1. Introduction

Specialists working in an area carry out their professional activities under the influence of an underlying paradigm, which strongly affects the kinds of problems that are identified, how they are framed and diagnosed, the methods that are used for analysis and the policy solutions that are subsequently generated. Sometimes this paradigm is well articulated and its influence recognised, in other cases this is less so.

Kuhn (1962) first introduced the concept of the paradigm shift in his book *the Structure of Scientific Revolutions*. Here he postulated that scientific revolutions occur when scientists encounter sufficient anomalies, or questions that cannot be adequately answered within the current paradigm, which lead them to question accepted norms and to search for a new framework for discovery and analysis. This paper argues that a similar situation has been faced by transport researchers and practitioners on several occasions over the past fifty years, but rather than precipitating the development of new paradigms, it has led to an evolution of the existing paradigm – mainly through adding ‘layers’ to its established core to address new concerns. Something of this phenomenon is alluded to in Heggie and Jones (1977), which argued that there are different analytical and modelling ‘domains’ that are appropriate for tacking different kinds of issue.

The focus in this paper is on the movement of people, rather than goods. Starting with a basic vehicle-based paradigm (P1) the paper identifies four subsequent enlargements that have brought new perspectives to transport research and policy making: trip-based (P2), activity-based (P3), attitude-based (P4) and, finally, dynamics-based (P5). Each poses its own research questions and lines of enquiry, involves different academic disciplines and frames the policy debate in a different way. Each places its own demands on data collection and analysis, with different requirements for modelling and evaluation.

While these various enlargements are presented as discrete entities, in practice it is recognised that there are not always clear cut distinctions at the boundaries between them, and that they have developed both sequentially and simultaneously. For example, should trip tours be regarded as lying within a trip-based or an activity-based perspective? Or, is habit part of the dynamics
or attitude-based perspective? Similarly, the paradigm expansions have not
strictly followed the sequential path set out here. While it is broadly true
that the early sequence was: vehicles -> person trips -> activities, the attitude and
dynamics perspectives started to appear in parallel with these first three. It is
also evident that the speed of advance in embracing new ideas and
methodologies has varied between countries; for example, the Netherlands
and the USA have been quicker at embracing activity-based concepts in their
operational modelling than is the case in the UK.

Each paradigm enlargement is briefly introduced in turn, outlining its
conceptual contributions, analytical components and implications for transport
policy. Attention then turns to wider methodological, disciplinary and research
issues. The paper discusses some of the gaps between analytical
requirements and capabilities, with the objective of identifying fruitful areas for
future research that will have major policy benefits. It considers what is likely
to be the next paradigm enlargement to make its mark on transport research
and policy, and discusses the implications for transport policy and research of
having followed this evolutionary rather than a revolutionary process.

Fundamentally, this paper argues that the initial vehicle-based paradigm still
stalks the profession like a ‘ghost’ at the core of the current enlarged transport
paradigm, and has a major pervasive influence. This is partly due to there
being major lags from concept to application, so that most modelling and
scheme evaluation methods still carry a legacy of being grounded within the
vehicle-based paradigm first developed over half a century ago. But this
arises also because the later paradigm extensions have been ‘bolted on’ to
this superstructure. In hindsight, had the profession embraced a full Kuhn-
type revolutionary paradigm shift, then the whole research and policy debate
around the day-to-day movement of people might now be taking a rather
different form.

Inevitably this paper presents a personal perspective, and shows a UK bias to
some degree, although I have attempted to draw widely on international
literature and experiences. Pas (1990) offered an overview of different ‘eras
of development’ in the field of travel demand modelling and analysis from a
North American perspective, although his focus was somewhat different in
that his emphasis was more on methodological advances contributed by
different disciplines, rather than on the conceptual framing of the subject area,
which is the primary focus of this contribution.

2. The Evolving Paradigm

2.1 The Initial Vehicle-based Paradigm (P1)

While in the USA the science of traffic planning began in the early decades of
the twentieth century due to the rapid growth in car ownership, this growth did
not significantly affect other countries until after World War Two. The formal
development of traffic and transport planning in the UK, and in much of the
rest of North-Western Europe and Australasia began in the late 50s and early
60s, using transportation planning methods imported by Alan Voorhees and others from studies in the major US cities such as Chicago (see Boyce, 1980). Drawing on that cultural context, the focus was on catering for the anticipated rapid growth in motor traffic associated with the increases in car ownership, following earlier trends in the USA, which was – largely correctly – foreseen in documents such as the UK Buchanan report (MoT, 1963) and in early traffic studies in London and some of the other major conurbations.

At that time, the growth in motor traffic was viewed as being an inevitable consequence of the increase in GDP and household incomes, and wholly beneficial economically and socially. While in the UK, Buchanan and others (e.g. Plowden, 1972) warned of the environmental deterioration that would result in urban areas if nothing were done to deal with the growth of the motor vehicle, it is noteworthy that the emphasis of Traffic in Towns was largely on redesigning our urban areas to accommodate vehicles, rather than on constraining the growth in car use.

