it is the overall utility which determines how attractive a mode is. The relative probability of choosing one mode over another is usually estimated by a "logit" model, as the ratio of the exponentials of these disutilities.

With the introduction of PRT, it is relatively easy to estimate how long passengers will take to travel from their origin to destination, including walking to and from the stations and waiting in the stations. The walking and waiting components are traditionally weighted more heavily than time spent sitting in the vehicle, because people view them as more onerous, and it seems reasonable to apply the same relative weightings as for the existing modes. The proposed fare can be added into the disutility via a "Value of Time" (VOT), which again is often a standardised quantity established across a range of other studies. However, in order to calibrate the model against the observed travel behaviour (ie the existing travel patterns and mode splits), it is generally necessary to employ "mode specific constants" (MSC) to be added to the disutilities of each mode. With a new mode there is no existing calibration to establish what the MSC might be for PRT, though its general level might be argued in comparison with the MSCs of the existing modes. Such an approach remains very uncertain, however.

### **3 Stated Preference modelling**

In the case of ULTra, a different method was adopted to estimate the likely demand for a proposed PRT network in Cardiff, UK. The system linked the city centre to the rapidly-developing Bay area, about 2kms away. As part of the European Commissions EDICT project, ULTra PRT Ltd commissioned Ove Arup and partners and the Institute for Transport Studies at the University of Leeds to make a "Stated Preference" study of a sample of travellers in central Cardiff (Arup, 2002). In this type of study, respondents are asked how they would choose between available modes. This is necessarily hypothetical, but it is far more than simply an "attitude study". It is essential that the questions are placed in a realistic context which the respondent can relate to, so that he or she is given realistic details of the travel choices. A well-designed stated preference study can extract a great deal of information from a small sample, and its consistency can be checked. By contrast, "revealed preference" studies, ie studies of existing travel behaviour, rely on large samples and contain much uncertainty because the choices seem to depend on many other factors besides the particular characteristics of the transport modes, and most of these factors relate to unknown personal situations.

As with conventional modelling, the difficulty remains that PRT is unknown to those making the choice. It was important, then, to precede the survey with several focus group meetings to establish how best to explain PRT to people, so that survey respondents would have a realistic idea of how it works, and what the journey would involve. Respondents were recruited by telephone and on-street selection according to quotas set for six agreed categories of choice. At the time (and still currently), the public transport choice for people travelling to the Bay was via bus or an infrequent rail shuttle, but with PRT installed commuters would have the choice of rail or bus to the centre, and onward travel by ULTra. The six choice categories were:

- i) **car vs rail+PRT** from the suburbs to the Bay (quota 100 interviews)
- ii) **car vs bus+PRT** from the suburbs to the Bay (quota 75 interviews)
- iii) **walk vs PRT** on alighting from bus or rail (quota 50 interviews)
- iv) **bus vs PRT** from city centre to the Bay (quota 75 interviews)
- v) **taxi vs PRT** from Central Railway Stn (quota 50 interviews)
- vi) **walk vs PRT** within the centre or the Bay (quota 50 interviews)

for a total sample of 400. In the event the quotas were achieved, or slightly exceeded, in all categories except taxi, where only 5 users could be found. This category was abandoned, and a total sample of 353 was interviewed.

Each respondent was given a showcard providing a detailed description of the ULTra system, and asked to provide information on their current journeys and mode use, plus age, sex, employment and income. Comparison with national data established that the sample was very representative of the whole population. They were also given cards detailing sets of choices between two modes, describing walk access times, waiting times, travel times and fare, for a particular journey relevant to the correspondent. Respondents were asked to say which of the two modes offered they would choose. Each respondent was given between eight and sixteen pairwise comparisons to choose, with differences in journey time components or fares, and with different modes providing they were relevant. The first batches of data collected were used to refine the questionnaires for the remaining respondents. The details of time and money presented with each choice pair were carefully calculated to ensure that, across the sample, the respondents' choices place tight limits on the trade-offs involved. Thus although the exercise was hypothetical, and related to a mode which had not been experienced, respondents were able to imagine realistically what the PRT service would be like and were forced to consider how one aspect might be traded against another.

## 4 Stated Preference analysis and results

For each of the five categories of choice (omitting category v for taxi), the analysis maximised the likelihood that a binary logit function:

$$P_{12} = \exp(\lambda U_1) / \{\exp(\lambda U_1) + \exp(\lambda U_2)\}$$

describes the choice of mode 1 over mode 2. Here,  $U_1$  is the (dis)utility of travel by mode 1, and is estimated from the component times and costs of the journey used for the choice, as:

$$U_1 = w_v T_{v1} + w_{wk} T_{wk1} + w_{wt} T_{wt1} + w_f F_1 + \text{const}$$

where the  $T$ 's are the time spent in-vehicle ( $v$ ), the time spent walking to and from the service ( $wk$ ), and the waiting time for the service ( $wt$ ) respectively, and  $F_1$  is the fare. The  $w$ 's are the weights to be attached to each component to reflect travellers' perceptions of how time and money affect their mode choice.  $w_f/w_v$  is a measure of the monetary value placed on time spent travelling in the vehicle, and  $w_{wk}/w_v$  and  $w_{wt}/w_v$  measure the greater weight travellers place on time spent walking and waiting than on time sitting in the vehicle. The various weights are estimated by maximum likelihood, a standard statistical technique, as is the coefficient  $\lambda$  in the logit function.

