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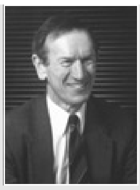

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Sustainable personal transport

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Transport by conventional means involves energy use, resource use and emission output which cannot be regarded as sustainable. Current transport is dominated by the car. This provides the flexible personal transport required by modern forms of cities, but is widely recognised as unsustainable. Current public transport is poorly accepted. Unfortunately, analysis also shows that current forms of public transport offer little, or even negative, benefit in sustainability over the car. A new transport system has been devised to meet the need for transport which is both effective and sustainable. ULTra (Urban Light Transport) is an innovative form of Personal Rapid Transit (PRT). In contrast to previous forms of public transport, there is no waiting, no stopping and no transfers within the system. In many circumstances, it can offer better transport than available by other means. ULTra has been designed to demanding sustainability requirements. Typically, ULTra provides a reduction by a factor of 3 in energy use and emissions output over existing forms of transport. ULTra is also complementary to existing forms of transport. By providing a network link to major rail or bus stations, it can improve the attraction of current transport services. Evaluations undertaken for the Department of Transport and supported by recent questionnaire studies, suggest that a comprehensive ULTra system could attract 25–30% of present car drivers. ULTra is now undergoing engineering development funded by the Department of Transport, Local Government and the Regions. Cardiff County Council has received funding commitments from the National Assembly of Wales which will lead to initial implementation of a system by 2005. It is believed that the system offers a new approach to public transport with a real prospect of significant gains in effectiveness and sustainability.

1. INTRODUCTION

As pointed out in Thomson's seminal book, *Great cities and their traffic*,[1] 'Cities are made up essentially of buildings *and* transport'. Modern life, and in particular modern cities, cannot exist without a supporting transport system.

At the turn of the last century, the capabilities offered by train and tram controlled the form of the city. Cities were strongly focused on a single city centre, and transport links concentrated on radial routes to and from the centre provided the key to the functioning of the city 100 years ago. But changes in culture, the economy, social relationships, beliefs, values and technology must also lead to changes in cities and their transport.

Today all cities are of multi-centre form. All cities have retail parks and industrial estates which are some distance from the old city centre. Such developments have only been possible because of the car. Indeed, the overriding force in urban development for the past 50 years has been the car. New forms of urban landscape have been created which can only be served effectively at present by car-based transport.

A second major change from Victorian times is the strong emphasis on achieving a satisfactory environment throughout the city, and the associated requirement for transport which is sustainable. It is widely recognised that transport is a dominant contributor to present urban environmental problems. There is an urgent need for transport solutions which are environmentally acceptable and match the transport needs of the new structure of the city.

In the UK, only 11% of all trips (excluding walk/bicycle) are taken by public transport, although this rises to 16% for commuting trips.[2] In the US, the proportion of public transport trips is only 3%. Passenger levels experienced in locations other than the centres of the largest cities demonstrate that current types of public transport are unable to meet the dispersed personal travel demand characteristic of current forms of multi-centre city. It is essentially impossible to satisfy these very diverse personal transport needs by versions of the old forms of corridor-based public transport which served Victorian cities so well.

Table 1 gives data from Brinkoff[3] on all cities in Europe with populations over a million. These data are based on official censuses and reflect the particular political boundaries defined by each of the cities. All of these cities will serve a total travelling population considerably larger than (typically double or more) the census population figure given. Note that London is more than double the size of any other European city and about seven times the size of the next largest UK city.

Figure 1 shows a census-based distribution of the 21·6 million people who live in UK cities over 100 000 in population as a function of city size. Again, these cities will have travel service areas probably double their census populations. It can be seen

City	Population
London	6 638 109
Berlin	3 425 759
Madrid	2 881 506
Rome	2 643 581
Paris	2 125 246
Hamburg	1 704 731
Vienna	1 609 631
Barcelona	1 505 581
Milan	1 300 977
Munich	1 205 923
Naples	1 002 619

Table 1. European cities with census populations over 1 million[3]

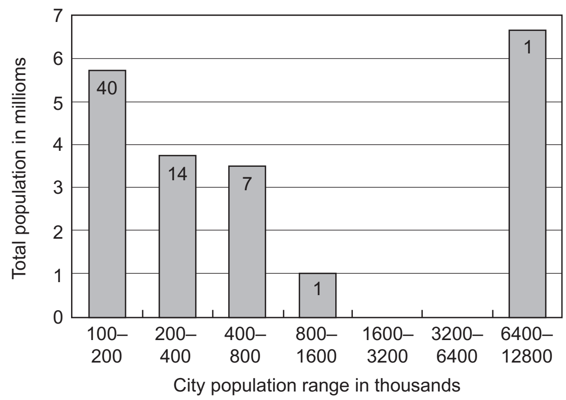

Fig. 1. UK population against size of city

that the great majority of the UK population live in cities and towns which are of modest scale.

