Determining Appropriate Public Transport System for a City

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Car ownership is growing in cities. This is leading to more congestion and environmental damage. To attract motorists from their cars it is necessary to improve the quality of public transport. In many cities this means building new systems. A variety of technologies are available, so decisions must be made to determine which is the most appropriate for a particular city. It is argued that the building of new transport systems can increase patronage and that cities in continental Europe have a much more positive approach to public transport than cities in Britain. There is scope for the transfer of knowledge about such systems from countries such as France and Germany to cities in Britain. As part of this process it is important to consider how decisions about the type of transport technology have been made. The methodology for the use of expert systems, a form of artificial intelligence, is described. The methodology is used to encapsulate the knowledge of experts in cities in continental Europe and to transfer it to cities in Britain, where decisions are being made about the type of public transport technology to that should be adopted.

Increasing car ownership is causing increasing congestion and environmental damage in cities. Greater car ownership leads to more car use and so reduces demand for public transport. In the long run as public transport revenue decreases the quality of service deteriorates and the downward spiral of public transport accelerates. Furthermore the shift from the use of public transport to the use of a car increases the rate of suburbanization, which in turn tends to favor car use and make public transport even more difficult to operate financially.

It would be perfectly possible to let this process continue, so that all urban mobility is offered by the car and public transport finally disappears. However there are a number of reasons why this is a bad idea:

1. It is impossible to provide all the road capacity to meet the demand, and so congestion occurs; this is inefficient because it wastes time and causes uncertainty in planning journeys.
2. Cars produce a variety of pollutants; although technical innovation can reduce emittants significantly in new cars, there are still many older cars on the road, and these pollute.
3. Some people will never be able to drive, for example, some of the young and the old, so there is a need to provide for their mobility. Some poor people cannot afford to buy or run a car, and lack of a suitable alternative can add to their deprivation, possibly leading to social problems.

Growing awareness of these issues has led to a recognition of the need to encourage urban public transport. This means not only that existing systems must be improved but also in some cases that new systems must be introduced. However such systems are expensive, can take a long time to build, and will have an impact on the city. Consequently care needs to be taken in making such decisions. It is possible to use computer models to assess the impacts of various possible systems, but such models require the specification of the systems to be tested. There is a need for a methodology to generate the systems to be evaluated. This procedure is a mixture of quantitative techniques and judgment in a political framework. This paper is concerned with the development of such a methodology by using techniques from the field of artificial intelligence.

In the next section the need for better urban public transport and the range of options are discussed. The issues involved in determining the appropriate form of public transport system are also discussed. Then the potential for using artificial intelligence techniques to address this issue is considered, and work on a project that uses such methods is reported.

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NEED FOR BETTER PUBLIC TRANSPORT

Some of the problems caused by increasing levels of car ownership and the need for better public transport have been discussed. The two issues are complementary: there is a need to make car use less attractive and public transport more attractive. Some motorists at least are willing to forsake the car. The *Lex Report on Motoring* (*1*) shows that 35 percent of motorists agree with the view, "I would use my car less if public transport were better." In London, where congestion is the worst in Britain, 49 percent agreed with the statement. Currently there is considerable interest in the potential for road pricing. This means charging drivers for the use of the road so that they are paying an amount that better reflects the costs that they impose in terms of congestion as well as environmental damage. It also puts the charge for car travel on a similar basis to that for public transport, because once a person has bought a car, the marginal cost of making a journey tends to be lower than the equivalent cost of making a journey by public transport, where there are usually no capital costs for the user, so that the marginal cost is higher. In Britain the Department of Transport has commissioned a $4.5 million research project into road pricing in London, probably involving some form of electronic charging system (*2*).

If people are to be discouraged from using their cars the alternative modes must not only be attractive but must also have sufficient capacity. In many cities this means investing in new systems, because the existing public transport is provided by bus and suburban heavy rail only. However buses suffer from the same congestion caused by cars, and suburban heavy rail tends to have poor spatial coverage because it is expensive to build and requires heavy flows of at least 10,000 passengers per hour to justify the investment (*3*).