As a consequence, the transport solutions to the problem of growing traffic levels were generally viewed as involving building new roads, increasing the capacity of the existing road network, and providing additional parking spaces; relatively little attention was paid to redesigning existing urban areas, in the way that Buchanan had advocated. This was the start of the 'motorway age' in the UK (Starkie 1982) and several other European countries, with the development of the national motorway network and more limited high capacity urban road networks (e.g. the new inner ring in Birmingham).

At this stage the profession was dominated by traffic engineers. The formal assessment of future demand was based on estimates of vehicle growth, related to forecast increases in income and population, and then using simple growth factor models to estimate traffic increases on links or at junctions; where by-pass roads were planned, this required the calibration of simple diversion curves. Data collection relied on roadside traffic counts and interviews, sometimes supplemented by limited household surveys.

Soon the magnitude of the growth in car ownership forced a more strategic view of the issue and a recognition of the need to construct purpose-built high capacity urban road networks. This encouraged a more strategic perspective and a more formal modelling of relationships between transport and land use, building on earlier conceptual analysis by Mitchell and Rapkin (1954). This brought two new disciplinary skills into the profession. First, those with mathematical skills to develop comprehensive vehicle trip origin-destination models, using gravity models, entropy maximising techniques and other tools from social physics; and, second, economists who could develop formal appraisal methods that would help to justify the large injection of public funds required to build major new road networks. The collective efforts of these various disciplines applied to large scale transportation studies soon led to the development of three-stage aggregate traffic forecasting models, combining vehicle trip generation, trip distribution and traffic assignment modules (see Lane et al, 1971).
Quite soon, however, it became evident that it would not be possible to cater for unrestrained car use in larger urban areas. In London, for example, even with proposals for an extensive urban motorway network, the three-stage traffic forecasting models were predicting demand levels several times greater than the planned capacity (Thompson, 1969). And even that planned capacity could not be delivered: the construction of the first section of one of the proposed motorways in inner London led to such a public outcry that the conservative administration in the Greater London Council was voted out in 1973, and the incoming labour administration promised an end to major motorway construction in London, under the slogan ‘homes before roads’.

This led to a policy impasse: what to do about the pressures for traffic growth in urban areas, if major road building is not an option? While part of the solution lay in using the existing roads network more intensively (through the introduction of one-way streets, on-street stopping restrictions and co-ordinated traffic signals at junctions, see Hart, 1976), the major breakthrough came by a redefinition of the problem – the first paradigm expansion. Rather than catering for unlimited vehicle movement in urban areas, the primary objective was switched, to cater for growing person movement instead – only some of which would be accommodated in motor vehicles.

2.2 First Enlargement: the Person Trip-based Perspective (P2)

From an enlarged person trip perspective, the focus becomes one of moving people from their desired origin to their destination, in the most efficient and attractive manner. So the form of vehicle in which this movement takes place becomes of secondary interest: it is simply an enabling technology, a way of moving people from A to B. Since public transport systems (buses, trams, trains, underground) use the limited available space much more efficiently than private cars, and can accommodate much higher numbers of people per unit area, the solution to the conundrum as to how to cater for the rapid growth in vehicle demand in a physically constrained area is to switch much of this growth to other forms of transport.

Analysis and modelling from a person trip perspective requires the addition of a modal split module (e.g. Hutchinson, 1974), and this development was associated with two major intellectual contributions from economists. First, the development of the concept of ‘generalised cost’ (i.e. the combining of various time and cost components of trips into a composite measure) – which also facilitated the monetarisation of time savings in the economic appraisal. And, second, the development of the theory and practice of random utility theory and disaggregate choice modelling (Ben-Akiva and Lerman, 1985). However, while economic theory recognised that travel is largely a derived demand, this concept was not reflected in the methodologies that were developed.

Methodologically, this enlargement of perspective was associated with the development of household travel surveys, and in particular the use of travel diaries. But here we observe an interesting divergence of practice. While estimating average person trip generation rates relies on data for at least one travel day, the subsequent modelling stages still operated at the individual trip
level, based on the legacy of the original vehicle-based trip analysis. Because of this legacy, the mode choice module of the four-stage model was originally developed to operate at the individual trip level, even though this makes no sense conceptually, as car modal choice is generally a tour-based not a trip-based decision.

In policy terms, the person trip perspective encourages the focus to change from road building to instruments that will encourage a switch from car to other modes of transport. Initially the alternative was seen to lie in improved public transport services; but, more recently, the policy application of the trip-based perspective has been broadened to include encouraging cycling and walking trips. Over time, it has also led to increased consideration of various traffic restraining measures (parking restrictions, road pricing, etc.), to encourage shifts from car to other modes.