In the largest cities such as New York or London, the older types of corridor-collective transport remain highly effective. Remarkably, public transport in New York accounts for just over one third of all public transport in the USA. The National Transport Statistics[2] show that 85% of transport to work in central London is undertaken by traditional public transport. For London as a whole, this figure reduces to 50%. However, as shown by the figures quoted above, London is highly atypical, on both a UK and a European basis. London transport requirements and experiences are anomalous. Transport solutions which meet London needs do not provide helpful guidance for national transport policy.

The dominant transport system in virtually all cities in the Western World is the car. Present-day forms of city are determined by the capability of the car to offer flexible anywhere-to-anywhere transport on demand. The National Travel Survey[4] shows that 83% of all commuting trips and 90% of business trips have only a single passenger in the car. The great majority of trips are undertaken by individuals travelling alone; thus, transport in collective groups is mismatched to the travel demands of a modern city. Collecting passengers together for mass transport leads to significant inefficiencies, especially for off-peak travel.

It is suggested that the principal problem of current approaches to transport lies in forcing transport solutions which were effective in meeting the problems of the nineteenth century to meet those of the twenty-first. The current requirement is for a flexible system which can respond effectively both to personal travel needs and to the crucial desire for sustainability.

2. PROBLEM DESCRIPTION

2.1. Overall considerations

In a modern city the local transport plan is recognised as a key element of the overall strategy to develop the city as a thriving and vibrant location for living and working. Cities now recognise that

(*a*) there is increasing concern over environmental and health issues, particularly emissions arising from vehicle sources
(*b*) supply of road space can no longer be matched to demand
(*c*) a shift to public transport should be encouraged
(*d*) economic and social regeneration require increased accessibility
(*e*) an integrated framework is needed to spread increases in trips over all modes of transport.

Thus cities seek to reduce the need to travel, especially by car, and in planning for the communities of the future look for sustainable development patterns and approaches which combat social exclusion.

The key feature of the transport strategy which emerges from this policy is one of integration, looking for all modes to contribute towards a transport system which is better both for the user and for those who are non-users. Thus sustainability arguments are now at the forefront of policy decisions. Unfortunately, existing forms of public transport, except in very particular circumstances, are mismatched to these policy needs.

2.2. Sustainability: comparative figures

Analysis of the sustainability of conventional transport reveals unexpected results. Fig. 2 is taken from data in Coffey and Lowson[5] and presents an estimate of typical use of primary energy by various modes of transport. This measure does not include life-cycle issues such as construction, etc. This would require separate accounting, but generally would not have a

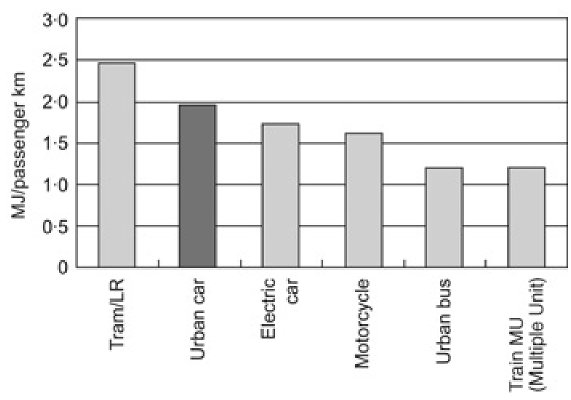

Fig. 2. Comparative energy use per passenger kilometre

major effect on relative assessments. The data are presented as average energy usage in megajoules divided by the number of passengers typically carried. Thus, for example the car data use the average 1·6 passenger per car level for UK car usage.

The key conclusion from Fig. 2 is that most forms of transport, whether public or private, have similar levels of energy use. It can also be seen that the most energy-effective forms of transport at present are buses and multiple unit trains. This is despite the bus having on average only a 20% passenger load factor.

