A NEW APPROACH TO SUSTAINABLE TRANSPORT SYSTEMS

Martin V. Lowson
University of Bristol and Advanced Transport Systems Ltd
martin@atsltd.co.uk

ABSTRACT

Transport is recognised as a critical contributor to both world energy use and environmental issues. The major part of this problem is caused by the car. It is therefore often suggested that substantial transfer to conventional public transport would offer significant mitigation of the problem. Official data from the US DOE, and from parallel analysis in Europe, show that the difference in energy and emissions level between various existing forms of transport compared on a passenger mile basis is small. This indicates that there is little scope for sustainability benefits by transfer from car to conventional public transport.

This paper considers a new transport system ULTra (Urban Light Transport) centred on fully automated electric vehicles, meeting the need for urban transport which is both effective and sustainable. 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 urban transport than available by other means. 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 existing transport services.

ULTra has been designed to demanding sustainability requirements. Because the system is electrically powered, there is zero emission in the city, but overall energy and emissions are substantially less than for other forms of motorised transport. The average primary system energy usage is 0.55MJ per passenger km. The typical benefit compared with cars is over 75%. Importantly, in peak periods when cars (and buses) are restricted by congestion this benefit rises to 90%. Detail studies undertaken under the EC EDICT contract for an application in Cardiff show that a net saving of 41 million MJ pa by the projected transfer from current transport to an ULTra system.

The system has completed its first stage of engineering development funded by the UK Department for Transport on a 1 km test track in Cardiff Wales. This culminated in successful passenger trials for which permission to carry the public was received from HM Rail Inspectorate.

The work suggests that novel approaches to transport systems can offer a significant new opportunity for the reduction of energy use and emissions from transport in cities.

BACKGROUND

It is well known that the transport sector uses a significant proportion of the worlds energy supply. IEA data [1] shows that transport uses 26% of all energy produced world wide, and 58% of the worlds oil production. Transport is also responsible for around 50% of all airborne emissions. But equally it has been clear for many years that the world faces a major problem in urban transport. Congestion in major cities has reduced traffic speeds to a crawl. Congestion is also a major cause of excess energy use and emissions output by transport. Over the years there have been an extraordinarily large number of analyses of the problem. To date no solution has been found.

This position provided the rationale and impetus for the ULTra project. There appeared to have been no fundamental reassessment of the requirements of urban travel and how best to meet them. The objective set at the start of the work was "To define an urban transport system for the new century, meeting future needs for flexible personal transport, while being highly acceptable in an urban environment" This was a dual objective, to improve transport for both the user of the transport system and for the community.

All existing types of public transport are based on collective transport along corridors. This emerged to serve the city centres in Victorian times. For all existing public transport there is a need

1. to wait for transport going to the chosen destination to arrive at the stop
2. to stop at a series of intermediate stations of the way

These features significantly extend trip time, and limit the attraction of such public transport to potential passengers. While it is possible to increase the separation between stops to improve trip time this can only be done at the expense of longer walk times to the stations ie poorer accessibility.

Pucher and Lefèvre [2] note that (p201) "Urban decentralization has greatly increased travel distances and has reduced the importance of trips to and from the city center, which public transport serves best. Travel between and within suburbs, on the other hand, is growing fast in all American, Canadian and European Cities, and it is precisely this sort of trip pattern for which the car is a virtual necessity. Such suburban trips are usually too long for walking or cycling, and they do not generate high enough travel volumes in route corridors to make (current) public transport economically feasible. Thus suburbanization has sharply reinforced the trend towards ever greater use of and dependency on cars". As stated in a recent UK Government Consultation Paper "people use the car because they are denied real choice". They are denied real choice because the city has developed into a form which cannot be served effectively by existing types of public transport.

The difficulties faced by current collective public transport systems are fundamental. Further, as Pucher and Lefèvre point out (p203) "Huge subsidies have been injected into public transport in most countries, but those funds have not succeeded in producing high quality public transport networks, ... accessibility by public transport has not improved over the years in spite of huge investments and subsidies. Public transport policies have failed to create a satisfactory alternative to the automobile."

