DETERMINING THE APPROPRIATE PUBLIC TRANSPORT SYSTEM FOR A CITY

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ABSTRACT

Car ownership is growing in cities. This is leading to more congestion and environmental damage. In order to attract motorists from their cars it is necessary to improve the quality of public transport. In many cities this means building new systems. There are a variety of technologies available, so decisions have to be made to determine which is the most appropriate for a particular city. In the paper 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 paper describes the methodology for the use of expert systems, a form of artificial intelligence, to encapsulate the knowledge of experts in cities in continental Europe and transfer it to cities in Britain where decisions are being made about the type of public transport technology to adopt.

INTRODUCTION

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 public transport to car increases the rate of suburbanisation which, in turn, tends to favour car use and makes 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:

(a) It is impossible to provide all the road capacity to meet the demand, and so congestion occurs; this is inefficient as it wastes time, and causes uncertainty in planning journeys.

(b) Cars produce a variety of pollutants; while technical innovation can reduce emittants significantly in new cars, there are still many older cars on the road, and these pollute.

(c) 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 improving existing systems, but in some cases, introducing new systems. However, such systems are expensive, and 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 impact 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 judgement in a political framework. This paper is concerned with the development of such a methodology using techniques from the field of artificial intelligence.

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

THE NEED FOR BETTER PUBLIC TRANSPORT

Some of the problems caused by increasing car ownership and the need for better public transport have been discussed above. 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 per cent 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 per cent agreed with the statement. Currently there is considerable interest in the potential for roadpricing. This means charging drivers for the use of the road so that they are paying an amount that better reflects the costs 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 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)*.

However, if people are to be discouraged from using their cars, the alternative modes must not only be attractive but 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. Buses suffer from the 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 10000 passengers per hour to justify the investment *(3)*.

Table 1 shows the characteristics of various urban public transport modes. The cheapest and quickest mode to introduce 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 in Germany or Adelaide in Australia, permits high-speed running along radial corridors, thereby avoiding congestion, but retaining the flexibility to cover the suburbs by using ordinary roads. It is debateable whether such systems can overcome the prejudice against buses. Many cities in continental Europe have retained trams, which can provide efficient movement of passengers to the city centre. However, street running 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 running on separate corridors. Such systems carry large numbers of people at high speed. The disadvantage is the need to find land upon which to build. In some places, such as Newcastle-upon-Tyne in the north of England, the system goes underground in the city centre. This can increase the cost substantially, but it may be necessary to provide sufficient penetration of the city centre 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. 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 city-centre penetration 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 centre.

It has been argued above that cities need good public transport to attract people from their cars, and that this may require major investment in new infrastructure. There are a variety of technologies available and so decisions have to be made on what is appropriate for a particular city. British cities need investment in public transport if the damaging effects of the car are going to be limited. Two key questions are: how does one decide what is the appropriate form of public transport technology to adopt; and how can the positive experience in cities in continental Europe be drawn upon? These questions are addressed in the next two sections.

DETERMINING THE 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 decide what type of system. A whole variety of factors are important. Some features of each city are unique, but there are many common factors. There are a variety of modelling techniques available to assess the impact of a new system characterised 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 judgement as much as formal modelling techniques, so to use the lessons from one city in another it is necessary to find a method of 'encapsulating' the relevant knowledge in order 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 in order to understand the type of knowledge to be transferred.

(a) Tyne and Wear Metro and the 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 Dr Tony 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 Dr Ridley. He was also responsible for the development of the Hong Kong Mass Transit Railway between the two positions mentioned above, so he has considerable experience in making the type of decision being discussed here. Ridley (Ridley, unpublished data) argues that for British cities to get a new public transport system built requires the following factors:

(a) A local political consensus, that is, agreement between all shades of political opinion;

(b) A good working relationship between central and local governments at various levels (technical, managerial and political);

(c) A consultant's report to give credibility to the project and to focus attention on the complexities of the issues;

(d) 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.

