Investigating the contribution of Demand Responsive Transport to a sustainable local public transport system

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ABSTRACT

Various studies have advocated the potential for Demand Responsive Transport (DRT) services to deliver sustainable local public transport. This paper investigates the sustainability credentials of DRT services using evidence from UK-based research. More specifically, six potential DRT market niches were identified, including those which offer potential commercial opportunities (e.g. airport surface access) and those that meet social needs (e.g. non-emergency hospital trips). Mode share of these DRT services, against car or bus travel, was simulated from mixed logit models within a panel data modelling framework estimated from survey data. The survey was conducted of over 400 respondents in urban (Rochdale, Manchester) and rural (Melton Mowbray, Leicestershire) areas.

Experience shows that it is particularly difficult to make DRT services financially viable. Of the DRT services investigated, those targeting airline or train passengers offer potential. However, they are in direct competition with the car, and so their success depends on the cost and availability of parking spaces. Some of the DRT schemes explored meet social needs, such as to access shopping facilities or hospitals, but they face cost challenges. In addition, institutional barriers for new DRT schemes need to be overcome in order to develop a sustainable local public transport system.

1. Introduction

The starting point for this paper is the nature of sustainability. Implicit in the sustainability concept is sustainable development, "to provide the needs of the present without compromising the needs of the future" as outlined in the Brundtland Report (World Commission on Environment and Development, 1987). Sustainability has evolved over the last 30 or so years from a marginal environmental concern to the mainstream in transport planning and practice. A useful framework to apply is to consider the three main elements or 'pillars' of sustainable development (UN General Assembly, 2005, p.11): economic development, social development and environmental protection.

Sustainable public transport has been defined as collective transport that in an on-going way meets personal travel needs and facilitates strong communities; supports economic development and equitable social participation; promotes environmental health; and has appropriate institutional arrangements and stakeholder involvement (including sufficient sustainable funding) to deliver (Stanley & Lucas, 2013). This paper has a focus on the public transport form of DRT (Demand Responsive Transport), which can be considered broadly similar to paratransit in the USA and defined as being "an intermediate form of public transport, somewhere between a regular service route that uses small low floor buses and variably routed highly personalised transport services offered by taxis" (Davison, Enoch, Ryley, Quddus, & Wang, 2012).

The aim of this paper is to investigate the local public transport solution of DRT using a sustainability approach. It is based on a survey conducted in 2012 of over 400 members of the public in the urban area of Rochdale in Greater Manchester and the rural district of Melton Mowbray in Leicestershire. The questionnaire included a stated preference experiment comparing bus or car with a new DRT service. Following an examination of six DRT service types ready for market development, model simulations based on the stated preference data were run for each service.

In the next section a literature review of DRT service development is provided. Section 3 covers market identification, a description of the primary survey data collection and model development. The penultimate section brings these methods together by presenting the six DRT services that have the greatest

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potential for market development in the UK. Finally, conclusions are presented.

2. A literature review of DRT service development

From an historic perspective, the concept of DRT has been around for some time with experimental flexi-route, dial-a-ride and community car and bus schemes appearing in the UK as early as the 1960's, as part of a series of rural transport experiments following the Jack Committee Report (Ministry of Transport, 1961, 1965). The concept was then refined, developed and expanded in the 1970's in the UK with a range of experimental services appearing (Nutley, 1988). Most schemes, however, were dependent on financial sponsorship from the Government and once the initial funding was removed they soon disappeared. Another wave of interest and financial sponsorship occurred in the 1980's, linked with the initial phases of bus deregulation in the UK. A further period of Governmental sponsorship arose again in the early years of the current century, linked with the availability of special rural bus grants, such as the Rural Bus Challenge. These schemes supported (amongst other services) the development of many new rural community-based transport initiatives promoted through bodies such as the Commission for Rural Communities (Jones, 2002). In this period there was also a rapid growth in dial-a-ride services, operating mainly in the larger urban centres, aimed to support the mobility needs of those who are unable to use conventional public transport. These have subsequently gradually expanded in the size and range of mobility services offered. Most schemes apply strict eligibility criteria to users and are essentially designed as supports for those with specific care needs. The numbers carried on these services can be substantial. For example in London in 2011 there were over 1.4 million passenger journeys by dial-a-ride services (Transport for London, 2012). Nearly all of the DRT services operating in the UK, with the Community Transport Association listing over 2000 separate schemes in England in 2012, perform either social or community roles and are very reliant on public funding (CTA, 2013). Similar development paths can also be observed elsewhere, particularly in the USA (Cervero, 1997).