Another 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. As already noted, it is widely recognized that transport is a dominant contributor to present 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.

During the past 200 years the principal forms of surface transport have moved from canal to rail to car-road, and become more oriented towards personal travel. From the wider historical perspective it is clear that a new form of surface transport will come into use during the present century. A new form of public transport meeting current urban requirements, including proper emphasis on sustainability, appears overdue.

2 SUSTAINABILITY: COMPARATIVE FIGURES

Analysis of the sustainability of conventional transport reveals results which are not widely recognized. Table 1 is based directly on figures given in the DOE Transportation Data Energy Book [3] and gives a direct comparison of primary energy by various modes of transport.[1] As noted in that report

> *"Great care should be taken when comparing modal energy intensity data among modes. Because of the inherent differences between the transportation modes in the nature of services, routes available, and many additional factors, it is not possible to obtain truly comparable national energy intensities among modes. These figures are averages, and there is a great deal of variability even within a mode"*

While this caution is justified, there remains a need to make comparisons between modes. It must be accepted that there will be error margins, but comparative analysis is an essential element of developing an effective policy.

	MJ/paxkm	Passenger km	% passenger km
Personal			
Automobiles	2.38	4,039,929	68.8%
Personal Trucks	2.96	1,677,180	28.6%
Motor cycles	1.36	20,436	0.3%
Total Personal	2.55	5,737,544	97.7%
Bus			
Transit	3.15	34,119	0.6%
Intercity	0.74	55,832	1.0%
Total Bus	1.65	89,951	1.5%
Rail			
Intercity	2.01	8,510	0.1%
Transit	2.08	22,700	0.4%
Commuter	1.92	14,104	0.2%
Total Rail	2.02	45,314	0.8%
Total all public	1.77	135,265	2.3%
Public less intercity	2.56	70,923	1.2%
Total	2.53	5,872,810	100.0%

TABLE 1 Comparative energy use for US transport modes

[1] Conversion to ISO unit of MJ and km has been made by using 1 kJ = 0.9478BTU and 1 mile = 1.609 km. Where averages were not given in the report these have been calculated from the figures provided. The measure used, MJ/passenger km, does not include life cycle issues such as construction etc. This would require separate accounting, but generally would not have a major effect on relative assessments.

The key conclusion from Table 1 is that most forms of urban transport, whether public or private, have similar levels of energy use. This is a similar conclusion to that drawn from analysis of UK transport modes [4]. It is however surprising to note that DOE figures show that the average transit bus in the US uses more energy to deliver their transportation capability than even Personal Trucks. The DOE figures also show that scheduled air carriers only use 2.61 MJ/passenger km, only just above auto levels, and lower than personal trucks or transit buses.

As shown in Table 1, DOE figures demonstrate that the average energy use of public transport in the US over all urban modes at 2.56 is actually greater than the average use of energy by private modes at 2.55.

Mode	Primary Litres per seat 100% load factor	Typical Load factor	Primary Litres per passenger
Train (350 km/h)	22	0.33	67
Train (225 km/h)	12	0.33	35
Car (VW Passat)	8.8	0.32	28
Plane	20	0.7	39

Table 2: Primary Fuel Usage on a 600 km Journey, based on Kemp (2004)

This is parallel to results recently presented by Kemp [5], which gave the comparison of primary fuel usage by seat for a trip from London to Edinburgh for 100% load factor shown in the first column of Table 2. To determine the typical fuel use per passenger it is necessary to make a projection of load factor. According to Watkiss et al [6] average load factors are 33% for rail routes, and 65-75% for air routes. For the car a typical occupancy of 1.6 in a 5 seater car is assumed. Using these figures gives the results shown in the final column for primary litres of fuel used per passenger.

The key conclusion from the data shown in Tables 1 and 2 is that transfer from car to other current forms of transport modes cannot generate significant savings in energy use, and may even be negative. 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.