The limited consideration of walking and cycling modes in the early days of the person trip-based perspective was probably partly caused by legacy methodological factors. The vehicle-based models had been aggregate and strategic in nature – focussing on inter-zonal not intra-zonal trips – so there was little interest in shorter trips, and many data collection exercises had excluded walking and cycling trips altogether. But, over time, the emphasis on people movement stimulated interest in the full range and purposes of these trips and encouraged a more sophisticated approach to forecasting, taking into account person as well as trip characteristics, using disaggregate travel demand models which required more micro, door-to-door data.

However, as early as the 1970s, some commentators were beginning to question whether the person trip perspective was providing a real understanding of why people travel, and whether it would be possible or desirable to cater for unlimited growth in person trips in denser urban areas, even if some of them could be switched to non-car modes. This questioning was stimulated by several factors: evidence of limited success in getting car drivers to switch to alternative modes, an evident lack of understanding of trip generation – and the 1973/74 oil crisis, which provided a warning of the dangers of becoming a heavily mobility-dependent society.

The latter led to observed short-term reductions in traffic and travel (coupled with increases in time spent on non-travel activities such as watching television, (1983)), and brought home the need for a deeper understanding of factors underlying travel behaviour, that required more than simply relying on extrapolating past patterns of growth. Heggie (1978), for example, in a study of the influence of car restraint policies in Oxford, identified twelve forms of household adaptation, most of which could not be directly modelled within a trip-based perspective.

These concerns simultaneously stimulated the funding of academic research by the SRC (Social Research Council) in the UK and the NSF (National Science Foundation) in the USA, from social science research teams, with the aim to improve our understanding of travel behaviour – the outputs from which resulted in the development of a second paradigm enlargement.
2.3 Second Enlargement: the Activity-based Perspective (P3)

From an activity-based perspective, travel is just one of many daily activities that people undertake, typically consuming around 4% of daily time budgets. It represents a space-shifting mechanism that enables people to move from one location to another, to take part in a succession of activities that draw on specialist facilities or involve groups of people who congregate at each location. Travel is thus explicitly treated as a derived demand. From this perspective, it is now meeting people's activity participation requirements that is of primary concern, and travel is secondary. Within this enlarged perspective, it becomes possible to address the question 'is your journey really necessary?', to consider trade-offs between travel, other forms of communication and other activities, and to assess the wider impacts of transport policies on people's daily lives.

The early research drew on and combined previous work on activity choices by Chapin (1965, 1974), an American planner, and on activity time/space constraints by Hagerstrand (1970), a Swedish Time Geographer, and so brought two new disciplinary perspectives into transport research. These contributed to the development of the 'activity-based approach' (Jones et al, 1983), which placed the main emphasis on 'understanding travel behaviour'. This introduced a number of new concepts into travel behaviour analysis, including:

- The recognition that activity participation is influenced by physiological factors (e.g. need to sleep and eat), as well as socio-economic roles (e.g. employee or carer) and personal preferences (e.g. certain leisure activities).
- In particular, the importance of stage-in-the-family-lifecycle as a major influence on observed household activity/travel patterns.
- The importance of activity and trip timing, and scheduling requirements in constraining choices and explaining observed behaviour patterns.
- Overall daily time budgets as a further constraining factor.
- The importance of inter-personal linkages and multi-person travel decision making.
- The scope for in-home activity substitution through tele-services or other home-based activities, and
- Viewing person trip generation rates as resulting from the balance between the number of in-home and out-of-home activities, and the selected complexity of trip chaining patterns.

Some of the elements of this approach can be found in applied research reported in the German literature. In particular the work of Kutter (1973), who developed a segmentation approach to modelling individual travel behaviour, and Brog and Erl (1983) who developed the 'situational approach' which provided a structured approach to examining household travel/activity patterns and the constraints under which these operated.
Methodologically, the activity-based perspective has introduced new forms of data collection, both in terms of measuring behaviour (e.g. the use of activity-based and time use diaries) and in the types of data concerning provision that need to be collected (e.g. detailed information on the location of facilities and their opening hours). While the perspective has stimulated much detailed research into daily behaviour and has led to major advances in modelling techniques at the research level, it has proved challenging to implement in practical urban studies which rely on modelling and appraisal methods.

Given the additional complexity and expense of collecting full activity diary data (plus the unfamiliarity of transport researchers and practitioners with this kind of data collection that was pioneered in the main by sociologists), several transport analysts have used comprehensive trip diary data instead, using the information on main trip purpose and time spent at destination to infer out-of-home activity patterns. While this has provided useful insights and contributed to important analytical advances, it has limited the adoption of a full activity perspective in two important respects. First, by excluding consideration of in-home activities and so largely ignoring in-home constraints on the timing of activity/travel patterns, and preventing consideration of trade-offs between in-home and out-of-home activity participation. Second, research by Khorgami et al (2010) has shown that the assumption of only one main trip purpose per destination (i.e. activity) is an oversimplification: typically, travellers engage in 1.2 primary activities per destination.