In considering factors influencing the use of different DRT service types, it is instructive to note that Balcombe et al. (2004, p. 99) reported that "as yet, few operational results are available [relating to DRT]", and did not report any numerical results on how demand factors and DRT use are related − this, in perhaps the most comprehensive review of factors affecting public transport use. Of those studies subsequently that have looked at market potential, Enoch, Ison, Laws, and Zhang (2006) provided a qualitative evaluation of DRT in the rural county of Wiltshire, but offered no quantitative measures as to what (or where) the most suitable market niches may be. Looking at the area level, TCRP (1995) identified the elderly, mobility limited, and those on low incomes as potential markets, a typology which also emerged in TCRP (2004a; p.35), which noted that the typical DRT rider in rural areas and communities is likely to be "poor, elderly, or disabled". Also in North America, survey results reported in TCRP (2004b) revealed that DRT was most often used in small areas and difficult to serve locations, though there were also examples where DRT operated in large (e.g. rural) areas, or else offered services at times of low demand. Demand models to explore the effects of various socio-economic factors on the demand for DRT in Greater Manchester (Wang, Quddus, Enoch, Ryley, & Davison, 2013) have revealed that potential for DRT services is higher in areas with low population density and that experience high levels of area deprivation.

Looking to the future, some authors have put forward the proposition that the personalised basis for DRT operation can be used to create a wider base of public transport schemes (Jokinen, Sihvola, Hyytia, & Sulonen, 2011; Mulley & Nelson, 2009), including some postulating the potential for commercial operations in offering high quality services to niche markets. Few of these schemes have, however, come into successful operation in the UK, although the potential of exploiting new technologies for communication and operation may offer a way to drive down the costs of their operation in future and offer the possibility of profitability in restricted markets (Nelson, Wright, Masson, Ambrosino, & Naniopoulos, 2010).

Meanwhile a number of studies have also advocated the wider use of demand responsive transport systems to replace conventional bus networks (e.g. Ambrosino, Nelson, & Romananazzon, 2003; Enoch, Potter, Parkhurst, & Smith, 2004; Nelson et al., 2010). This advocacy has been based on the contention that new communication and dispatching technologies can greatly expand the responsiveness of public transport systems to user needs and be more widely attractive (Brake et al., 2004). These studies have focused mainly on how it is possible to improve the general supply of services in the core DRT market of serving social and community transport needs, especially coping with the travel needs in areas of low overall demand. Thus far, nearly all of the wider proposals for DRT adoption have been premised on services receiving continuing high levels of public financial support (Mulley & Nelson, 2009).

The growth of financial austerity in the public sector in the UK and elsewhere has meant that many of the dial-a-ride and community based DRT operations have had to look for new sources of finance to sustain their services. Ironically, these same financial pressures mean that County Councils are looking to reduce the costs of supporting conventional bus services and are advocating their replacement with increased DRT provision as a means to reduce costs (Juffs, 2010). In some areas, for example in Cambridgeshire and Leicestershire, the proposals are to remove the vast majority of financially supported conventional bus services in their rural areas and replace them with DRT services. There is no statutory compulsion in the UK requiring local authorities to financially support public transport services, nor any standards of provision to which they have to adhere. As a consequence, the move to more locally based DRT services is an attempt to preserve a minimum safety net of services while reducing their financial dependency. As they replace conventional bus services it is anticipated that these services will be open to the general public and regulated as more traditional public transport services.

An operator survey, conducted in 2011, shows the recent state of play regarding the delivery (i.e. the supply) of DRT systems in Great Britain (Davison, Enoch, Ryley, Quddus, & Wang, 2014). It recorded 369 existing DRT schemes from 59 organisations. However, the future of DRT seemed to be uncertain owing to a reduction in funding. This could mean that DRT schemes are withdrawn either nationally in response to demand or in specific areas in response to funding. An alternative could be that DRT schemes increase, either as investment in conventional public transport declines and the voluntary sector plays a growing role in transport provision, or as public transport mobility changes in response to an ageing population.

Finally, one other point to note is that the adoption of DRT services relates to institutional barriers, which in many ways represent the biggest challenge facing operators (Enoch et al., 2004). Bluntly, in the UK context at least DRT falls between the very different regimes governing buses and taxis with regards to everything from tax to insurance, driver licensing, operator licensing, and subsidy provision.

In summary, from the literature it would appear that from a sustainability perspective there are clear social benefits of DRT services, but it is a challenge to make them economically viable.

This paper investigates whether DRT can be economically viable as a local public transport mode within a broader sustainability framework.

3. Methods

3.1. Market identification

Initially, nine in-depth exploratory interviews with DRT sector experts and three focus groups, primarily consisting of DRT providers, were undertaken to better understand the current and potential demand for DRT. Using a marketing framework (adapting an Ansoff Matrix), developments at the micro, meso and macro levels were explored to determine the circumstances necessary for effective targeting of DRT potential market niches (reported in Davison et al., 2012). The current areas of success (market penetration) and opportunities for market development, product development and diversification for DRT services are summarised in Table 1, a matrix of product versus market. Market penetration is where there is an existing or strong product in an existing or strong market. Product development and market development concerns progress in one of these elements, whilst diversification requires progress in both product and market. The six market niches highlighted in italics are current or strong DRT markets, and are investigated in this paper. The applicability of the six market niches was discussed with DRT practitioners at a workshop, which has informed the development of the market niches.