(b) Shidami Human Science Town

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

(a) the duel-mode vehicles could have direct access to both the suburbs and the city centre in conventional bus mode and use the elevated section linking Shidami to Nagoya to provide a high-speed, frequent service in guided mode;

(b) the construction costs were lower than for a rail-based system;

(c) 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 in the north of England will be discussed. In that case light rail was chosen in preference to 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 discussion on the use of artificial intelligence methods.

THE USE OF ARTIFICIAL INTELLIGENCE METHODS

The need to provide new urban public transport technology has been demonstrated above. 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 in small urban areas, with the various alternatives shown in Table 1 fitting into the continuum in between. There are a variety of modelling techniques available to assess the impact of the various types of technology. 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 modelled. However, while such methods can assist to assess the appropriateness of the technology they are not able to take into account all the relevant factors because a lot of judgement is required, and that can only come from experience. The nature of the type of system being considered here mean that such decisions are made very infrequently, so that many transport planners may be involved in only one such decision in a lifetime, and so each decision is taken from first principles. One way to help overcome such problems is to cumulate the knowledge of the various experts who have made such decisions in the past under a variety of situations. This can be done 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:

(a) **the domain**, which is the subject area;

(b) **the knowledge base**, which is a collection of facts, definitions, rules of thumb and computational procedures applied to the domain;

(c) **the 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 'if (premises) then (consequences)';

(d) **the user interface** which will usually be a visual display unit and keyboard linked to the computer running the expert system.

In the case being considered here, 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 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 form:

(a) 'if the maximum money available is less than $1.5 million per kilometre, then you cannot afford to tunnel' or

(b) 'if traffic congestion is a problem in the city centre, then you must segregate the new system from cars' or

(c) 'if atmospheric pollution is a serious problem in the city centre 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 modelling techniques, a very powerful tool can be produced. The conventional modelling 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 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:

(a) The knowledge needed for task performance is specialised and narrowly focused;

(b) True experts exist, that is, people who know more than novices;

(c) The task is neither trivial nor exceedingly difficult;

(d) Conventional computer programs are inadequate for the task;

(e) The potential payoff from an expert system is significant;

(f) An articulate expert is available and willing to make a long-term commitment to build the expert system.

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

Hence, it seems that there is scope for the use of expert systems in the determination of the appropriate type of public transport system. A project to do this is described in the next section.

THE UTOPIA PROJECT

In order to study the issues identified above, a project has been set up at the Centre for Transport Studies (CTS) at University College London (UCL) with funding of about $190000 from the UK Science and Engineering Research Council for three years starting in January 1993. The project is known as UTOPIA (Urban Transport Operations and Planning using Intelligent Analysis) and has the following objectives:

(a) To help produce more civilised cities by improving transport operations and planning;

(b) To transfer between cities experience of decision-making about appropriate transport technology;

(c) 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 which have made such decisions, such as Grenoble and Lille. The expert system lies at the core of a model that draws upon other modelling 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 discussions 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 above 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 UITP (Union International des Transports Publics) in Brussels or through direct contacts such as Tony Ridley mentioned above in the context of the Tyne and Wear Metro and the Docklands Light Railway, who is now Professor of Transport Engineering in the University of London Centre for Transport Studies where the UTOPIA project is being undertaken, although he has not direct involvement in the project. (His presence will help to meet the sixth criterion on Ortolano and Perman's list in the previous section).

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

Different experts will provide expertise based on 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 you might if you 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 they prefer.

It is recognised 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 known can be incorporated into the expert system. However, 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 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 which 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 of 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 using different criteria and consulting the knowledge of a range of experts. The system offers the opportunity to draw upon a range of experts within a period of a few hours in a way that would probably be quite impractical if the experts had to be consulted in person.

PROGRESS ON THE UTOPIA PROJECT

As indicated above, the UTOPIA project started in January 1993. Initially emphasis has been placed on identifying appropriate public transport systems to study, 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 above, discussions have been held with Tony 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 have taken place with experts about the decisions concerning the building of the Manchester Metrolink. This is a light rail system which 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 analysed later more systematically for use in the expert system.