Table 1 shows the characteristics of various urban public transport modes. The mode that can be introduced in the cheapest and quickest manner is the standard bus running in traffic because it needs little new infrastructure. However it is subject to delays because of congestion and tends to have a poor image and so does not attract motorists from their cars. A guided bus system, such as that in Essen, Germany, or Adelaide, Australia, permits high-speed running along radial corridors, thereby avoiding congestion, but it retains the flexibility of covering the suburbs by using ordinary roads. It is debatable whether such systems can overcome the prejudice against buses. Many cities in continental Europe have trams, which can provide efficient movement of passengers to the city center. However, running on streets means that trams are delayed by cars, so in some cities, such as Vienna and Prague, tram routes are being removed as metro lines are being opened. Segregated light rail is really a modern form of tram, but it runs in separate corridors. Such systems carry large numbers of people at high speeds. The disadvantage is the need to find land on which to build the system. In some places, such as Newcastle-upon-Tyne in the north of England, the system goes underground in the city center. This can increase the cost substantially, but it may be necessary to provide sufficient penetration of the city center to attract car users. Higher capacity can be provided by a full-scale metro running underground. This system completely segregates the passenger from the surface, so that road congestion has no effect. The disadvantages are the high capital cost and the length of time it takes to build the system. These factors tend to mean that areal coverage is poor, particularly when a new system is built. Suburban rail can also convey large numbers along corridors, but penetration into the city center is usually poor.

In practice a large city needs a combination of public transport modes, with buses in the suburbs where their flexibility can be exploited, a high-capacity rail-based system along the radial corridors, and an efficient distributor system in the city center.

It was argued above that cities need good public transport to attract people from their cars and that this may require a major investment in new infrastructure. A variety of technologies is available, and so decisions must be made on what is appropriate for a particular city. British cities need investment in public transport if the damaging effects of cars are going to be limited. The following are two key questions: How does one decide what is the appropriate form of public transport technology that should be adopted, and how can Britain draw on the positive experiences in cities in continental Europe? These questions are addressed in the next two sections.

DETERMINING TYPE OF PUBLIC TRANSPORT SYSTEM

If it is accepted that there is a need to invest in new public transport systems, it is necessary to be able to determine what type of system is appropriate. Many factors are important. Some features of each city are unique, but there are many common factors. A variety of modeling techniques is available to assess the impact of a new system characterized by its capacity, speed, route pattern, and so on. These techniques can be used as part of an evaluation framework. What is lacking is a systematic way of generating the alternatives to be considered. In fact such decisions are based on experience and judgment as much as formal modeling techniques,

TABLE 1 Costs and Other Characteristics of Public Transport Modes

	Maximum capacity (1000pph/direction)	Commercial speed (km/h)	Operating cost per km per annum ($ x 10^6)	Capital cost for twin lanes ($ x 10^6)	Total cost over 30 year life ($ x 10^6)	Cost per passenger-km in cents
Standard bus in traffic	7.2 - 9.6	15	0.5 - 0.7	0.4 - 0.5	5.7 - 8.1	0.8 - 0.9
Guided bus	19 - 29	15 - 25	1.2 - 2.1	1.1 - 2.6	14.7 - 26.7	0.8 - 0.9
Tram (street running)	9 - 25	15 - 25	0.3 - 0.9	6.7 - 13.3	10.7 - 23.3	0.7 - 1.9
Light rail (segregated)	9 - 25	30 - 40	0.3 - 0.7	3.3 - 6.7	6.7 - 14.0	0.5 - 1.1
Metro (underground)	35 - 70	30 - 40	0.7 - 1.3	20.0 - 43.0	26.7 - 60.0	0.5 - 1.3

Note:

It is assumed that system is operating at 50 per cent capacity for 18 hours a day, 363 days a year over 30 years. The total operating costs over the 30 year life have been annualised at 8 per cent a year. The figures have been converted from £ to $ at an exchange rate of £1 = $1.50

Source:

Modified from a table in a review of people mover systems and their potential roles in cities, by B H North, published in the Proceedings of the Institution of Civil Engineers. Transportation, Volume 100, pp 95-110 so to use the lessons from one city in another it is necessary to find a method of encapsulating the relevant knowledge to transfer it from one city to another.

Before considering this matter further, it is relevant to examine some examples of decisions made on this topic to understand the type of knowledge to be transferred.