3.2. A survey of the propensity to use DRT services

In order to determine the propensity to use DRT from the general population, the urban area of Rochdale in Greater Manchester and the rural district of Melton Mowbray in Leicestershire were chosen as the two UK survey locations. Both areas have had recent

Table 1
Areas of DRT market penetration and opportunities for market development, product development and diversification (also shown in Davison et al., 2012).

	Existing/strong products	New/less certain products
Existing/strong markets	**Market penetration** • *Rural, general public* • Without access to car & conventional public transport • Mobility impaired • Non-emergency patient transport • *Suburban & rural shopping, general public* • Educational establishment for students with special educational needs	**Product development** • Urban orbital, general public • *Airport access for passengers & employees* (Market penetration in USA/Europe) • *Rail station access for passengers* • *Workplaces outside urban core for employees* • *Hospitals & other destinations, for specialist needs*
New/less certain markets	**Market development** • Educational establishments for students in rural areas • Trip attractors: tourists in rural areas • Integrated DRT supply for the general public	**Diversification** • Suburban, general public (Product development in USA) • Entertainment venues in urban centres • Sport venues, ticket holders • Meeting/conference venues, employees • Services & goods to rural areas

Note: The six market niches highlighted in italics are investigated in this paper.

developments in DRT service provision. Rochdale has the highest DRT service provision for areas in Greater Manchester; Melton Mowbray is a rural area in which the local authority organisation, Leicestershire County Council, is considering the replacement of conventional bus services with DRT operations. The target was to obtain overall 200 face-to-face survey interviews in each locality. The survey contained questions about the socio-economic characteristics of respondents, respondents' travel behaviour, respondents' attitudes towards DRT type services and respondents' views about the circumstances under which they would consider using such services. These were followed by a stated preference experiment comparing bus or car (depending on whether the respondent was a car or bus user) on whether the respondent was a car or a bus user with a new DRT service. A quota sampling approach was employed, based on age structure and car use, to eliminate the strong potential influence of these two variables on the results.

Respondents were asked to state their preferences on a five point scale between two service options, based on a range of time and cost attributes for each mode. Those assigned to the car group were given the choice between a car journey described in terms of journey time, operating and parking cost, and time to walk from the parking site to the final destination. The alternative DRT was assumed to pick up at home and deliver to the door of the final destination and was described by its journey time, the fare charged and the potential wait time (difference between scheduled and actual time) at home for the service. For those in the bus group the choice was between a conventional bus journey and DRT described in terms of journey start time, journey time (each way), cost for return trip, and walking time to and from the destination. For both experiments, each respondent faced eight choice cards with the attributes described above. The cards were designed in accordance with the D-efficiency principle (Bliemer & Rose, 2011) using the software NGene.

There were 409 respondents (207 in the car group, 202 in the bus group), split between 209 in Rochdale and 200 in Melton Mowbray, and they faced a total of 3272 choice cards. An example of the bus versus DRT choice card is shown in Fig. 1. The 207 respondents in the car group always or frequently had access to a car. Of the 202 respondents in the bus group, 177 could not drive a car independently (156 with no driving licence, 21 a provisional licence) and 25 had a driving licence but seldom had access to a car. The definition of the two groups does not mean that their members exclusively used only that mode for travel. The car group did make use of buses while the bus group also occasionally travelled in cars. Overall, the bus group members used bus travel five times more than the car group. Household car ownership was 1.6 cars per household in the car group and only 0.45 in the bus group; both lived about the same distance from a bus stop; while the car group (£29,600 per annum) had twice the average household income of the bus group (£14,653 per annum). Over 50% of the car group were in employment with a sizeable element (27%) retired. In contrast, the bus group had about 25% in employment, 30% retired and high proportions of students, the unemployed, carers, and homemakers.

Attribute	Conventional Bus	DRT
Journey start time	Bus arrives 20 minutes late	You are picked up on time
Journey time (each way)	40 minutes	50 minutes
Cost for return trip	£4	£3
Walking time to and from the destination	15 minutes	You are delivered to the door

Note: "Bus arrives 20 minutes late" has been explained to respondents, in that they arrive for a scheduled service and must wait.

Fig. 1. An example of the bus vs. DRT choice card.

Table 2
RPL model with error components − Car sample N = 1617 (207 respondents, 8 choice cards each, 39 discards).

Variable	Coefficient	t-statistics
Random parameters in utility function		
Start time	−0.07346	−5.83***
Journey time	−0.06680	−7.12***
Non-random parameters in utility function		
Cost	−0.43127	−10.10***
Alternative specific constant for 'car'	2.29697	11.23***
Standard deviations of random parameters		
Start time	0.07346	5.83***
Journey time	0.06680	7.12***
Standard deviations of latent random effects		
Sigma E-car	1.63532	6.19***
Sigma E-DRT	3.32582	8.72***
Log likelihood	−1120.8	
AIC	1133.3	

*** significant at the 99% confidence level−random parameters with constrained triangular distribution, results obtained with 50 Halton replications.