At the request of Bill 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 shown below with summaries of the main points of the responses.

THE INTERVIEW ON THE MANCHESTER METROLINK

Place of interview	Offices of the Greater Manchester Passenger Transport Executive (GMPTE)
Date of Interview	Wednesday 3 November 1993
System being discussed	Manchester Metrolink
Interviewees	Bill Tyson (Director of Planning and Promotion, GMPTE) Tony Young (Operations Planning Manager, GMPTE)
Interviewers	Roger Mackett, Nick Tyler, Marion Edwards (all CTS at UCL)

Q1 What alternatives were considered?

The following options were considered:

(a) Closure of the two British Rail (BR) lines to Bury and Altringham;

(b) Continuing to run the two lines, but with some investment;

(c) A light rail system, running on the two BR line with street-running between the two city centre termini;

(d) As (c) but with tunnelling under the city centre;

(e) As (d) but heavy rail, that is a metro;

(f) As (c) but a busway;

(g) As (f) but using guided buses

This large number of options was considered because there was an explicit 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.

Q2 How explicit was the process of deciding between the alternative options?

It was an explicit process, using consultants to evaluate the alternatives. The patronage estimates for all the proposed systems were similar, so the decision was mainly based on costs. Tunnelling 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 (a), (b), (c) (f) and (g). 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.

Q3 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 from the affected streets (for example, gas and electricity). The former point means that congestion from cars, including mis-parking would have had a greater adverse effect. The latter point occurs because light rail cannot be diverted when road-works occur whereas a bus can.

Q4 What factors were taken into account when deciding on the type of technology? (For example, capacity, speed, influence on demand)?

(a) Capacity, to carry flows in the range of 1000 to 5000 passengers an hour with a maximum of about 10000 passengers per hour over the central sections;

(b) Maximum speed of not less than 80km/hour with high acceleration and deceleration rates;

(c) Ability to operate over the existing rail lines without extensive additional engineering costs;

(d) High levels of reliability;

(e) Acceptable environmental features;

(f) Capability for expansion beyond the initial network;

(g) (In the case of non-tunnelling options only) Ability to run on the street;

(h) Use of proven technology;

(i) Capability to carry large amounts of cross-town passenger movement.

Q5 Have there been compromises made because the vehicles run both off and on the streets? Was tunnelling under the city centre considered?

The system could never be driverless if street-running is used. However, the use of automatic vehicles was not considered seriously 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. Tunnelling was considered, but rejected fairly early on in the decision process.

Q6 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 using a DBOM (Design, Build, Operate and Maintain) contract which will last for fifteen years after opening. (Central Government required that the system was 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 twelve consortia were short-listed. Of these, eight were selected for the first-stage tender. Five of these dropped out, leaving three who tendered. The differences between the three final designs included the vehicles, the overhead system and the station design.

Q7 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 rather than one large one. With a single large contract a contractor can 'hide' delays, but on the positive side, has to take into account the long term maintenance implications of decisions at the design and building stages.

Q8 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.

Q9 What effects do you expect the systems to have on Manchester in terms of, for example, employment patterns and car usage?

After one year, patronage has already reached the level predicted for after two 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 the building of the system was to help the local labour market, which it has done. One of the four major aims of the Manchester Structure Plan is to retain the urban core, which it seems Metrolink is likely to aid. 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 the year 2000. Independent studies of the effects of the system are being carried out by the University of Salford and the consultants Oscar Faber TPA.

THE USE OF INFORMATION ON THE UTOPIA PROJECT

Thus it can be seen that much useful information on the decision about the Manchester Metrolink 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 process have been received and will be used to supplement the oral information summarised 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 Database (ICD)'. 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 elsewhere. It is clear that there are 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. While the work is still at an early stage it is showing great promise and generating great interest.