It is widely recognised that there is a need to decouple transport from energy and environmental problems. However it should also be recognised that this problem is also an opportunity. An approach which provides a new solution to the transport–environment conundrum will also provide a new business and industrial opportunity.

3. THE ULTRA SYSTEM

ULTra ("Urban Light Transport") is an automatic on-demand transport system that has been designed to be both cost-effective and environmentally friendly. It is in essence a personal automatic taxi. The system uses small four-seater electric vehicles automatically controlled on rubber tyres on a segregated guideway. The vehicles have a maximum speed of 25 mph

(40 kph). All stations are off-line, so that vehicles operate non-stop from origin to destination and maintain average speeds well above that of road traffic in an urban environment. Vehicles are available on electronic demand as the passenger arrives at a station. For most passengers there will already be a vehicle waiting, but if there is not the nearest empty vehicle will be called up automatically, so that average waiting times are very short.

Figure 1 ULTra Vehicles on the Cardiff test track

Vehicle Details
The prototype ULTra vehicle is illustrated in Figure 1. It is based on conventional automotive technologies, is electrically powered with four rubber tyred wheels. Principal parameters are given in the box. The vehicle is equipped with two permanent and two flip-down seats and has a level entry from the station. Thus, there is plenty of room for wheelchairs, shopping or pushchairs

ULTra Vehicle:
Principal Parameters

Gross Weight	800kg
Empty weight	400kg
Max speed	40kph
Length	3.7m
Width	1.45m
Height	1.6m
Passengers	4
Continuous power	2kW

Because the vehicle is light and only travels at low speed power requirements are low. As well as providing sustainability benefits this means that battery power with opportunity recharging is practicable. Tests have shown that it is practicable to recharge a 5 minute trip in 1 minute. Battery pack weight at 64kg is only 8% of gross weight, compared to many electric vehicles which require up to 50% of gross weight for batteries. This could makes electric vehicles practicable.

Questionnaire studies in Bristol and Cardiff [7] show that 98-99% of respondents believe the vehicle interior and exterior to be good or excellent.

Guideway Details
The track has been designed in conjunction with Arup. Details are given in the box. The track is low weight, since it is supporter a small scale vehicle. Indeed the loadings from the vehicle at 2000 Pa are less than the design loadings for building floors at 5000 Pa, meaning that the infrastructure can be inserted into any building built to modern codes without the need for structural alteration. Considerable attention was given to minimising visual intrusion during the design. Thus, it was very pleasing to find in questionnaire studies [7] that over 90% of people were very happy with the appearance of the track and less than 1% felt that it would be an unacceptable intrusion in their city.

ULTra Guideway Principal Parameters

Overhead or At-grade	
Width	2.1m
Overhead	
Depth	0.45m
Height above roadway	5.7m
Column spacing	18m

The cost of elevated construction is lower than an equivalent footbridge. The smaller-scale structure facilitates running the guideway as mostly single track in interconnected loops. The network is able to penetrate built-up areas more closely than the larger-scale public transport. Adding additional stations, to improve system accessibility, reducing walking distances to the service does not affect speed or capacity of the other parts of the system. Stations can be at grade or elevated. Stations on the ground are low cost to build, and can be placed at a small spacing to reduce passengers' walking time, improving accessibility without loss of speed.

From the point of view of the passenger the ULTra system offers significant benefits

- Very little waiting
- Non stop travel giving short trip times
- Personal / small group transport
- Exceptionally quiet
- Emissions free transport allows direct use within buildings

Mass Transit Capability

	Seats	Frequency	Seats per hour
Bus	50	5 mins	600
Light Railo	200	10 mins	1200
ULTra	4	3 secs	4800

Table 3 Analysis of Theoretical Capacity

It is ironic that, although 97% of all trips in the US and around 85% of all trips in Europe are in fact done by small vehicles, ie cars, conventional wisdom is that effective public transport must require some super scale vehicle for "mass transit". Except in the very largest cities this view is false. ULTra, although a small vehicle, provides a transit system with a capacity equal to that of buses or light rail. A simple model of this is given in Table 3.