Because the activity-based perspective is very rich conceptually, it has contributed to a much broader debate about the reasons why people travel, and has provided policy makers with an enlarged set of policy instruments and perspectives. For example, travel behaviour can be influenced by reducing constraints on the timing of activities (e.g. flexi-time at work to encourage peak spreading), or by encouraging home working and the use of tele-services (e.g. internet shopping and home deliveries) as a substitute for personal travel.

However, despite this policy interest in communication substitution and in home delivery or home-based services, it is interesting to note that there have been very few large data collection exercises that have sought to collect all this information within one survey. One exception is the work of Zumkeller (1996), who has collected data on travel and communications behaviour simultaneously.

More strategically, the activity-based perspective has facilitated a debate about whether the primary aims of transport policy should be to cater for vehicle or person trip-based mobility or to provide enhanced accessibility to facilities (which may not require physical movement), a debate that has grown in relevance in recent years with policy concerns about social inclusion and sustainable lifestyles. It has also increased awareness of the unintended consequences of certain transport policies (e.g. the re-use of a household car by another household member if the existing car user switches to another mode of transport), and the wider impacts of policy measures on family life.
During the development of the vehicle-based paradigm, and the subsequent trip-based and activity-based enlargements, the emphasis in each case has primarily been on working with objective, quantitative variables (e.g. traffic flows, travel costs, or activity durations), although sometimes recognizing that perceived values may differ from objectively measured values. With the growth in development of ITS technologies to provide better travel information, the greater market focus in public transport provision following the privatisation of bus and rail services in many other countries, and a growing interest in using marketing tools to encourage walking and cycling, it became evident that there were important subjective aspects of decision making that needed to be better understood.

This led to an infusion of ideas from marketing and social psychology, and the broader development and application of a third paradigm enlargement, whose routes can be traced back to at least the 1970s.

2.4 Third Enlargement: the Attitude-based Perspective (P4)

There are several strands of work that can be identified under this broad heading, which together have contributed several new kinds of data collection and analysis techniques, and have involved major inputs from psychologists and the market research community, in particular.

Car companies, such as General Motors, have long taken an interest in the attitudes and perceptions of their customers as an input to their product development, and some public transport operators had started to seriously market their services by the 1970s (Hovell et al, 1975). With the development of person trip-based disaggregate travel choice models in the 1970s, some researchers took advantage of the opportunities this afforded to include attitudinal variables in the analysis. For example, drawing on psychological scaling measurement techniques, Nicolaidis (1975) incorporated a comfort variable into a mode choice model, while Spear (1974) measured convenience in his PhD work. However, such attitudinal variables contributed relatively little to the explanation of mode choices - Hartgen (1974) found that such variables only contributed 10%-20% of the total explanatory power of his models - and so this was not seen as a major policy priority, at that time.

A second strand of work dealing with attitudinal aspects of travel behaviour was stimulated through the development of stated preference techniques, which enabled transport operators and product developers to identify optimal combinations of attributes that would result in goods and services which would appeal to particular market segments (e.g. Louviere et al, 2000). Such packages commonly included both objective and subjective attributes. These methods have been extensively applied in order to estimate consumer preferences, market demand and to value product attributes (e.g. time, comfort) and the negative externalities of transport (e.g. noise and accidents), and have made important contributions to modelling and appraisal methodologies.
A third important strand of attitudinal work has sought to investigate the wider subjective components of travel decision making, drawing on ideas such as the Theory of Planned Behaviour (Ajzen, 1991). This has helped to identify the range of personal and peer factors that can affect perceptions, attitudes and intended behaviour, in relation to the conventionally better understood objective decision variables (e.g. travel times and costs). It has led to a large number of studies that have sought to look at attitudinal influences on travel choices (e.g. Anable, 2005).

A fourth area of work has been stimulated by the need to understand and model the effects of improved traveller information provided by ITS systems on traveller behaviour, particularly route and mode choices. The economic theory that underlay the disaggregate travel demand models (and the application of stated preference techniques) assumed that people had access to comprehensive travel information when making choices. Hence, such models could not forecast the effects of improved traveller information, as this was already assumed to be available (or was accounted for in the error term).

Overall, most of this work has been directed at enabling the policy solutions that originated within the other paradigm enlargements (e.g. providing more attractive modal alternatives to car travel) to be investigated and applied in a more rigorous and sophisticated manner. It is only relatively recently that this attitude-based perspective has led to the development of new policy instruments, notably through the application of initiatives such as ‘TravelSmart’ in Australia and the Smarter Choices initiatives in England (Cairns et al., 2004), using a range of information and marketing techniques to encourage voluntary reductions in car use.

In addition, as transport policy has put increasing emphasis on restraining car use, and there have been attempts to introduce more restrictive measures such as congestion charging, the nature and role of public opinion has become of greater research and political importance. With academics in several countries investigating this issue, both nationally and at a European level (e.g. Schade and Schlag, 2003).