Surprisingly, LRT figures show an average increase in energy use per passenger carried compared to cars. The figures were based on actual levels of energy use and passengers carried on the Newcastle and Manchester metros. Since these data could be controversial, a recalibration has recently been undertaken (this work will be published separately). The most recent UK data give a slightly worse energy use for LRT. Energy-use figures for transport modes over the whole of the USA have also been derived.[6] These have been found to be essentially equivalent to those given in Fig. 2. Thus it is believed that Fig. 2 continues to provides a good basis for comparison.

The modest differences between the various types of transport shown in Fig. 2 suggest that transfer from car to conventional forms of public transport is unlikely to provide major benefits in sustainability. This analysis suggests that major gains are only likely to arise from a new approach matched to personal travel requirements and explicitly designed for improved sustainability.

3. THE ULTra SOLUTION

3.1. Basic concept

ULTra offers a new approach to the transport problems of the twenty-first century. An initial description of the system was presented by Lowson.[7,8] A picture of the first prototype vehicle is shown in Fig. 3. ULTra has been designed to provide significant benefits for both the user and the non-user of the system. The concept has arisen from systematic analysis of the needs of modern transport. The analysis suggested that the optimum system should offer transport which

Fig. 3. Prototype vehicle

(*a*) is available on demand
(*b*) goes non-stop from start to destination
(*c*) is easily accessible and offers a full choice of destinations
(*d*) is strongly environmentally friendly
(*e*) is low cost
(*f*) has demonstrably high safety together with personal security
(*g*) integrates well with other forms of transport.

3.1.1. Available on demand. ULTra is an automatically controlled, personal taxi system of four-seat vehicles that run on their own segregated guideway network. Transport is available on demand at any of a series of stations distributed around the city like cab ranks. Passengers can have exceptionally high confidence in the ability of ULTra to convey them to their destinations without delay. The empty vehicle management system ensures that a vehicle is nearly always available at the cab-rank as required. Simulations of the full Cardiff application at peak periods have shown that nearly all passengers (>90%) would obtain immediate service from a waiting vehicle. Wait times in all applications studied to date are comfortably within the design target of 90% of all trips met within a minute.

3.1.2. Non stop. Because all stations are off-line, there is no need for vehicles to stop during their journey. Maximum speed has been limited to 40 kph (25 mph) to improve safety, but trip times are still reduced by a factor of between 2 and 3 compared to cars or buses in a congested city centre, or to light rail.

3.1.3. Accessible. ULTra provides car levels of flexibility and response to non-car owners, including the young and the old. In the city centre or under other conditions of congestion, ULTra provides a far better transport service than is available from the car, or any current form of public transport. A smart-card system permits any user to request direct transport to any other station on the network.

ULTra provides significantly increased accessibility for those with a wide range of disabilities.[9] There is no change in level between platform and vehicle floor and the vehicle door has been designed to facilitate entry. Appropriate lifts are provided for any high-level stations. The vehicle design can accommodate a wheelchair and companion, and wheelchairs can be turned around inside the vehicle. Following discussions with the mobility group of DTLR, special emphasis will be put on providing a system which meets the needs of the partially disabled (e.g. those who are partially sighted or have movement difficulties).

3.1.4. Environmentally sustainable. As discussed earlier in the paper, sustainability issues are critical for twenty-first century transport. ULTra offers massive reductions in energy, emissions output and resource usage compared to existing types. Because ULTra is electrically powered, there is zero emission in the city, but in any case overall energy and emissions are significantly reduced. The average system energy usage is 0·55 MJ per passenger km. This can be compared with figures of between 1·2 and 2·4 MJ shown for conventional forms of transport in Fig. 2. The typical benefit compared with cars exceeds a factor of 3. Importantly, in peak periods when cars (and buses) are restricted by congestion this benefit rises to a factor of around

8. This energy saving translates directly into reduced CO_2 emissions.

Resource usage is also considerably reduced because of the small scale of the system. Typically, resource usage is down by a factor of between 6 and 10. This provides significant benefits in cost as well as in sustainability.