Thus the analysis provided all the weights to be used in the calculation of the disutility or generalised cost of travel by each mode, and the effective Values of Time, to be used in

estimating modal split, though of course these values are specific to the situation in Cardiff, and to pairwise choice rather than a multi-modal choice. All the statistical t-values on the various coefficients were highly statistically significant, and the overall goodness of fit, while not high ( $\rho = -0.1$ ) was typical of stated preference models. Confidence in the findings is engendered by the fact that the Values of Time indicated by the model were well in line with the overall VOTs obtained by Wardman in a review for the UK Department for Transport (Wardman, 2002), as shown in Table 1. VOTs in the Bus vs PRT segment are consistently higher than the Wardman values, but this is ascribed to pre-paid bus passes making bus trips between the centre and the Bay effectively zero cost. Further confidence is gained from the fact that using the SP parameters in a study of PRT vs LRT in Corby (ATS, 2004) provided very similar results to those obtained using standard modelling parameters in a mode split model developed by Colin Buchanan and Partners.

When the coefficients obtained from the SP analysis were entered into the binary logit models and applied to the expanded data for all travel to the Bay, predictions of total demand could be made for the ULTra network (Arup, 2003). This suggested 13,260 daily passengers at a flat fare of £1 per vehicle (average £0.80 per person), or just under 4 million annually on Phase 1 of the proposed system, with 10% of trips occurring in the peak hour. When the calculations were extended to Phase 2, which was an extension of the network around the city centre, demand increased to 18,800 daily trips and 5.6 million annual trips. Demand predictions for Phase 2 are likely to be less reliable because they extend the SP results to trips which were not examined in the SP survey.

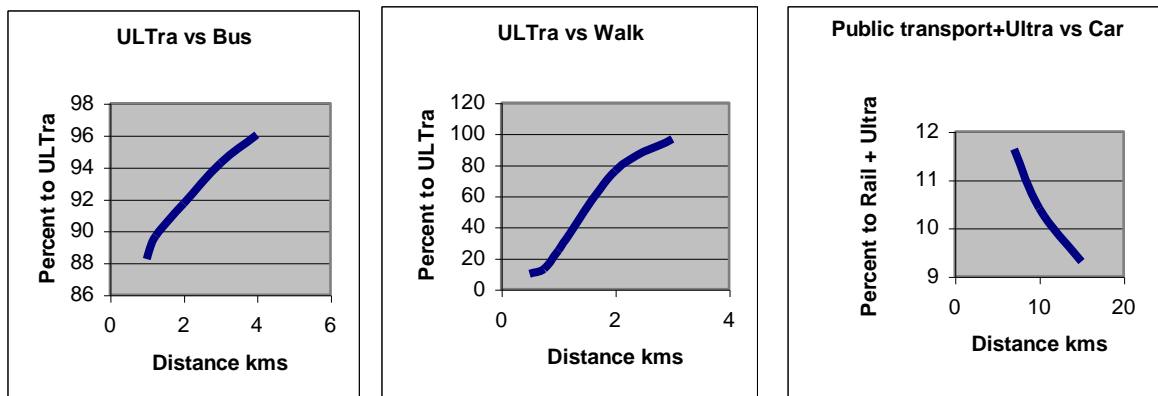
**Table 1 Values of Time implied by the SP model**

		Walk vs PRT		Bus vs PRT		Car vs PRT	
	Journey purpose	Cardiff SP	Wardman 2002	Cardiff SP	Wardman 2002	Cardiff SP	Wardman 2002
<b>IVT</b>	Commute	3.00	5.3-7.1	7.80	3.8		
	Leisure		2.5-3.4	5.70	3.4		
<b>Walk</b>	Commute	6.90	11.1-13.3	21.60	10.5		
	Leisure		6.9-8.3	15.70	9.5		
<b>IVT</b>	Car					5.75	6.18
	Rail					8.94	5.53
	Bus						7.73
<b>Walk</b>	Public Transport					23.42	23.13
	PRT					21.08	N/A

These coefficients obtained in the SP study can be applied with more confidence to trips over a range of distances than could be the case by merely using generic coefficients and VOTs in

a standard multinomial logit modal split model. Even in this approach, however, it is still necessary to apply a MSC to the car mode, in this case a negative MSC, to recreate the observed split between car and public transport. Thus the approach does not overcome this unknown quantity for a new mode. We are left with the argument that the appropriate MSC for PRT should logically lie somewhere between that for bus and that for car, since PRT has attributes somewhere between these two modes. For lack of other evidence this might be halfway between bus and car, though it could be argued that the quality of service provided by PRT is closer to car than to bus.

For Cardiff, the model suggested modal splits against walk, bus and rail plus ULTra as shown in Figure 1. Over any appreciable distance ULTra attracts the great majority of trips against bus or walk. For longer commuting trips from the suburbs most trips are by car. The modal share to public transport declines at longer distance because the fixed car park charge at the Bay end becomes a smaller portion of the total car generalised cost.