During the 1980s and 1990s, another set of concerns began to emerge which affected all the previous perspectives. This concerned the lack of attention that had been paid to changes in behaviour and attitudes over time, and some practical problems that had arisen in attempting to forecast behavioural responses (e.g. evidence of asymmetric behavioural responses and ‘ramp up’ effects, or of path dependency in attitude formation). This led to the development of a fourth major paradigm enlargement that has had an important influence on transport research and transport policy.

2.5 Fourth Enlargement: the Dynamics-based Perspective (P5)

The vehicle-based, trip-based, activity-based and attitude-based perspectives had all primarily looked at conditions cross sectionally, at one point in time – albeit taking into account different needs at various stages in the family lifecycle, for example. The dynamic-based approach provided a longitudinal
perspective (Wrigley, 1986) and added a number of key insights, in particular that:

- Behavioural responses and attitudinal formation are not instantaneous
- There may be ramp-up effects over a number of years
- There may be major leads and lags in decision making
- There may be considerable variability in travel behaviour, from day to day and week to week
- Responses may be asymmetrical, and that
- Decisions may be conditioned by previous experiences.

An early recognition of some of these factors was provided by Goodwin (1977), who highlighted the significance of habit and hysteresis in travel behaviour, and within a decade there was an broad range of research providing a dynamic perspective on transport issues, from car ownership modelling to public transport demand estimation (Jones, 1990).

The dynamics perspective has encouraged the development of household panel surveys, multi-day and multi-week travel or activity surveys, and the use of time series data sets. Much of this has required the application of more sophisticated econometric estimation techniques, or the development of techniques suited to analysing spatial and temporal variation in behaviour patterns (Schonfelder and Axhausen, 2011). It has provided researchers and policy makers with an awareness that individual changes in behaviour are much greater than the observed net aggregate changes might suggest (similar to the distinction between gross and net migration); that long-term elasticities are generally much higher than short-term ones (Goodwin, 1992), so that policy initiatives may take several years to take full effect; that there is considerable inherent variability in daily behaviour; and that habit plays an important role in daily travel/activity behaviour, in limiting responsiveness to policy or market initiatives, in the short term.

While this paradigm expansion has added an important new temporal dimension to all the previous paradigm extensions, it has not added directly to the kinds of primary variables used to account for observed behaviour (other than by using lagged terms).

Its main influence in policy terms, therefore has not been to add new types of instrument to the policy tool box, but rather to encourage a longer term view of the impacts of policies, and to point to the advantages of targeting existing instruments on people at points of transition in their lives, when they are actively considering their travel and activity options. This perspective has proved particularly important given the greater involvement of the private sector in funding major transport schemes, where the speed of ‘ramp up’ and the discount rate have a major influence on cash flow and financial viability.
3. Implications for Policy and Methodology

The figure alongside summarises the five perspectives and their relationships to one another. Starting originally with a vehicle trip paradigm, the addition of person trips broadened this, to view the demand for car travel as being a subset of the demand for personal movement. Similarly, under an activity-based perspective, person trips in turn become a subset of daily behaviour, representing one means of satisfying activity needs – but there are others too. The attitudinal perspective can enrich understanding of the factors affecting decisions taken within a vehicle, person trip or activity perspective, and introduce new kinds of policy instruments of its own; while adding the dynamics dimension provides a deeper understanding of attitude formation, variability and behaviour change.

Each of these five perspectives has its own requirements for data collection and analysis, and has implications for how travel behaviour is modelled, for which policy instruments are considered to provide effective interventions, and for how their potential impacts are appraised/evaluated. Some of these implications for policy formulation and methodological development are considered further below.

3.1 Implications for Policy Formulation

As noted at the start of the paper, each perspective has served to enlarge rather than replace the basic vehicle-based paradigm – although certain stakeholders may choose to operate exclusively within a particular perspective (e.g. the vehicle-based perspective of the motor industry, or the attitude perspective of the market research industry). As a consequence, over time there has been a tendency for transport issues to be seen in less simplistic and more complex terms, and this has greatly expanded the definition of transport problems and the armoury of potential policy instruments. This proposition is illustrated here in terms of the changing treatment of transport performance, environmental issues and the use of urban road space.