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TABLE 1 Costs and other characteristics of public transport modes

	Maximum capacity (1000pph/direction)	Commercial speed (km/h)	Operating cost per km per annum ($\$ \times 10^6$)	Capital cost for for twin lanes ($\$ \times 10^6$)	Total cost over 30 year life ($\$ \times 10^6$)	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

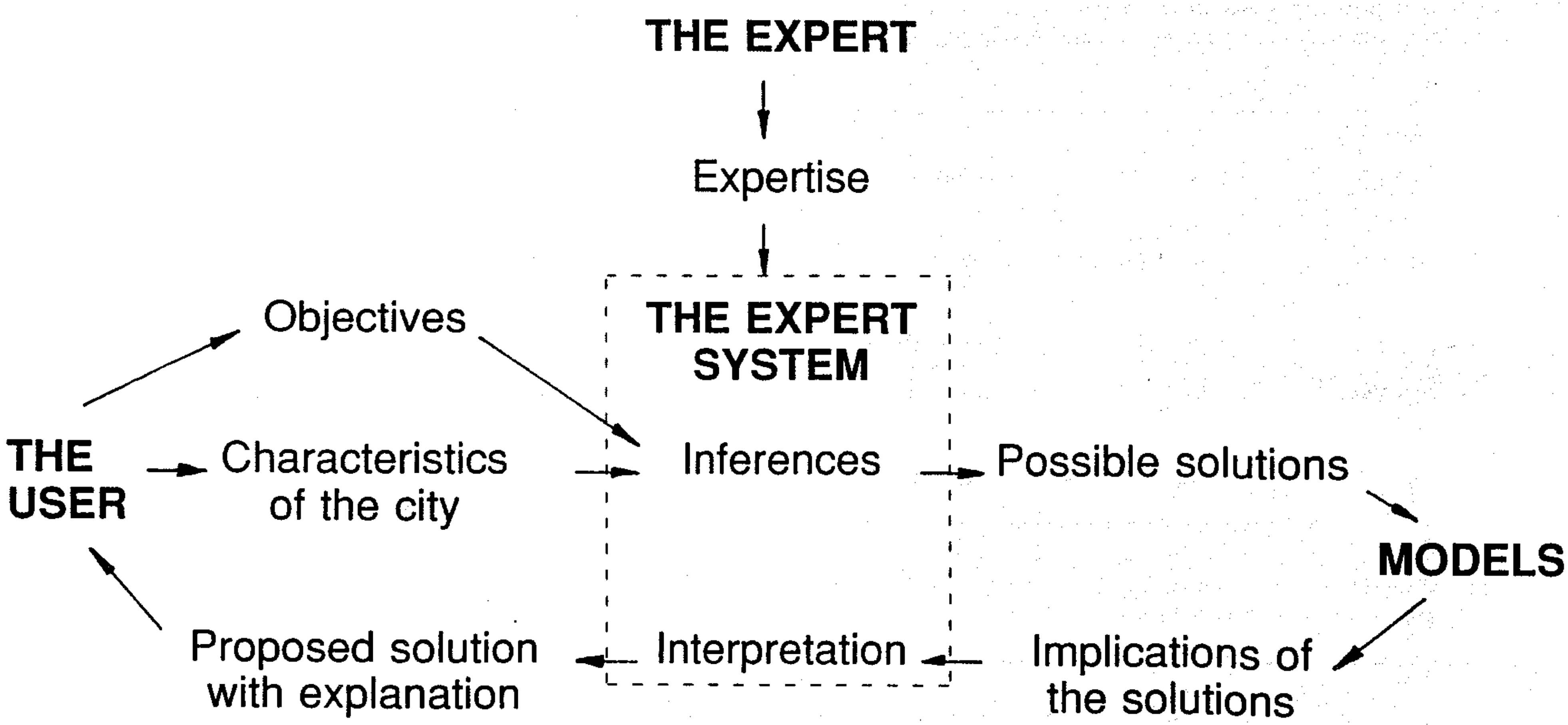

FIGURE 1 The methodology being adopted in the UTOPIA study