Very few respondents within the survey had heard of DRT (although around half were aware of dial-a-ride) before, although most were favourable towards the DRT concept, particularly the pre-booking and door-to-door aspects.

3.3. The development of DRT potential usage simulation

Choice cards from the two experiments described above were analysed using a Random Parameters Logit (RPL) or Mixed Logit model with panel specification, taking therefore into consideration the repeated nature of the choices in our dataset, with each respondent facing eight choice cards, and the likely correlation among those. RPL relaxes a number of the restrictive assumptions of the basic logit configuration allowing to take into account of both observed and unobserved heterogeneity (e.g. Hensher & Greene, 2003; McFadden & Train, 2000). In our approach, another level of individual heterogeneity was added to the basic RPL by including error components, that allows for the detection of unobserved heterogeneity at the alternative specific level, in addition to random parameters (for a more detailed description of this extension to the RPL model and other examples of its application readers are referred to Beville & Kerr, 2009; Yao et al., 2014). Models considering error components are therefore particularly suitable for a dataset with repeated choice observations from the same individual (Campbell, Hutchinson, & Scarpa, 2008; Greene, 2012) and an RPL extended to error components outperformed a simple RPL for our study.

In order to produce simple simulations of mode choice share under a number of 'what if' situations, responses were recoded into a binomial choice such as Bus vs. DRT or Car vs. DRT, while cards where respondents selected the neutral option were removed (these were 39 for the car sample and 109 for the bus sample). Tables 2 and 3 report results of the RPL with error components application to the car and bus samples. In both specifications, the cost variable and the alternative specific constant were kept fixed, while the time parameters were considered to be random. Models were run with both normal and constrained triangular distributions for the random parameters. For the car sample, the constrained triangular outperformed the normal distribution and produced the expected signs, while the contrary was observed for the bus sample, where the normal distribution was then kept for the final models.[1]

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[1] For a discussion of choice of type of statistical distribution for time random parameters, readers are referred to Hess, Bierlaire, and Polak (2005).

Table 3
RPL with error components − Bus sample N = 1507 (202 respondents, 8 choice cards each, 109 discards).

Variable	Coefficient	t-statistics
Random parameters in utility function		
Start time	−0.07444	−6.57***
Journey time	−0.05630	−6.23***
Walking time at destination	−0.10214	−4.06***
Non random parameters in utility function		
Cost	−0.73153	−12.04***
Alternative specific constant for 'bus'	0.05654	0.19
Standard deviations of random parameters		
Start time	0.04027	2.38**
Journey time	0.05874	5.76***
Walking time at destination	0.11405	3.91***
Standard deviations of latent random effects		
Sigma E-Bus	2.97393	11.04***
Sigma E-DRT	0.35489	1.51
Log likelihood	−1046.7	
AIC	1352.2	

*** significant at the 99% confidence level, ** significant at the 95% confidence level−random parameters with normal distribution, results obtained with 50 Halton replications.

Table 2 shows that all coefficients are significant and display the expected sign. The model above does not contain the variable walking time at destination, which was detected as not significant, given the predictive nature of our exercise. The significant and positive sign associated with the alternative specific constant for car indicated that this option is chosen more frequently than the DRT option after controlling for the effects of the attributes. Error-components for both alternatives are significant, therefore indicating the presence of individual heterogeneity for both alternatives (at a greater extent for the DRT alternative given the larger coefficient) that was not captured by the random parameters solely.

Table 3 shows the results for the bus sample. As above, all coefficients apart from the Bus alternative specific constant are significant and display the expected sign. Additional individual heterogeneity could be detected for the Bus alternative only, given the significance of the relevant error component.

The coefficients presented above were used to run simulations (where the values of the explanatory variables were fixed in accordance to the service conditions depicted by the six scenarios) and obtained the relevant mode shares. The results are shown below for each DRT service. They represent the number of times one or the other mode would be chosen out of 100 trips to the relevant locations.

4. An exploration of the six DRT services

The following six DRT possible service variants were explored in order to assess their potential to offer a basis where DRT services could be sustainably developed in the future. These DRT services are (as shown in Table 1): a rural hopper service linking a number of rural settlements to a market town; a shopping service serving (normally) a large supermarket; an airport access service; a station access service designed mainly for commuters; an employment shuttle giving staff access to a large suburban employment centre; and a hospital access service. For each of the six DRT services, a description of the type of DRT service in the UK is provided, followed by a summary of model assumptions and a broad estimate of the likely level of potential from the model simulations. The simulations are exploratory and there are a number of extra characteristics stated in the descriptions (e.g.

luggage for airport trips, time constraints for employment) that could not be included.