In the case of transport performance, the absorption of additional perspectives has led to an expansion in scope over time, both in terms of what is classed as ‘transport’ and what is considered ‘good performance’. For example:

- Vehicle-based: focus on minimising journey times for private vehicles
• Person-trip-based: concern for how the transport system serves the needs of other modes too (buses, cyclists, pedestrians), leading to a move towards minimising person delay

• Activity-based: understanding of the role of transport in facilitating activity-scheduling leading to growing awareness of the importance of reliability, and of having a good tele-communications network as a complement to efficient transport networks

• Attitude-based: users’ perception of network performance, often leading to consideration of a wider range of factors, such as quality of service provision, and personal security; and

• Dynamics: associated with growing interest in network performance in real time, and its ability to recover from shocks of different kinds (e.g. traffic accidents)

From the viewpoint of the environment, when it comes to tackling CO₂ emissions, each strategic perspective offers its own set of potential, generally complementary, solutions:

• Vehicle-based: more fuel efficient and/or alternative fuelled vehicles

• Person trip-based: switch to lower carbon modes

• Activity-based: use tele-services, or trip chain, or carry out substitute activities in the home

• Attitude-based: encourage voluntary travel behaviour change and eco-driving

• Dynamics: target interventions at decision points in people’s lives, allow for build up over time

Probably the greatest lingering influence of the original vehicle-based paradigm is to be seen in the design and operation of urban roads. Here objectives and methodologies still primarily reflect the original vehicle-based perspective, with an emphasis on maximising vehicle capacity at junctions, for example. Sometimes a partial trip-based perspective is adopted, by seeking to minimise journey time delays for all vehicle users, but this rarely includes consideration of delays to pedestrians crossing the road at traffic signals (e.g. see GLA Economics, 2009).

Traditionally, the urban road network is classified purely in terms of its movement or link function, for vehicular traffic (e.g. primary distributor -> access road). Adopting an activity-based perspective encourages a much wider consideration of roads as Places that are important public spaces, where there is economic and cultural exchange, and would also take account of the many non-travel activities that take place on and adjacent to the street (Jones et al, 2007); while adding an attitude perspective would encourage much greater attention being paid to such things as concerns about the quality of the public realm and about levels of street crime.
3.2 Implications for Data Collection, Modelling and Appraisal

Data collection

Each of these five perspectives has its own requirements for data collection, from roadside counts and driver interviews (vehicle-based) to one-off household surveys (trip-based) to panel surveys (dynamics-based); from the recording of trips to the recording of time use (activity-based); and from the reporting of behaviour to the measurement of perceptions and attitudes (attitude-based).

Generally speaking, the profession has been able to keep pace technically with the changing demands for new kinds of data and associated data analysis, although the limited funding for data collection has often been an issue. It has been aided by advances in counting and tracking technologies (licence plate recognition, smart cards, mobile phones, GPS, etc.), as well as by drawing on best practice from other disciplines such as marketing (e.g. see Bonnel et al, 2009). Improved data collection techniques have quickly spread between countries, although the falling response rates in personal interview surveys is a worrying trend in most countries.

The situation is very different, however, in relation to modelling and appraisal. Here there is much less sharing of expertise between countries and a major methodological time lag compared to advances in concepts, data collection and policy debate, with major limits on what can be forecast and assessed in a quantitative manner – and hence, to some degree, what can be funded and implemented. This sustained lag effect and lack of apparent progress is not new; nearly two decades ago Pas (1990) raised this same issue in his keynote conference paper “Is travel demand analysis and modelling in the doldrums?”.

Modelling

Table 1 summarises the general situation concerning the extent to which some of the modelling capabilities that would be useful under different paradigm expansions have been developed – recognising that such a summary is inevitably a simplification and generalisation. It shows a number of areas that still need considerable research attention.

The construction of the vehicle-based paradigm saw the gradual development of the first comprehensive suites of transport models, consisting of vehicle trip generation, origin-destination matrices (between traffic zones) and traffic assignment modules. Modelling from a person trip perspective led to a switch from vehicle to person trip generation (with an added interest in different trip purposes and travel modes), and required the addition of a modal split module which, as previously noted, led to the development of the concept of ‘generalised cost’ and a move to disaggregate choice models. However, the final outputs were still primarily vehicle-based, and were obtained through the traffic/transport assignment models. The resulting four-stage trip model is now well established and still forms the mainstay of many transport modelling
exercises around the world – although the degree of disaggregation varies in different parts of the modelling suite and in different countries.

The inclusion of activity-based, attitudinal-based and dynamics perspectives into mainstream models has been patchy, at best, as shown in Table 1.

<table>
<thead>
<tr>
<th>Paradigm expansion</th>
<th>Vehicle based</th>
<th>Person trip based</th>
<th>Activity based</th>
<th>Attitude based</th>
<th>Dynamics based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Widely used modelling capabilities</td>
<td>• Vehicle ownership forecasting</td>
<td>• Trip generation</td>
<td>• Time of day switching</td>
<td></td>
<td>• Ramp-up effects when forecasting</td>
</tr>
<tr>
<td>Limited modelling capabilities or applications</td>
<td></td>
<td></td>
<td>• Activity set generation</td>
<td>• Modelling impacts of information provision or image enhancement</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Modelling requirements and capabilities under each perspective

While there have been significant advances in many aspects of activity-based modelling (Timmermans, 2005), very little of this work is as yet used in operational models outside the Netherlands and the USA (except in relation to time-of-day switching in models examining the potential impacts of congestion charging). There have been several attempts to ‘bridge’ trip-based and activity-based perspectives, by developing trip tour models from travel diary data, but with varying degrees of success. As a consequence, many of the policy measures associated with this paradigm cannot yet be adequately addressed by standard quantitative models. For example, to what extent can tele-services reduce the need to travel? Does the encouragement of mixed use development lead to greater trip chaining or to trip consolidation?