There is now a consensus[10,11] that a sustainable level of energy use is 1·8 kW/h. This is based on an evaluation of the energy constraints of solar radiation on the earth's surface. Since ULTra uses 2 kW continuous power and will carry an average of 1·6 passengers, this means that, uniquely for powered transport, ULTra meets agreed sustainability criteria.

Because ULTra is of considerably lower power than other forms of transport there is a significant reduction in noise from the vehicles. Initial measurements during vehicle drive-by give 43 dBA at 2·5 m from the vehicle, with the noise being indistinguishable at 10 m against a background noise of 35 dBA.

3.1.5. Low cost. Designs undertaken by Arup show that infrastructure construction costs for the overhead guideway are less than for the equivalent footbridge, and for at-grade track less than the equivalent footpath. This is because the system loadings are less than the pedestrian crush loads required for footway design. This also means that the system can be run into buildings designed to existing floor loading codes with no structural change. The structural design and cost predictions have been confirmed in the build of the prototype system, described in section 5.1. Complete system cost also includes other infrastructure such as stations, together with vehicles, control systems and support such as ticketing and CCTV. These costs vary considerably with details of the application but typical costs for a complete system in a variety of applications have been around £5 million per km of guideway. A further discussion is given in section 5.

3.1.6. Safety and security. Safety is the prime design requirement for any transport system. ULTra is designed to exceed the best safety standards of modern public transport.[12] The detailed concept safety paper developed by Advanced Transport Systems Ltd has received a 'letter of no objection' from HM Rail Inspectorate. By providing an effective form of transport, which will encourage existing car users to use safer public transport, ULTra can be projected to provide significant benefits in terms of reducing fatalities, and serious or slight injuries. For the Cardiff application, analysis of existing statistics suggests that the benefit of the ULTra system would be a saving of around 50 accidents a year.

ULTra offers significant benefits in personal security. All trips are only undertaken with companions chosen by the traveller. During peak periods 90% of trips are available immediately on demand. Off-peak, this figure rises to 100% since vehicles can be assured to be available at all stations. Thus, the risks associated with waiting for public transport are virtually eliminated. Further, all stations will be under continuous coverage by CCTV, with direct links to the controller available from all vehicles and from all stations.

3.1.7. Integrated transport. ULTra is complementary to existing forms of transport. By providing a network link, with on-demand access, to major bus and rail stations or to park-and-ride sites, it will improve the attractiveness of these modes. Thus, ULTra can contribute to improved transportation both directly and by enhancing the appeal of other modes.

3.2. Other system features

3.2.1. Network. As noted above, ULTra runs on its own guideway network with off-line stations. Typically, the network is arranged in a series of loops serving key transport locations around the city. These loops are combined by merge/diverge sections. In combination with off-line stations this provides non-stop travel. Track is passive, and switching is achieved by in-vehicle steering using an electronic guidance system. Stations have spacings similar to bus stops. The network form allows the guideway to be one way, providing important benefits in cost and visual intrusion. A variety of application studies have been completed[13] and it is typically found that, to provide reasonable accessibility, individual tracks need to be spaced at around 500 m separation, or about every sixth side road.

System capacity is governed by allowable vehicle headways. These are in turn governed by acceptable emergency stopping distances. The vehicle will be equipped with seat belts, but it is prudent to design emergency deceleration profiles so that passengers remain on their seat even if they are not wearing their safety belt. Analysis supported by practical tests has shown that an acceptable stop from 25 mph (11·18 m/s) for an unrestrained passenger can be achieved in 10·2 m.[14] This permits a target mature headway of 1 s for the system, although initial operations are planned with margins of over a factor of 2 on this headway.

Operation of the network is based on a synchronous system with fixed 'slots' for each vehicle at the prescribed headways. This requires free routes to be identified from start to destination through all merges before launch of a trip from the station. Extensive simulations have been done to optimise the synchronous control process, including development of effective empty vehicle management algorithms. It is found that around 65% of the available line capacity can be used. However, in nearly all applications the critical factor on overall system capacity is found to be the stations rather than the line. Multi-berth stations permitting a throughput of up to 500 vehicles per hour have been devised.