4.1. Rural hopper

This type of service is found throughout rural areas and is normally designed as the direct replacement for a conventional bus service. Such areas are difficult to be satisfactorily served as the demands for public transport are low and geographically scattered, the distances to be travelled are reasonably high and vehicle occupancy is likely to be very low. The replacement of conventional bus services with DRT operation is often seen as a way of reducing public financial support. In many areas of operation, DRT replicates the characteristics of the bus service it replaces, in respect to the villages served such as the days of week of operation and the pickup points in the villages. The main difference is that users pre-book their journeys and hence determine which areas on that day will, and will not, be served, hence the route is variable in nature and generally longer than the fixed route it replaces. If no bookings are received on any day then the service will not operate. The objective is to increase load factors by eliminating empty running, but to compensate for this the service distance, and hence the operational cost, is increased because of the more circuitous route.

The likely market niche to be served consists mainly of those rural inhabitants without access to a car. This implies that the trips made have a strong possibility of not happening without the provision of the bus service, unless there is a high degree of casual lift-giving in the community. In most rural areas about 10% of the population live in non-car owning households, but it is the second and third person living in households where the car is used for the journey to work that comprises the major potential market. In most situations, from experience in the 'DRT for DRT' project, it is women that form the majority of users, with shopping and health trips comprising the main reasons for travel. DRT use for the journey to work tends to be low because the actual length of the journey cannot be defined in advanced as it will vary in form according to the number and location of the other users to be collected on route.

The DRT service would collect users at village bus stops and then drop them at central points in the market town. This means that those with walking difficulties will encounter problems in using this type of service. Door-to-door services for those with disabilities tend to be provided completely independently, often through social car schemes, usually using volunteer car drivers, such as in schemes run by the Royal Volunteer Service (WRVS) for older people in Great Britain.

The vehicle type mostly likely to be used will be minibuses, with a maximum of 16 seats, reflecting the necessity to negotiate small lanes and serve relatively low demands. Such services could be operated either by a commercial operator, or increasingly by community groups (sometimes now known as 'social enterprises') under contract to a local authority.

Given the nature of the areas served, user journey lengths are unlikely to exceed a length of about 1 hour. Given that vehicle speeds with pick-ups will average about 15/20 mph, then this means than the areas served may well be less than say 15 miles from village to town. This would imply average journey lengths of 7 or 8 miles each way. Inevitably, the service will be subsidised as it is unlikely to have sufficient demand to generate much revenue. DRT fares of about of £4/5 a return could be charged but if the service is run under public service vehicle rules and is open to all, then the elderly (probably the bulk of users) will be able to use their travel concessions with the operator having to claim compensation from local authorities or the government for such travel. If, as in many DRT operations, users have to become members of a club to use the services then national travel concessions may not apply and full

fares will be charged. This complication is just one of the more common manifestations of the 'institutional barriers to DRT operation' raised in the literature review earlier.

It is possible, by making a few assumptions, to look in more detail at the characteristics of the DRT operation:

1. Assume that the maximum journey length is 1 hour and equivalent to 20 miles. Depending on the location of the garaging of the vehicle then it might require to travel (say) 5 miles to position itself before starting the trip. This means the vehicle will travel 25 miles per trip.
2. Assume that the service collects passengers up to 5 miles from town, so giving average passenger journey length of 7/8 miles, probably taking about 30 min. Adding an average waiting time of 10 min and an egress time from the set stop in the market town of 10 min gives an overall trip time of 50 min.
3. The return DRT fare is run at three levels: £5.00, £8.00 and £11.00.

On the previous scheduled bus service, journeys would have been quicker (say) 20 min (no divergence off straight route, shorter dwell time at stops and faster between stops). Fares are set at £8 per journey. For the car alternative the journey time is likely to be lower at 15 min, with a total cost of £15. When these assumptions are put into our simulation model, we obtain a DRT mode share of 63%, 38% and 18% respectively for a return fare of £5, £8 and £11 respectively. For current car users, DRT is less attractive. For instance, when the DRT return fare is £5, the DRT mode share is 52%.

4.2. Shopping services

The shopping centres that could be served by such a DRT operation tend to be large stand-alone supermarkets and out-of-town shopping centres that, in general, are not very well linked into the public transport network. This means that people with limited, or no access, to the use of the car find it difficult to access these sites and have to often shop at more expensive locations. The typical DRT operation would be to pick up in a relatively socially deprived neighbourhood, and then go directly to the shopping centres.

Services are often offered at particular times and on certain days of the week, for example, only Tuesday and Friday mornings. Bookings are made in advance and with limited capacity the vehicle might operate more than one run on the day, according to demand. The service picks up and drops at the door. This means those with walking difficulties, and unable to use conventional bus services, can directly benefit from the services. It is generally older people that use the shopping DRT, as they like shopping together and see it as a social outing.

The biggest difficulty in operation seems to be the general lack of enough space on the vehicles for all of the shopping on the return trip. It is understood that on the Preston CTA (Community Transport Association service), a restriction of 4 bags per user was introduced on their 16-seater vehicles. Local authorities have tried to get large retailers to help fund these services because they obviously benefit from the extra spend the users generate at the affected stores. Few have become involved and see it as the public role to fund the services.