Table 3 gives data based on the design standard at the initial installation. In its mature form at 1 second headway and an assumed 65% utilisation ULTra will carry over 2,300 vehicles per hour in each lane, each of which can take up to four people. This compares with typical figures of about 1000-2000 vehicles in a single lane of side road or motorway respectively, while a single ULTra lane occupies 1/3rd 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 typical Cardiff application average trip lengths are 1.3 km. Thus ULTra offers a peak practical passenger carrying capability of over 2,500 per hour per lane.

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 1 million. For larger cities the system can provide local capabilities and a network link to larger mass transit, considerably improving the attraction of the conventional modes.

ULTra has completed prototype system testing on a 1 km track in Cardiff under contract from the UK Department for Transport. This culminated in very successful passenger trials for which permission to carry the public on the system was received from the Rail Inspectorate. Many Local Authorities and Airports have expressed serious interest in the system and negotiations leading to the first application are in progress.

4. SUSTAINABILITY

As noted in Section 2 of this paper sustainability issues are critical for 21st century transport. Analysis, shown earlier in Table 1, suggested that most forms of urban transport, public or private offered similar levels of energy use and emissions output. Because ULTra is electrically powered there is zero emission in the city, but in any case overall energy and emissions are significantly reduced. Based on a continuous power usage of 2 kW, an average speed of 10m/s an average passenger load of 1.4 and an empty vehicle overhead of 40%, the average primary system energy usage is 0.55 MJ per passenger km. This can be compared with figures between 1.7 and 3.2 shown for conventional forms of transport in Table 1. The typical benefit compared with cars is over 75%. Importantly, in peak periods when cars (and buses) are restricted by congestion this benefit rises to 90%.

This energy saving translates directly into reduced CO2 emissions. ULTra meets the recommendation of the Intergovernmental Panel on Climate Change, that the CO2 emission should be reduced by at least 60%. This target is set for 2050. ULTra is able to exceed this target in the present decade.

The system emits no exhaust pollutants, and in attracting travellers from car it saves carbon monoxide, hydrocarbons, nitrogen oxides and particulates from being emitted into the atmosphere.

Resource usage is also considerably reduced because of the small scale of the system. Because each vehicle is reused many times during the day, case study evaluations show that each 400 kg empty weight vehicle does the job of about 30 to 40 cars of 1000 kg each. Infrastructure costs, and resource usage are down by a factor of between six and ten compared to roads or freeways.

Because ULTra is of considerably lower power than other forms of transport and driven by electric motors that are virtually silent, there is a significant reduction in noise from the vehicles. Initial measurements during vehicle drive-by at 6m/s give 43dBA at 2.5m from a single vehicle, with the noise being indistinguishable at 10m against a background noise of 35dBA. At the full operating speed noise levels are projected to be around 10dBA higher. Even so, it is clear that the system will be inaudible against the background in most urban situations. One advantage of the system is that, with such low noise levels, zero emissions and small-scale infrastructure, it is practicable to place the guideway and stations within buildings where it is convenient to do so.

5. SUSTAINABILITY: CARDIFF CASE STUDY

Substantial interest has been expressed in the system worldwide. In-depth studies, supported by the EC under the EDICT program, have been preformed on potential applications in four European locations: Cardiff, Almelo (Holland), Huddinge (Sweden) and Ciampino (Italy). Partner teams in each city are examining the benefits of PRT systems to deliver new solutions to specific problems in each application. Bly [8] presented the results of a detailed evaluation of an application in Cardiff. This covered all aspects of the system, but the environmental aspects are of special relevance here.