In addition, activity-based approaches encourage consideration of the impacts of transport policy measures and travel choices on other household members and other aspects of daily life, but very few models have included such wider activity pattern effects. [For a recent exception, see the work by Hensher et al. (2008) on joint decision making in car purchase decisions.]

Similar problems arise under the attitude-based paradigm; here we cannot generally forecast within conventional models the effects of improved information through ITS, or the influence of Smarter Choices initiatives on travel behaviour, which involve the use of marketing campaigns to improve the awareness and image of non-car modes.

In the case of the dynamics paradigm, the problem is slightly different in nature. Here several techniques are available to capture these aspects of decision making, from incorporating leads and lags in model estimation, to
simulating population turnover; but they are not widely used by practitioners, due to lack of suitable data and limited estimation skills within the transport profession.

However, not all issues can be clearly associated with only one of these perspectives. One topic that lies at the interface between person trip-based, activity-based, attitude-based and dynamics-based perspectives is that of travel time variability. Conceptually, this becomes of particular importance within an activity-based perspective, due to the implications of uncertain travel times for activity pattern scheduling; but, in terms of travel choices, it is the perceptions of reliability that are of importance. From the viewpoint of estimating network reliability, this can only be done by looking at networks dynamically, but having taken these perspectives into account, then the concept can to some degree be operationalised within existing person trip-based models.

Although the general thesis in this paper is that it has been the development of paradigm expansions which has advanced thinking and set the policy agenda, this has not always been the case in practice. On some occasions it has been policy ideas that have forced new conceptual thinking (e.g. the influence of tele-working on travel behaviour), and at other times policy and practitioner thinking has been seriously constrained by the available models.

One of the best examples of the latter restricting influence of established models was the use of the fixed origin-destination matrix in traffic assignment modelling. This was adopted during the 1960s, within the vehicle trip-based paradigm, as a known simplification when computing limitations made it impractical to iterate with trip destination choices, and in a policy environment where the objective was to cater for – not constrain – the growth in traffic demand. However, over time, the recognition that this was a pragmatic simplification was lost, and the belief emerged among practitioners and policy makers that vehicle trip demand was inelastic and so had to be catered for (or switched to other modes). This both encouraged the view that increased road capacity would eliminate congestion (and not generate increased demand), and that it would be impractical to reduce road capacity in congested networks (e.g. to provide bus priority lanes). In the UK, it took the SACTRA report (SACTRA, 1994), and subsequent empirical studies, to demonstrate the fallacy of this assumption (Cairns et al, 1998).

Appraisal

In the case of appraisal there has been even more divergence between practices in different countries. But in the UK at least, until recently the techniques have lagged further behind the development of the newer perspectives than is the case with modelling, in terms of their ability to fully operationalise these factors. Taking the UK as an example, Table 2 shows that most of the quantified and monetarised variables used in national and local scheme appraisals are still associated with the vehicle-based or person trip-based perspectives.
<table>
<thead>
<tr>
<th>Paradigm expansion</th>
<th>Vehicle based</th>
<th>Person trip based</th>
<th>Activity based</th>
<th>Attitude based</th>
<th>Dynamics based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generally used appraisal variables</td>
<td>• Operating costs</td>
<td>• Travel time savings by purpose</td>
<td>• Health benefits</td>
<td>• Quality of a journey</td>
<td></td>
</tr>
</tbody>
</table>
| Missing or very limited variables | • Travel time variability | • Value of activity participation | • Value of improved information | • Implications of turnover on valuation
| | | • Value of access/choice | • Value of enhanced quality and image | • Option values for potential future needs |

Table 2: Appraisal requirements and capabilities under each perspective

This means, for example, that the appraisal of sustainable transport strategies has to satisfy appraisal requirements that were originally developed to justify investment in car-related infrastructures. In particular, in the UK:

- Vehicle-related effects are predominant in the monetarised parts of the appraisal process, from operating cost savings, to the negative impacts of air and noise pollution and road traffic accidents.

- The main contribution of the person trip-based perspective is through the valuation of travel time savings, for different trip purposes, which is readily convertible into average vehicle values. Only recently have serious efforts been made to measure the benefits of reductions in travel time variability, which have emerged as being of great importance both from an activity and an attitudinal perspective.