Tyne and Wear Metro and Docklands Light Railway

The Tyne and Wear Metro in Newcastle-upon-Tyne in northern England was opened in 1980. It was planned and operated by the Tyne and Wear Passenger Transport Executive under the directorship of T. Ridley. The Docklands Light Railway was opened in 1987 as part of the regeneration scheme in London Docklands. It was planned and operated by London Underground Ltd., the managing director of which was also T. Ridley. During the time between his work on these two systems he was also responsible for the development of the Hong Kong Mass Transit Railway, so he has considerable experience in making the type of decision being discussed here. Ridley (T. Ridley, unpublished data) argues that the following factors are required to get a new public transport system built in British cities:

1. A local political consensus, that is, agreement between all shades of political opinion;
2. A good working relationship between central and local governments at various levels (technical, managerial and political);
3. A consultant's report to give credibility to the project and to focus attention on the complexities of the issues; and
4. Luck.

Clearly, this is not quite the same issue as deciding between different types of technology, but it is illustrative of the factors that influence decisions in this field.

Shidami Human Science Town

An example in which a choice between a guided busway and a rail-based system was made was in Shidami Human Science Town to the northeast of Nagoya, Japan (*4*). A high-quality public transport link to the city center of Nagoya, about 12 km away, was required. In this case the guided busway was chosen for several reasons.

1. Duel-mode vehicles could have direct access to both the suburbs and the city center in the conventional bus mode and use the elevated section linking Shidami to Nagoya to provide a high-speed, frequent service in the guided busway mode,
2. Construction costs for the guided busway were lower than those for a rail-based system, and
3. The proposed system provided sufficient capacity initially but could be upgraded to a rail-based system later as demand grew.

In a later section of this paper the decisions about the appropriate scheme for Manchester, England, will be discussed. In that case light rail was chosen over guided bus. In Manchester and Shidami the final choice was between a light-rail system and a guided busway, and different solutions were found to be appropriate. This is a crucial point because the type of public transport system built must be appropriate to the problem being addressed. Wachs (*5*) argues that investment in rail transit in Los Angeles is taking funds away from local bus services, which are already overcrowded, and that what is really needed is increased local bus services together with adaptive improvements to the street network such as bus lanes and traffic signal priority for buses.

A research project has been set up to examine how these types of decision are made and to use methods of transferring the experience between cities. It is described after the discussion on the use of artificial intelligence methods.

USE OF ARTIFICIAL INTELLIGENCE METHODS

The need to provide new urban public transport technology has been demonstrated. However such investment is very expensive and takes a long time to come to fruition. Experience shows that different types of technology will be appropriate in different cities, with heavy rail most likely to be suitable in very large cities and buses most likely to be suitable in small urban areas, with the various alternatives shown in Table 1 fitting in between. A variety of modeling techniques for assessing the impacts of the various types of technology is available. The use of such techniques might well involve the characteristics of speed, route coverage, capacity, and so on, of a set of alternative technologies. The effects on patronage and fare revenue plus the costs could then be used in some form of cost-benefit analysis. Environmental effects such as emissions could also be modeled. However although such methods can be used to assist in assessing the appropriateness of the technology they can not take into account all the relevant factors because a lot of judgment is required, and that can only come from experience. By the nature of the type of system being considered here such decisions will be made very infrequently, so that many transport planners may be involved in only one such decision in a lifetime. Each decision is taken from first principles. One way to help overcome such problems is to circulate the knowledge of the various experts who have made such decisions in the past under a variety of situations. This can be done by using artificial intelligence methods, in particular, expert systems. Essentially an expert system is a computer program that provides advice on solving a problem, for example the best way to design a system, using the knowledge of experts. As Ortolano and Perman (*6*) explain an expert system has the following elements:

1. *Domain*, which is the subject area;
2. *Knowledge base*, which is a collection of facts, definitions, rules of thumb, and computational procedures applied to the domain;
3. *Control mechanism*, which is a set of procedures for manipulating the information in the knowledge base; this may be in the form of logical deductions from a set of facts and rules of the form of "if (premises) then (consequences)"; and
4. *User interface*, which usually is a visual display unit and keyboard linked to the computer running the expert system.

In the case being considered, the domain is the decision about the type of technology for an urban public transport system. The knowledge base will contain information about the characteristics of various technologies (speed, weight, capacity, and so on), the different types of system used in different cities along with their characteristics, the costs of the various systems, and so on. The control mechanism will be based on information from experts and could be of the following forms:

1. "If the maximum money available is less than $1.5 million per kilometer, then you cannot afford to tunnel,"
2. If traffic congestion is a problem in the city center, then you must segregate the new system from cars, or
3. If atmospheric pollution is a serious problem in the city center you need to use electric traction.