The main competitor to the shopping DRT would be a conventional bus service, and so we limit our analysis here to the bus sample. Most of the larger retail centres offer free and large-scale parking and as inevitably both DRT and buses have much longer journey times, car users are unlikely to be attracted. Journeys to the retail centres tend to be of the order of 3 or 4 miles and with low urban speeds and pick-ups DRT journey times could be of the order of 30 minutes. Fares are likely to be low and could be subsidised

down to say £4 per return trip. The return DRT fare is run at three levels: £4, £6 and £8. The bus alternative would be faster at 20 min but would have 5 min wait and 5 min access time. Fares on the bus have been set at £6 per trip.

On this basis, we obtain a DRT mode share of 69%, 53% and 37% for a return fare of £4, £6 and £8 respectively.

4.3. Airport access

When looking at airport access, there are two distinct airport types: large airports which are generally well served throughout the day by public transport services and so can have public transport modal split shares approaching 50%; and smaller airports where the role of the car predominates (see Enoch, 2012).

In addition, each airport comprises two separate user types — passengers and staff. Although passenger numbers are much higher (about 1000 jobs for every 1 million passengers) the staff make 440 trips to and from the airport per year (assuming they work 220 days) compared to a trip in and back per passenger. If the 20% of passengers that connect between flights are excluded, and we take account of the third of passengers who are dropped-off/picked-up, generating 4 not 2 access trips per air journey, then of all the access trips into a typical airport about 16% are made by staff and 84% by passengers.

This means that if DRT access services are going to be relevant then they should be aimed at areas with currently poor public transport links to the airports. These areas will tend to be away from main rail routes and airport bus services. Hence, it is perhaps no surprise that DRT passenger shuttles operate to and from a large number of airports across the USA — including many of the larger ones (Cervero, 1997).

The staff trips will tend to be short in nature and other than during unsociable hours, are likely to be well served by the network of public services that focus on the airport. It is only when (and/or where) there are no public transport services that a possible DRT operation could be worthwhile. In Manchester a local DRT service runs from Withenshawe into the airport early in the morning (before 5am) to carry early shift starters. Even here it is assumed that users will return later in the day on normal bus services. A similar employment-related DRT service (Allobus) serves Charles de Gaulle Airport in Paris.

A major deterrent to public transport use in airport access is the need to carry luggage. Interchanging between services and modes — rail to rail interchange (and even from parked car to terminal bus shuttles) — has been identified as one of the main deterrents from public transport use to access airports. It is in this area that direct door to terminal door DRT services can show a major advantage and there could be an accommodating driver to help.

The avoidance of car parking charges (as per the station access scenario, discussed later in the paper) because of the often longer length of car stay, can be considerable. The plentiful use of the more expensive taxi for airport access shows that there is a strong willingness to pay a premium among the airport users for a more personalised type of service.

Some points to consider are that:

1. The arrival time is an important element of the successful delivery of the DRT service. Reliability and dependability should be to the fore in delivery. Access to airports is only occasionally required, while for the station users it will be a daily occurrence. The user is therefore taking on more risk.
2. Car access to the airport will entail just two trips — in and back. For the DRT it will be four trips and so on sustainability grounds, the service should accommodate arriving passengers on the second leg, and departing ones on the third one, or to have a

load factor twice as high than the car to achieve equivalence in emissions per person. If differentials in fuel use are taken into account the load factor needs to be even higher.
3. When car parking capacity at the airport is filled, or (more likely) previous car parking land-take is used for other purposes by the airport as it expands, then there is an increasing incentive for the airport itself to sponsor DRT services. Given that most airports target public transport modal splits laid down as planning requirements, this will tend to reinforce this practice.
4. The pricing of DRT services will have to undercut present taxi fares to be commercially attractive and to compensate for the longer journey times and the sharing of the vehicle with others.

To obtain possible market share for DRT we have assumed:

1. Journey length 25 miles to airport
2. DRT takes 60 min; direct bus 55 min (this include 10 min access time) and by car 40 min.
3. Wait times are 10 min for both the DRT and bus.
4. Egress time just 5 min for DRT and 10 min for bus.
5. The return fare is set at £20 and £24 for the DRT, and £20 for the bus; the car faces £30 for operating costs and £20 for car parking giving a total of £50 per return trip.

On this basis, the DRT is estimated at a possible 22% (£24 fare) and 52% (£20 fare) of bus users. There was a difficulty with the simulation of car users, possibly due to the triangular distribution used for the random parameters, and no meaningful results were obtained when simulating a DRT fare of £24. However, when this was fixed at £35, the share of DRT was as high as 69%. When price was fixed at the same amount, £50 for both modes, the share of DRT was 15% and so this simulation did not produce meaningful results.

4.4. Station access

Increasing rail use in recent years has placed a growing pressure on the car parking capacity at many stations and a growing need to expand such facilities. In the interim rail companies have exploited the situation by gradually increasing car parking fees, with charges over £12/day common at many major stations. The avoidance of paying such fees on a daily basis is the rationale behind the idea of offering high quality DRT type services for commuters.