3.2.2. Mass transit capability. ULTra is also a mass transit system. In its mature form at 1 s headway and an assumed 65% utilisation it will carry over 2300 vehicles per hour in each lane, each of which can take up to four people. This compares with typical figures of about 1000–1800 vehicles in a single lane of sideroad or motorway respectively, while a single ULTra lane occupies one-third of the ground space required by a conventional road. Typical passenger loads can be assumed the same as cars. This averages 1·6 but reduces in peak periods to about 1·4. For the Cardiff application, typical trip lengths are 1·3 km. Thus ULTra offers a peak passenger-carrying capability of over 2500 persons per hour per lane. As shown in Fig. 4, this single-lane capacity offers a useful margin over the average

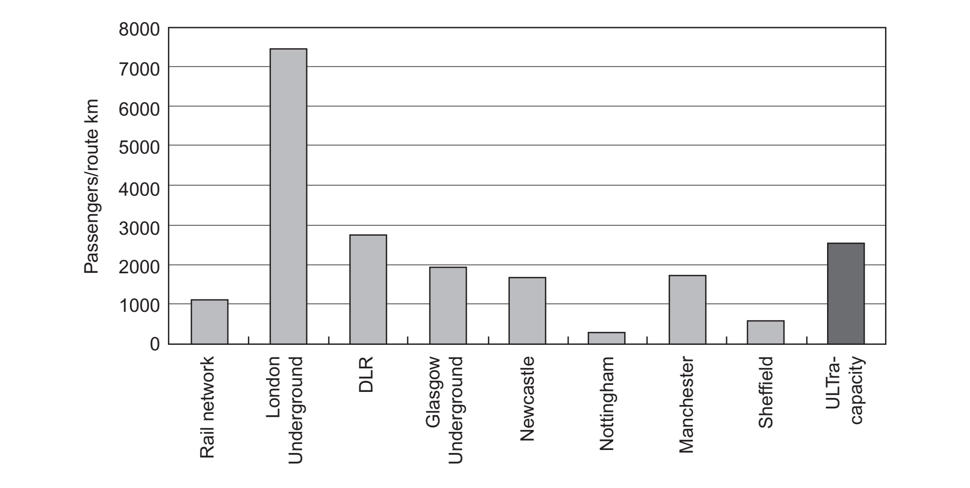

Fig. 4. Peak hour loading estimates

peak hour loads per route km experienced by current rail-based public transport systems, other than the most intensely used heavy rail or underground systems. These figures are based on data from the National Transport Statistics.[2] This capacity is not a 'crush load'; passengers in ULTra are always conveyed in comfort.

The system is not designed to meet the most intense mass transit needs of the largest city centres like London or New York, where only underground or equivalent systems can meet the requirement. However, ULTra provides an excellent and exceptionally cost-effective match to the needs of cities with populations below 2 million.

3.3. Implementation studies

A variety of implementation studies have been carried out both for DTLR and for local councils. Medus and Lowson[13] examined three key issues in the planning of ULTra networks: visual intrusion, severance (the restriction of movement of non-users) and the identification of possible routes.

It was found that guideway in the city centre normally requires to be elevated in order to avoid severance. In order to minimise visual intrusion the guideway system has an overhead depth of only 0·45 m and has been judged to be acceptable in initial questionnaire evaluations (see section 5.2 below). Strategies to minimise the visual intrusion of the system include use of at-grade track where possible and integration with existing street furniture. There will be cases where visual intrusion issues become important; however, this has not emerged as a critical issue in system evaluation studies to date.

The use of existing transport rights of way was shown to allow a significant proportion of track to be placed at grade in typical applications. This provides cost and visual intrusion benefits together with low added severance.

Direct comparison of the ULTra system was made with a previously proposed light rail system for south Bristol. A complete and detailed analysis allowed comparative figures to be developed. The approach was to examine in detail the consequences of substituting ULTra technology for LRT technology along exactly the same alignment.

In many cases, it was found that using ULTra technology simplified the integration process when compared to LRT technology. This is principally due to the reduced scale of the ULTra system compared to a traditional LRT system. In some areas, it was found that the ULTra track required elevation to avoid conflict with pedestrian and/or vehicular movements at ground level. Elevated track needs to provide 5·7 m clearance for free vehicular access. A number of short tunnels were also required for the same reason. The LRT system also had the same conflicts, but in most cases the LRT decision was to operate at street level, using signal-controlled intersections. ULTra did not utilise street running because of the use of automatic vehicles. The entire route was therefore systematically reconsidered for ULTra. Approximately 54% of the track could be placed at grade, 44% elevated and 2% underground. This amount of track at grade provides considerable benefits in cost and aesthetics with little added severance.