Such knowledge could come from interviewing experts in person or from written documents.

These are very simple examples, but when combined together and linked to some more conventional modeling techniques, a very powerful tool can be produced. The conventional modeling technique might be used to calculate the effects of the most appropriate alternatives, which would then be fed back through the expert system to give an explanation of why the proposed solution is the most appropriate and why others have been rejected.

Ortolano and Perman (*6*) identify six conditions for deciding whether a particular task can be codified into an expert system.

1. Knowledge needed for task performance is specialized and narrowly focused;
2. True experts, that is, people who know more than novices, exist;
3. The task is neither trivial nor exceedingly different;
4. Conventional computer programs are inadequate for the task;
5. The potential payoff from an expert system is significant; and
6. An articulate expert is available and willing to make a long-term commitment to build the expert system.

The problem being addressed here appears to meet the first five criteria: few people have made such decisions, so it is a specialized task, but such people do exist; the task is not trivial, but it does not approach the impossible; although conventional computing techniques are useful they do not really address the crucial question of how to choose the appropriate system; and given the huge costs of such systems and the problems if the wrong solution is developed, the potential payoff is huge. Whether the final condition is met depends on the particular application.

Hence it appears that there is scope for the use of an expert system in the determination of the appropriate type of public transport system that should be selected. A project to do this is described in the next section.

UTOPIA PROJECT

To study the issues identified a project was set up at the Centre for Transport Studies at University College London with funding of about $190,000 from the U.K. Science and Engineering Research Council for 3 years starting in January 1993. The project is known as UTOPIA (Urban Transport Operations and Planning Using Intelligent Analysis) and has the following objectives:

1. To help produce more civilized cities by improving transport operations and planning,
2. To transfer between cities experience of decision making about appropriate transport technology, and
3. To use artificial intelligence techniques to improve decision making in the field of transport.

The core of the UTOPIA work will be the use of expert systems to import knowledge to Britain from experts in cities in continental Europe that have made such decisions, such as Grenoble and Lille in France. The expert system lies at the core of a model that draws on other modeling techniques to show the implications of the various strategies produced. The model will then be applied to a variety of cities in Britain, particularly those where discussion on the possible solutions to the problems of congestion are being conducted, such as Leeds, where both light-rail and guided bus systems are being considered, and Bradford, where trolley buses may be reintroduced. The cities in Europe to be examined are places in France and Germany such as those discussed and other interesting cases such as Essen, with its guided busway, and Amsterdam, where a light-rail extension to the metro was opened in 1990.

A major task is the identification of the appropriate experts who have been involved in making these decisions. The method being used is to start from local contacts with knowledge of the topic and to ask them who else to talk to. In this way a network of experts can be built up. A second method that may be used, especially for cities outside Britain, is to distribute a questionnaire by mail to cities in continental Europe, for example, to the general manager of the system, as identified from a source such as *Jane's Urban Public Transport Systems* (*7*); via contacts at the Union International des Transports Publics (UITP) in Brussels; or through direct contacts such as T. Ridley, mentioned earlier in the context of the Tyne and Wear Metro and the Docklands Light Railway and who is now at the University of London Centre for Transport Studies where the UTOPIA project is being undertaken, although he has no direct involvement in the project. [His presence will help to meet the sixth criterion on Ortolano and Perman's (*6*) list in the previous section.]

The questionnaires will be framed in such a way that they can be answered only by an expert. It will be essential to know who has actually responded to the questions. The questionnaire will include a request for a personal interview. This will be undertaken only if it is clear from the questionnaire and other soundings that the person concerned really is an expert. It could be possible for a person to fill in the questionnaire dishonestly, but this seems unlikely, and as knowledge is circulated it should be possible to eliminate any such cases.

Different experts will provide expertise on the basis of different experiences. This means that it will be possible to apply, say, the Essen experience or the Lille experience to a city like Leeds and come up with different proposals in the same way that one might if one took two experts to the same city. The expert system will explain how it comes to each solution. These can then be explored with the local planners in Leeds to see which one they prefer.

It is recognized that many decisions are essentially political. For example a particular type of technology may be produced locally, and supporting local manufacturing industry may be an objective. To some extent such factors, if they are known, can be incorporated into the expert system. It cannot replace the political process, but it can help to improve the process by making it more transparent. The ability of expert systems to explain their decisions is particularly useful in this context.