The issue of accommodating all of the needs of car access to the rail system has arisen as an issue in bids for rail franchises, as the capital required to build new car parking capacity (often on restricted sites) can be very high. The use of DRT type services to increase capacity can offer considerable savings to the train operating company and so make a DRT offering financially attractive.

Also, the market for such services is well heeled commuters who are more likely to be more concerned with issues of saving time, reliability and comfort and less concerned with financial issues per se. Given they are normally already paying considerable amount per year for the rail season ticket, access and parking costs may be seen as somewhat marginal. Avoiding the time needed to look for a parking space, sometimes located not directly in front of the station building, when the time budget is limited, with the risk of missing the preferred or booked rail service, may be the best selling point for DRT services.

A possible operating model for such services would depend upon:

1. Collecting pre-booked users and delivering them to the station in time to easily connect with a determined train service.

2. Using high quality, easy entry reliable vehicles — small to avoid too much divergence for pick-ups and to allow good average speeds.
3. Ability of users either to book a regular pick-up from a certain train or to book on the day pick-up from other services.
4. This implies that the operator should have the capability to have services available on a demand responsive basis to meet a range of user needs, especially on the return journey.
5. Charge a premium fare that is above car operating costs but is below the costs of car parking.
6. Overall the user must find the service as dependable and reliable as possible. Failures in the delivery of the service, and/or not having in place an adequate service recovery strategy would certainly lead quickly to a loss of users.

There are a number of current station access operations that offer elements of the above, but most run like conventional bus services with fixed routes and timetables and no pre-booking. Most of these services only cover nearby catchment areas where access journey times are short. The experience is that they are not attractive to most car commuters as they lack the personal and reliable service qualities required.

Whilst there are station access DRT feeder bus services operating around the world, relatively few of them operate in the UK — the best known probably being the Bicester Taxibus, which is operated by Chiltern Railways in order to relieve the pressure on car parking at the station (Enoch et al. 2004). Less well known is the County Connect service which links villages in Northamptonshire with Market Harborough Station in Leicestershire. An innovation that appears to be working well here is the use of a smartphone App which allows booking of a place on the service at 1 h's notice. This is being extensively used by those on the train coming home, to book a DRT service to meet them at the station.

The assumed characteristics of a DRT operation would be:

1. Average journey length to station 10 miles and at 30 mph takes 20 min.
2. Pick-up at door and drop-off at station means no access or egress time. Assume wait times low at 5 min around scheduled times.
3. Fares will be high to reflect quality and avoidance of car park charges - £10, £15 and £20 return.

The alternative would be car travel at 15 min journey time. Costs at 60p/mile for 10 miles each way gives £12 and car parking cost of £8/day giving £20 each day. With a return fare of £10, the DRT could offer a saving to users of £50 per week. On this basis, we obtain a DRT mode share of 59%, 38% and 21% for a return fare of £10, £15 and £20 respectively.

4.5. Employment shuttle

It is only credible to propose DRT operation shuttle serving an employment area when the area has poor or non-existent public transport. The most likely scenario would be to an outer suburban/peripheral business park with a large number of employees working in shifts, who tend to reside in approximately the same geographical area. To be successful, the service would need to offer door-to-door operation (or pick up very near home) and meet most shift work timings. From an operational viewpoint, it would be possible to have three times a day inward and three times a day outward operation with pre-booking, so that home trip destinations are known and allow prior route selection and planning.

Because of its suburban location, car access is likely to be good and car parking would normally be free and plentiful. The success of

the DRT service would be aided if companies restrict car parking, or the service is supported and operated as part of site travel plan.

For such a service it is probably best to use a number of small vehicles (8/10 seats). These will provide faster operations and allow shorter journey times than using larger vehicles, which will have to deliver higher numbers of workers and have longer routes to develop reasonable load factors. This means the operation will generate high vehicle mileage, fuel consumption and driver labour costs.

Given these characteristics it is probable that this type of operation would have to involve a commercial operator working under contract for the local authorities or the employers.

Fares should be set at a premium (especially if supporting unsocial hours) and vehicles need to be of a relatively high quality to directly compete with the standards of car use.

Some assumptions about the possible service characteristics:

1. The length of journeys could be quite long. Assume that they on average equate with average journey work distances of about 10 miles including diversions for pick-ups.
2. Average speeds of operation could be about 25 mph (short dwell times and fast vehicles) so giving average journey times 25 min. Say on average 5 min wait time for services but no access or egress times.
3. Fares should be around the car costs (£9.60) and so have been set at £8.00, £9.60 and £11.50.

The car is the only likely competitor and will be quicker, (say) an average journey time about 15 min. Assuming a direct distance of 8 miles then 60p/mile gives £9.60 operating costs for a return trip. There are likely to be no car parking charges at an employment centre, and no wait time, egress or access times. On this basis, we obtain a DRT mode share of 26%, 21% and 16% respectively for a return fare of £8.00, £9.60 and £11.50 respectively.