The full assessment of ULTra along the south Bristol LRT alignment enabled a financial and economic comparison to be made. The results of this are summarised in Table 2 and discussed below. Note that both sets of figures are based on the original estimates and would require upward revision if repeated today.

The LRT estimates are those reported in the study undertaken for Bristol City Council. The changes in infrastructure costs are principally due to the change in vehicle size. The LRT infrastructure needs to support 200 persons per 40 t vehicle, while ULTra infrastructure only needs to support four-person vehicles weighing less than 1 t. This provides significant cost savings. The reduced vehicle costs come from a combination of reduced size and the economies of larger production numbers. ULTra vehicles use well-developed automobile component technologies, which provide additional cost savings. ULTra also has lower predicted operating costs, because the vehicles have no drivers and very low energy costs.

Description	LRT	ULTra
Total capital cost (£M)	110·0	50·0
Infrastructure (£M)	70·0	27·0
Vehicles (£M)	30·0	13·0
Operating costs (£M)	5·4	3·9
Revenue (£M)	5·8	8·9
Trading profit (£M)	0·4	5·0

Table 2. Financial and economic comparison between ULTra and LRT

In comparison with the LRT, the overall number of passengers per year is projected to be higher with the ULTra system. This is because the ULTra system is projected to be more attractive to car drivers. In a number of other detail studies of modal split using cost-of-time models,[15] it has been found that transfer rates of 25–30% from the car can be achieved. This compares to 7–8% for the LRT. The reason ULTra is more attractive to car drivers is that waiting times are minimal—in most cases zero. This compares to 5–10 min for the LRT. Also journey times are typically half those of the LRT system.

Increased passengers/year provides greater revenue to the system and, combined with reduced operating costs, this means the expected trading profit for ULTra is £5·0 million per year compared to only £0·4 million per year for the LRT-based system. A £5·0 million trading profit means that ULTra has the opportunity to repay its capital costs whereas the LRT system would be dependent on a 100% capital grant from the Government. This was the reason why the south Bristol LRT system was not pursued.

A wide variety of other comparative studies have shown that ULTra is typically one-third the capital cost of the equivalent light rail system while also providing a significantly improved transportation service. In all cases, it has been found that the full cost of mature ULTra systems can be met from the fare box.

Generally, it has been found that ULTra can be fitted into the majority of urban environments. There is no problem with gradients of 15% or more, and the small scale of the system provides a variety of additional opportunities not available to larger forms of public transport. For example, as noted previously, the low loading of the ULTra guideway means that it can be routed directly through existing buildings with no requirement for any structural reinforcement.

A study recently undertaken for Cardiff County Council has shown that ULTra is particularly well-suited to application in Cardiff to link the existing city centre with new developments in the Bay area. Council policy envisages 50% of all trips to the Bay area being undertaken by public transport in the longer term. ULTra provides a valuable new capability to assist meeting this important policy objective. Because ULTra is complementary to other forms of public transport it can encourage modal choice in favour of public transport by providing a network link to serve public transport corridors. The study suggested that between 3% and 10% of existing car users could transfer to public transport once an ULTra link is available. Additional policy options on parking and traffic management to reduce car use would enhance this process.

The study demonstrated that ULTra can provide effective and environmentally attractive solutions to the transport needs of Cardiff city centre and the Bay area. The work showed that provision of an ULTra system in the centre and Bay areas will attract new users onto conventional public transport. A business analysis showed that the system is viable, without using arguments about secondary economic benefits.

However, an analysis using NATA (New Approach to Transport Assessment) guidelines was also completed using DETR recommendations for costs.[16] NATA is normally used for assessing of the benefits of roads and some assumptions are not necessarily appropriate for the ULTra system. Additional relevant recommendations are also given by the DETR.[17,18] An assessment was undertaken to provide an estimate of the value of the social benefits arising from implementation of the ULTra scheme in Cardiff. Significant benefits were projected from time savings, congestion relief and lessening of accidents together with a small benefit from energy saving. Additional health benefits were projected to accrue from reduction of emissions, but these are not normally included in a NATA assessment.

The overall ratio of benefit to cost was found to be 6·2. As noted, the scheme is also projected to make a commercial profit from operation.