The ULTra system in Cardiff is projected to carry 5.67 passengers per year, attracting 8% of present car commuters to the Bay Area to use the combination of rail or bus into the centre and then onward by ULTra. An estimate of the net saving in energy can be made from the reduction in car-kms travelled, less the energy used by the ULTra system itself. It is assumed that transfer from other public modes has no effect on energy use, since these services will still be operated. The estimate is that there will be a reduction of 12 MkWh in the energy used by car in 2006, an increase of 1.1 MkWh in the energy used by ULTra, for a net saving of 11 MkWh or 41 million MJ. the equivalent of 3 million litres of fuel per year, with parallel savings in emissions. It is estimated that, over the base year 2006, installation of the ULTra system reduces total emissions in central Cardiff by 45 tonnes of carbon monoxide, 3.6 tonnes of volatile organic compounds (VOCs, or hydrocarbons), 5.7 tonnes of nitrogen oxides (NO_x) and 0.30 tonnes of particulates or black smoke. The saving in energy also corresponds to a reduction in the greenhouse gas carbon dioxide (CO_2) of 3750 tonnes.

An assessment of a public scheme needs to include the other social benefits accruing to both users and non-users of the system. These cannot all be monetarised, but they are important because they may contribute to the local policy objectives. Techniques for making these estimates have been formalised by the UK Department for Transport. The savings in travel time, car operating cost, reduction in congestion, and in accident and injury may be summed to give a monetarised benefit as a 30-year NPV, which in turn gives the social cost benefit. The net rate of return on the investment is 27% pa, greatly exceeding the required justification for public projects, while the NPV total benefit to cost ratio over 30 years is 5.2 at 3.5% discount, and 3.9 at 6%.

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. DOE figures show that public transit currently provides zero energy gain over private modes. There is a need to examine public transport which can equal or 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 - 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 extended ULTra system. It is also a system that is complementary to existing forms of public transport. By providing a network link, it can improve the attractiveness of existing modes.

ULTra offers a system with around one quarter of the energy use of the car and similar gains over conventional public transport, combined with zero emission in the city. Detail studies undertaken under the EC EDICT contract for an application in Cardiff show that a net saving of 41 million MJ pa by the projected transfer from current car transport to an ULTra system.

The system has many novel features for urban transport that relate directly to improving the quality of urban life for both the users and the non-users of the system. The system has completed its first stage of engineering development funded by the UK Department for Transport on a 1 km test track in Cardiff Wales. It is currently undergoing final engineering development with a view to first application in 2006. Further details can be found at www.atsltd.co.uk.

ACKNOWLEDGEMENTS

The ULTra project has been supported by the Engineering and Physical Sciences Research Council, Rees Jeffreys Road Fund, Department of Trade and Industry, Department for Transport, National Endowment for Science Technology and the Arts, the Altran Foundation, Cardiff County Council, and the European Community; also by the University of Bristol, Arup, AMEC and Corus. This support has been fundamental in getting the project to its present stage. ULTra is a registered trademark.

REFERENCES

1. IEA Key World Energy Statistics
2. Pucher, J., and Lefèvre, C. "The Urban Transport Crisis in Europe and North America". Macmillan 1996
3. Davis S.C "Transportation Energy Data Book Edition 21" US Department of Energy ORNL-6966 Sep 2001
4. Coffey, R., and Lowson, M.V. "A comparative analysis of energy consumption and emission of urban transport systems", in *"Urban Transport and the Environment II"*, Eds. Baldasano Recio and Sucharov, Computational Mechanics Publications, Southampton ISBN 1-85312-451-6 1996
5. Kemp, R., "Environmental Impact of High Speed Rail" Paper at I Mech E meeting on High Speed Rail Developments April 2004
6. Watkiss, P., Jones, R., Rhodes, D., Hardy, A., Handley, C., Walker, C., "A Comparative Study of the Environmental Effects of Rail and Short-haul Air Travel" Report for Commission for Integrated Transport ED50021 September 2001
7. Lowson, M.V., "A New Approach to Effective and Sustainable Urban Transport" Transportation Research Board: Paper 03-2140 2003
8. Bly, P., "Cardiff Site Assessment Report" EDICT project EVK4-CT-2001-00058 Report D 6-2 April 2004