The methodology being used in the UTOPIA project is shown in Figure 1. The user will be the planner in the British city who

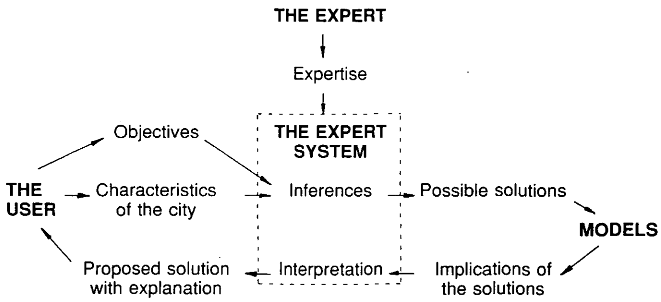

FIGURE 1 Methodology being adopted in UTOPIA study.

will define the objectives of the new system and provide information on the city. The objectives may be specified in terms such as capacity, speed, cost, and environmental effects. The expert system will incorporate various sets of expertise that have been encapsulated previously. Some possible solutions will be generated. Because an expert system is not ideal for handling complex mathematical functions, other models in, say, FORTRAN or C will be used to calculate the detailed implications of the system to be fed back through the expert system to provide an explanation to the user for why the chosen solution is appropriate. The user may then decide to revise the objectives, so the whole process is then repeated. Alternatively a different set of expertise can be used. The system is being designed to be interactive so that the planner can explore a range of options by using different criteria and consulting the knowledge of a range of experts. The system offers the opportunity to draw on a range of experts within a period of a few hours in a way that would probably be impractical if the experts had to be consulted in person.

PROGRESS ON UTOPIA PROJECT

As indicated the UTOPIA project started in January 1993. Initially the emphasis was placed on identifying appropriate public transport systems that should be studied, talking to various relevant people to help to identify experts and to build up knowledge, talking to British experts, and starting to develop the expert system.

As mentioned discussions have been held with T. Ridley, who was actively involved in the discussions about the Tyne and Wear Metro and the Docklands Light Railway, and further discussions will be held with him. More recently discussions about the decisions concerning the building of the Manchester Metrolink have taken place with experts. This is a light-rail system that opened in spring 1992. It uses two former suburban rail lines with street-running to link the former termini. The interview will be described here briefly to illustrate the nature of the process. The responses are based on notes taken by the author. The interview was tape-recorded and will be more systematically analyzed later for use in the expert system.

At the request of B. Tyson, one of the interviewees, a letter was sent in advance indicating the questions to be answered. These formed the basis of the discussion. They are provided below, with summaries of the main points of the responses.

INTERVIEW ABOUT MANCHESTER METROLINK

Place of interview	Offices of the Greater Manchester Passenger Transport Executive (GMPTE)
Date of interview	Wednesday, November 3, 1993
System being discussed	Manchester Metrolink
Interviewees	B. Tyson (Director of Planning and Promotion, GMPTE), T. Young (Operations Planning Manager, GMPTE)
Interviewers	R. Mackett, N. Tyler, M. Edwards (all CTS at UCL)

Question 1: What Alternatives Were Considered?

The following options were considered:

1. Closure of the two British Rail lines to Bury and Altrincham;
2. Continuation of the two lines, but with some investment;
3. A light-rail system, running on the two British Rail lines with street-running between the two city center termini;
4. As for Option 3, but with tunneling under the city center;
5. As for Option 4, but heavy rail, that is, a metro;
6. As for Option 3, but a busway; and
7. As for Option 6, but using guided buses.

This large number of options was considered because there was desire locally to look at a wide range and because the Department of Transport (that is, the central government department responsible for transport) said that it wanted a wide range to be considered.

Question 2: How Explicit was the Process of Deciding Between the Alternative Options?

It was an explicit process in which consultants were used to evaluate the alternatives. The patronage estimates for all the proposed systems were similar, so the decision was mainly based on costs. Tunneling was eliminated early on because of the high cost of access into and out of it and the lack of visibility of the system. This left Options 1, 2, 3, 6, and 7. Busways were then eliminated at the evaluation stage because of the high costs of removing the rail tracks. This left three options: closure, continued heavy rail with no rail connection between the two lines, and street-running light rail.

Question 3: If Alternative Technology was Considered, Would the Design of the System have been Different, for example, Alternative Routes, Stopping Points, or Interaction with other Traffic?