4. OTHER SYSTEMS

There are many alternative approaches to future transport. In the author's view there are many other applications where novel ideas will offer more effective solutions to current transport problems than reworking of solutions which date back to the nineteenth century. ULTra is an example of a class of systems known as personal rapid transit (PRT). A wide variety of PRT systems have been examined since the 1960s. An exceptionally complete archive of current and older ideas, both PRT and other concepts, can be found at the innovative transportation technologies website run by J Schneider, http://faculty.washington.edu/~jbs/itrans. Many of these ideas are conceptual only, but systems which are currently under test and/or operation include the following.

(*a*) *Austrans* (http://www.aebishop.com/). This is a higher-speed (120 kph) system based on a modified rail technology with nine passenger vehicles.
(*b*) *Cybercars* (http://www.cybercars.org/). Several systems of automatically controlled cars have been demonstrated by INRIA in Versailles, France. These are intended to operate on conventional roads.
(*c*) *Cybertran* (http://www.cybertran.com/). This is intended for high-speed (up to 240 kph) longer-distance links offering 6–20 passenger cabs and off-line stations.
(*d*) *Morgantown PRT* (http://faculty.washington.edu/~jbs/itrans/morg.htm). This operates with fully automatic cabs on a dedicated guideway. It has been running successfully for 20 years and has now carried 50 million passengers without incident. Although called PRT, the cab capacity is 21, and it is in reality a collective-corridor system linking two parts of a University campus. Nevertheless, it does demonstrate that a fully automatic demand responsive system can be technically successful.
(*e*) *Park shuttle* (http://faculty.washington.edu/jbs/itrans/parkshut.htm). Ten passenger automatic buses are in passenger-carrying operation in Rotterdam and at Schipol airport on short routes (<1 km).
(*f*) *RUF* (http://www.ruf.dk/). This Danish system claims to offer a combination of high-speed and high-capacity transport in cities. RUF is a dual-mode solution in which vehicles can operate both automatically on track and under driver control off track. (It is proposed that ULTra will offer dual-mode capability at a later stage.)
(*g*) *Serpentine* (http://www.serpentine.ch/). This Swiss automatic system has been in limited passenger-carrying operation in a park in Lausanne. It consists of small low-

speed (15 kph) vehicles intended to operate on a dedicated part of a conventional road.

5. CURRENT PROJECT POSITION

5.1. Engineering tests

The ULTra system is currently undergoing prototype testing on two tracks: a simple track in Bristol and a more complex 1 km guideway with overhead sections in Cardiff. Initial results have been very encouraging. Vehicle and track have been successfully integrated and circuits of the guideway have been completed under fully automatic control. Fig. 3 shows the first prototype vehicle. Fig. 5 shows another vehicle on the Cardiff test track.

Substantial interest has been expressed in the system worldwide. In-depth studies, supported by the EC under the EDICT programme, have started on potential applications in four European cities, namely Cardiff, Eindhoven, Stockholm and Rome.

5.2. Results of an initial questionnaire survey

A survey was undertaken at a public exhibition of the prototype ULTra vehicle in Bristol in September 2001. Questionnaires were completed by 138 people, of whom 44% were male and 56% female. These results must be treated with caution since there is no operating experience on which the answers can be based. A selection of the questions put, together with the answers in percentage terms, are provided in Table 3.

The responses to questions 1 to 4 relate to the appearance of the system. No respondent felt that the vehicle appearance was poor; indeed, the majority thought the vehicles would look excellent. Response to the interior arrangements was also very positive although not as strongly positive as to the external appearance. The visual appearance of the elevated structure was generally regarded as good, with 29% rating it excellent. It is especially noteworthy that the response to the elevated track in Bristol gave a notably positive response, with no definitely negative responses and only 16% being unsure.

The answer to the fifth question suggests that ULTra would find ready acceptance as a transport mode. Comparing the answers to the fifth and sixth questions, it can be seen that the figures for the potential usage of ULTra are typically double the current usage of public transport in each of the first three categories. It appears that ULTra does offer a significantly more attractive form of public transport.

It will be seen from question 6 that 60% of the respondents either never or very occasionally use public transport. An analysis of their replies to question 5 ‘If an ULTra system were available I would probably use it’ is given in Table 4.