**Figure 1 Mode split versus distance**

## 5 The place of PRT in a public transport network

An important finding of the Cardiff study was that the presence of the PRT network between the city centre and the Bay doubled the proportion of commuter trips made by public transport to the Bay, whether by bus or rail, even though ULTra catered for only the last 2 kms of the journey. Thus integrating PRT into an existing public transport system doubled patronage on the existing bus and rail services. This finding is supported by modelling of the likely effect of several advanced transport systems in Gateshead, UK, as part of the CityMobil project. This suggested that a 21km PRT network serving the inner city would increase the use of rail travel by 168% in the peak and 232% in the off-peak (May, 2011). It is not simply the demand which a transport improvement attracts to itself which matters, but its effect across the larger public transport network, where it can substantially increase the demand for other public transport services, and encourage transfer from car..

Against walk or bus ULTra takes the great majority of trips as the journey distance increases. This is to be expected, since in contrast to bus PRT has very little waiting (average wait times are typically 0.3 minute, with more than 90% under one minute), no intermediate stops or interchange, and a running speed which, at around 35kph, is substantially better than urban

road averages. This is illustrated in Table 2, which contains the component times of a notional, but fairly typical, 5km journey as made by urban bus, LRT or Metro, and ULTra. Weights of 2 are applied to the walk and wait components to sum the total generalised times of the journey by the different modes; a weight of about 2 is typical of transport modelling in the UK, though the SP study suggested rather higher weights of 2.6 to 2.8, and such higher values would make PRT still more favourable.

**Table 2 Journey time components by public transport modes**

	<b>operating speed, kph</b>	<b>walk access mins</b>	<b>waiting time mins</b>	<b>in-vehicle time mins</b>	<b>total generalised time</b>
<b>Bus</b>	<b>18</b>	<b>10</b>	<b>5</b>	<b>16.7</b>	<b>46.7</b>
<b>LRT/Metro</b>	<b>27*</b>	<b>10</b>	<b>0.3</b>	<b>11.1</b>	<b>41.1</b>
<b>ULTra</b>	<b>35<sup>+</sup></b>	<b>10</b>	<b>5</b>	<b>10.0</b>	<b>30.6</b>

\* metro speeds may be higher than LRT at around 30kph, depending on station spacing, but access takes longer

+ ULTra max running speed is 40kph, but this takes account of routeing and accn/decn.

Of course, the other part of the overall cost is the fare. Previous studies have shown that PRT can probably cover both operating and capital costs at typical urban levels of demand (EDICT 2004, ATS 2004, Hammersley 2010), but at low demand the fares necessary to cover the investment costs of LRT or PRT will make bus the cheapest mode in generalised cost terms. Moreover, buses have the flexibility to penetrate low-density suburbs, though they tend to follow very indirect routeing at low frequencies.

It is a question of using the best mode for the circumstances, and not simply of competition between them. Thus PRT should be used as part of a wider, integrated network, including Park and Ride, for which it is obviously well-suited since it carries people in the group in which they arrived by car, and with little waiting.

Construction of a fixed-guideway system, whether for PRT or LRT, is problematic in an already developed area, though in previous studies made by ULTra PRT Ltd of the opportunities for installing a PRT network through existing urban development, whether in Cardiff (EDICT, 2004), Corby (ATS 2004), Swindon or Bath (Hammersley 2010), the availability of possible routeings has been surprisingly high. The ULTra infrastructure is slim and narrow, and this maximises the number of through-ways which might be employed. Much of the guideway will be elevated to avoid severance, and this enables the right-of-way to be shared with pedestrian footpaths. Zero emissions and very low noise allow the system to travel within buildings, and in close proximity to pedestrians with the minimum of disturbance.

## 6 Summary

Transport modelling is an uncertain predictor at the best of times, though still the most practical tool we have. It is especially difficult to apply when the modes involved are new and have no basis from past experience. Stated Preference modelling of PRT in Cardiff has tied traveller choices more realistically to local conditions, but the problem of deciding what Mode Specific Constant should be added to its generalised costs remains. We can probably not do better than assume the PRT MSC lies somewhere between the MSCs for bus and car, and probably half way between, though arguably closer to car than bus.

As seen above in the case of commuting to Cardiff Bay, the introduction of a relatively limited PRT network (7.7km of one-way guideway) would have a very positive effect on Cardiff's existing public transport services, doubling the number of commuters to the Bay who use rail or bus, even though PRT caters for only the last kilometre or so in the overall commuter journey to the Bay. Thus PRT can have a substantial effect in increasing demand for existing public transport services.

Providing PRT as a distributor from other major transport interchanges is likely to have a similar impact. Even a small PRT network can provide an effective distributor in large commercial developments, as Tegner (2009) suggests, or in office campuses or airports. As noted above, Park and Ride is likely to be much more successful in convincing car users to park outside the central area and travel, with little or no waiting and car-like comfort, by PRT.

PRT can compete very well with conventional public transport services, but it will work best as an integrated component of an urban public transport network, where it can increase the overall use of public transport.

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