4.6. Hospital access

Once again, as for the case of airports, there is a distinct split between staff, patient and visitor as possible DRT users. Staff trips are likely to be short distance, frequent and could entail arriving and leaving at unsocial hours for shift work. In contrast, patient and visitor trips will in general be much longer and vary considerably in frequency. Some will be once-off entailing just to and from single trips, while others will come for a period on a daily or weekly basis for treatment.

Most hospital access DRTs in the UK are operated for outpatients rather than staff and visitors. The majority of users are the elderly, often unable to use conventional bus services or because of the location of the hospital, find it difficult to access home by public transport services.

Nearly all hospital DRT services are operated door to door and many are volunteer based using a range of vehicle. Many volunteer car schemes are purely designed for medical access while dial-a-ride minibuses appear to carry many medical trips. It is expected that as the number of elderly people increase, distances to hospital increases, and the UK National Health Service (NHS), especially the ambulance service, withdraws from the provision of non-emergency transport services, the dependency on DRT type services by those who do not have access to a car for medical purposes will dramatically increase. Use is not determined by matters of journey times or fare level, but by the social and physical imperatives to obtain medical advice and treatment.

Other factors influencing DRT demand would be:

1. The increasing financial pressure on the NHS means that car parking charges (which are already high for a free service) are likely to rise and push more people on to DRT type services.
2. Distances from car parks to hospitals are in some cases quite long − DRT can stop at the door, so avoiding lengthy walking.
3. Services are time sensitive as set by hospital appointments.

The relative merits of DRT against the use of the car can be assessed by setting up the following scenario. Assuming that the hospital is 10 miles away and that the DRT takes 60 min for the journey including pick-up time; has a 10 min wait time and takes 5 min to access and egress. The DRT return fare has been set at £12 and £16. For the car the assumptions are that journey time is 20 min, operating costs for a return trip are £12 and car parking costs £4.

Using these criteria, it is estimated that the DRT would carry about 18% and 9% of current car users at return fares of £12 and £16 respectively.

5. Discussion and conclusions

The paper has investigated the local public transport solution of DRT using a sustainability approach. The developed framework has focused on the development of a 'sustainable Demand Responsive Transport (DRT)', a service that is economically viable, meets social needs, and is environmentally friendly. The literature review highlighted the clear social benefits of DRT from community-related services such as dial-a-ride. Over the last 30 or so years in the UK, despite a range of Government interventions, it has been difficult to make DRT financially viable. This has not been helped by the current economic downturn, although it has meant that in some rural locations DRT is viewed as a potential alternative to fixed-route bus services.

The novel application of mixed logit models has generated interesting and informative simulations of the six proposed DRT services. It is acknowledged that the modelling effort could be developed further by examining specific bus services and building a network DRT model to examine the interactions between the level of demand and the service offered.

Of the DRT services investigated, those with a goal of delivering economic benefits have targeted airline or train passengers and individuals requiring access to employment sites. From the model simulations, the airport and station access DRT services generated a greater market share and offer more promise than the employment shuttle. However, the difficulty for all of these DRT market niches is that they are in direct competition with the car and so their success depends on the cost and availability of parking spaces. Given that around half of bus and taxi costs relate to drivers, it could the case that once driverless vehicles become available then the role of small vehicle public transport operations such as DRT might increase.

Social needs were mostly explored through the rural hopper, shopping and hospital access market niches. Here, the challenges related to the cost implications of longer than normal in-vehicle journey times caused by the dispersed populations served, and of the need for door-to-door as opposed to checkpoint to checkpoint services (necessary due to the predominantly elderly and/or mobility impaired user profile). At the same time, minimal revenue raising opportunities through higher fares are available in such situations due to the passengers being on low incomes. On the other hand, there may be scope for lowering costs through the use of social enterprise operators and in the hospital access case through obtaining revenue from alternative NHS budget sources. Interestingly, the hospital access service provides not only a social need element for patients and visitors but also a benefit to those in employment working at the hospital.

The environmental sustainability elements were more difficult to consider across the six DRT services, as differences between the market niches have been on economic and social grounds. Thus, there would not be much variation between the DRT vehicles utilised and associated load factors for the six services, and therefore also the environmental externalities generated. The level to which a vehicle is environmentally-friendly, whether car, bus or DRT, would vary within as well as across mode, and would be closely linked to the ability to purchase more efficient vehicles. Rather than examining transport modes in absolute levels of environmental sustainability (e.g. Department for Environment, Food and Rural Affairs, 2010; Litman & Burwell, 2006), DRT needs to be considered in relative terms to the competing alternatives (typically bus or car).

The question is whether we know enough about the alternatives and what constitutes 'success' in environmental sustainability, as well as the social and economic elements, albeit to a lesser extent. It is recommended that further research unpicks the meaning of these three pillars in a DRT context to provide a more rigorous and applicable sustainability appraisal, and develop thorough environmental and economic assessments. Institutional barriers can play a major role in how a DRT scheme is designed and how effective it will be. Therefore, in advance of introducing a new DRT scheme, it is necessary to determine the institutional barriers that need to be accommodated in order to develop a sustainable local public transport system.

Acknowledgements

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