It is clear that users who are unwilling to use existing public transport would be very prepared to use ULTra. This questionnaire result closely matches results of the modal shift analysis previously undertaken for DETR, which suggested that between 25 and 30% of current car users could be attracted from car use onto an ULTra system.

Other questions covered fares. 62% of people were willing to pay a higher fare than the bus to use ULTra. The mean acceptable per-vehicle fare is £1·68. Since financial analyses for Cardiff were based on a fare of £1 per vehicle, this response is most encouraging.

5.3. Initial application

The National Assembly of Wales has approved a bid by Cardiff County Council which will allow the Council to support the first stage in the implementation of ULTra. The first stage will enable the system to be operated between the Bute Street railway station and the Inner Harbour, Wales Millennium Centre, National Assembly of Wales and County Hall. Progress to the link between the Bay and the City Centre will be progressed in parallel, possibly as a public/private partnership project. It is envisaged that vehicles could be operating in the Bay area by early 2005, with the City Centre being connected during 2005 if the partnership approach is successful. The estimated costs of the complete 7.7 km scheme are £39 million. Projected passenger levels are 5 million per year.

Fig. 5. Vehicle on Cardiff test track

Cardiff is particularly suited to the ULTra system because regeneration has totally changed the transportation requirements. The docks area, a former industrial zone, is now a prestigious business

Question	Response				
	Excellent: %	Good: %	Average: %	Poor: %	Awful: %
1. How do you feel the ULTra vehicles would look in Bristol?	53·6	37·0	8·0	0·0	0·0
2. How do you rate the internal arrangements of the ULTra cab?	31·9	58·0	5·8	0·7	0·0
3. How do you rate the visual appearance of the elevated track?	29·0	41·3	22·5	2·2	0·0
4. How do you feel about an ULTra elevated track in Bristol?	No problem: %	Probably OK: %	Not sure: %	Could be difficult: %	Definitely negative: %
	55·8	26·8	12·3	3·6	0·0
5. If an ULTra system were available I would probably use it	Several times a day: %	A few times a week: %	Several times a month: %	Very occasionally: %	Never: %
	23·2	44·9	21·7	8·7	1·5
6. I use public transport in Bristol	Every day: %	Twice a week: %	Once a week: %	Very occasionally: %	Never: %
	10·1	15·9	11·6	47·1	13·0

Table 3. Response to an initial questionnaire

Several times a day: %	A few times a week: %	Several times a month: %	Very occasionally: %	Never: %
25·6	37·8	24·4	12·2	0·0

Table 4. Potential use of ULTra by present non-public-transport users

and residential centre but one which is, at present, disconnected from the main city centre. Journeys between the two centres are already causing a variety of difficulties. Analysis shows that ULTra offers an effective solution, contributing to the objective of 50% of passenger trips to the Bay area being delivered by public transport in the medium term.

6. CONCLUSIONS

Meeting the challenge of providing sustainable mobility will require consideration of innovative solutions. Existing forms of public transport are mismatched to the form of present cities, which have been shaped by the capabilities of the car. There is a need to examine public transport which can better the convenience of the car, but at considerably reduced environmental impact.

The ULTra system has been conceived to meet this requirement. It can be regarded as an automatic personal taxi system, since it responds to individual demands, and passengers only share trips with chosen companions. This feature makes it uniquely attractive as a public transport system. Because ULTra retains many of the qualities of car-based transport—that is, privacy, immediate access, non-stop travel—it can appeal to users who are unwilling or unable to change to current modes of public transit. Transport choice models supported by questionnaire analysis suggest that 25–30% of current car users would be prepared to transfer to an ULTra system. It is also a system which is complementary to existing forms of public transport. By providing a network link, it can improve the attractiveness of existing modes.

Evaluations show that ULTra can be integrated into the urban environment at densities which provide a useful service but also minimise adverse impacts. In particular, the use of existing transport rights of way allows a significant proportion of track to be placed at grade, with little added severance, thereby providing cost and visual intrusion benefits. Studies show that ULTra can provide an immediate benefit for use on routes being considered for tram systems. It is projected to be financially viable. Evaluation of overall economic benefits following NATA principles indicates a benefit-to-cost ratio of 6·2.

The system has many novel features for urban transport that relate directly to improving the quality of urban life. It is currently undergoing engineering tests with a view to first application in Cardiff in 2005. Further details can be found at www.atsltd.co.uk.

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