With a busway there would not have been so much segregation of the system from other traffic, and it would not have been necessary to move so many other services (for example, gas and electricity) from the affected streets. The former point means that congestion from cars, including misparking, would have had a greater adverse effect. The latter point occurs because light rail cannot be diverted when roadwork occurs, whereas a bus can.

Question 4: What factors were taken into account when deciding on the type of technology (for example, capacity, speed, and influence on demand)?

1. Capacity, to carry flows in the range of 1,000 to 5,000 passengers per hour, with a maximum of about 10,000 passengers per hour over the central sections;
2. Maximum speed of not less than 80 km/hr, with high acceleration and deceleration rates;
3. Ability to operate over the existing rail lines without extensive additional engineering costs;
4. High levels of reliability;
5. Acceptable environmental features;
6. Capability of expansion beyond the initial network;
7. Ability to run on the street (in the case of nontunneling options only);
8. Use of proven technology; and
9. Capability to carry large amounts of crosstown passenger movement.

Question 5: Have compromises been made because the vehicles run both off and on the streets? Was tunneling under the city center considered?

The system could never be driverless if street running was used. However the use of automatic vehicles was not seriously considered because of the desire for proven technology, the problems of keeping the line secure, and possible political problems of driverless vehicles in an area of high unemployment. Tunneling was considered, but it was rejected fairly early on in the decision process.

Question 6: To what extent have the level and method of funding influenced the design of the system?

The total level of funding affected decisions. With more funding the final system would have been of a higher quality, for example, refurbished suburban stations and better-quality seats in the vehicles.

The whole scheme has been implemented by using a DBOM (design, build, operate, and maintain) contract that will last for 15 years after the system opens. (The central government required the system to be built and operated by the private sector under contract to GMPTE.) There was a tendering process. The initial stage was to invite expressions of interest, and as a result of this 12 consortia were short listed. Of these, eight were selected for the first-stage tender. Five of these dropped out, leaving three that tendered. The differences between the three final designs included the vehicles, the overhead system, and the station design.

Question 7: What would you do differently if you were starting now?

GMPTE would have carried out more of the design and left less of it to the contractors. More thought should have been given to the design specification at the interfaces with third parties, such as British Rail and the city planning department. There should have been a more detailed reference specification. It might have been better to have had several small contracts instead of one large one. With a single large contract a contractor can hide delays but, on the positive side, must take into account the long-term maintenance implications of decisions at the design and building stages.

Question 8: Who actually decided on the type of system: politicians, managers, or technical staff?

Politicians actually made the decisions, with technical advice from the managers. Consultants were used to carry out much of the background work.

Question 9: What effects do you expect the systems to have on Manchester in terms of, for example, employment patterns and car use?

After 1 year patronage has already reached the level predicted for after 2 years. It appears to be attracting people out of their cars. There is anecdotal evidence that some people served by Metrolink are selling their second cars and even their first cars. One aim of building the system was to help the local labor market, which it has done. One of the four major aims of the Manchester Structure Plan is to retain the urban core, and it appears that Metrolink is likely to aid in that aim. It also helps to give an air of confidence to the city; for example, it featured prominently in Manchester's bid for the Olympic Games for 2000. Independent studies of the effects of the system are being carried out by the University of Salford and the consultants Oscar Faber TPA.

It can be seen that much useful information has been obtained and that much of it can be converted into statements of the form "if (premises) then (consequences)" for use in the control mechanisms in the expert system. Several volumes of reports produced at various stages in the decision-making process have been received and will be used to supplement the oral information summarized here.

On the technical side effort has been put into the design of the expert system. Much of the work has concentrated on the design of the Intelligent Cities Data Base. This will form part of the knowledge base of the system. It will also be used during the knowledge acquisition process, allowing experts and users to enter data on their cities in a systematic way, responding to questions from the computer. It will also provide the most appropriate value for a particular city in a particular year if none is available.

CONCLUSIONS

This paper has argued the need for better urban public transport systems. It has also suggested that cities in continental Europe tend to have a more positive approach to public transport than British cities, so there is scope for British cities to learn from experiences elsewhere. It is clear that there is a variety of public transport technologies available, and it is important to understand the implications of each. Choosing the appropriate type of system for a city requires considerable expertise. One way to apply the expertise from cities in continental Europe to British cities is to use expert systems. That is being done in the UTOPIA project. Although the work is still at an early stage it is showing great promise and is generating great interest.

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