The later perspectives introduced a range of new variables, circumstances and potential policy options which needed to be fully appraised, but current methods only do so in a qualitative manner within a multi criteria analysis framework. In particular:

- Virtually nothing from the attitude-based perspective has yet fed through into formal evaluation, with the exception of some recent work on the journey ambience experience when walking and cycling (Department for Transport, 2009). Most of the benefits of ITS cannot yet be directly captured in appraisals (e.g. benefits of enhanced information and reduced stress)

- From an activity perspective, it might be more efficient to undertake an activity set with reduced amounts of travel (through trip chaining, site consolidation, or in-home activity substitution), but at present reductions in trip rates tend to be viewed negatively: time savings per trip count as a plus, but trips ‘foregone’ tend to be viewed as a disbenefit rather than a benefit.
These more recent perspectives also question more fundamentally some of the underlying tenets of existing appraisal procedures. For example:

- Current UK economic appraisals of travel time savings count the full time savings for existing users, and discount these for up to 60 years ahead. Yet, given the relatively high turnover rates in practice (dynamic perspective), the existing users are nearly all replaced with ‘new’ users within a few years, so should the full benefits continue to be applied, when the ‘rule-of-a-half’ is applied to new users?

- Appraisal focuses on valuing unproductive travel time savings (e.g. driving time) rather than on valuing productive time spent (e.g. working time on a train) – so this encourages transport investment on roads (where time is spent less productively) rather than on rail (where there is more potential to use time productively).

- Metz (2008) has noted that, since travel time budgets have remained stable over decades, it is evident that, in aggregate, travellers do not retain time savings but exchange these for longer distances – so, in the long run, there are no time savings. This suggests that appraisal should be measuring the benefits of gains in accessibility, not reductions in journey travel times.

4. **Conclusions**

This paper has sought to illustrate the important – though little recognised or understood - role played by the prevailing underlying transport paradigm in shaping researcher and practitioner perspectives and priorities, and strongly influencing the development of data collection and analytical methodologies. Each paradigm enlargement has been associated with an influx of new disciplinary concepts and tools, but has left behind many research gaps, particularly in the areas of modelling and appraisal (see Tables 1 and 2).

Looking back over the past 50-60 years, we can observe important legacy effects arising at various stages of the paradigm enlargement – some only temporary, others more permanent - which have constrained much of what is still applied in practice, and influenced some of the academic debates and practices. For example, starting from a strategic, vehicle trip-based paradigm, in analytical and modelling terms:

- The enlargement to person trips carried with it a legacy that has had the following consequences, which have remained for varying periods of time:
  - Short-term: a lack of interest in walking and cycling trips, because they were largely intra-zonal rather than inter-zonal in nature, and were not seen initially as major substitutes for car travel
  - Medium-term: conducting the analysis and modelling of mode choice between car and non-car modes at a trip level, when it is inherently a tour-based decision
  - Long-term: lack of consideration of interactions between household members and their travel patterns, where activities are shared or
allocated, or there is competition for car access among household members.

- The enlargement of the paradigm from person trips to activities has been constrained by the following legacy considerations:
  - The use of travel diary data for most activity-based analysis has prevented an analysis of the trade-off between in-home and out-of-home activities.
  - The discrete analysis of person trips has tended to encourage research on activity episodes (e.g. forecasting activity durations), rather than focusing on examining complete daily activity/travel patterns.
  - The person trip analysis also tends to focus on individual trips by individual travellers (as a legacy from the vehicle-based perspective), and there is very little experience of looking at interactions between the decisions of different household members.

Looking to the future, there is still considerable scope for the later paradigm expansions to stimulate new research avenues and further enrich the policy debate. In the case of the activity-based work, for example, the use of this perspective could be used to investigate the influence of the actions and practices of non-transport agencies on activity/travel patterns. Similarly, there is scope to make much greater use of the attitudinal knowledge in psychology and social psychology, to encourage further behavioural change, or to re-frame debates about traffic restraint and sustainable lifestyles. There is also a long way to go in bringing our modelling and appraisal methods in line with conceptual thinking.

The various paradigm expansions have been associated with an influx of academics and professionals from disciplines other than engineering. For example, econometricians have contributed to work in dynamics, and psychologists to the attitudinal work.

One obvious question is whether there are further paradigm enlargements which are destined to influence transport research and policy thinking. These usually result from issues that cannot be adequately addressed using existing concepts and tools. One recent example concerns the growing importance of leisure and social travel and the recognition of the need to better understand the determinants of such travel. Here insights are emerging from the sociological literature, with contributions specifically in terms of the influence of social networks on travel behaviour (Arentze and Timmermans, 2008), and the broader development of ‘Mobilities’ research (Urry, 2007). While these are adding to research through new concepts, data instruments and analytical tools, it is not yet evident whether, in time, they will add new policy instruments to the practitioner’s current armoury.

One unexpected current observation that is beginning to raise basic questions is the evidence of a levelling off in car use per person in the USA, Australia, the UK and several other European countries (Schipper, 2009). This apparent

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1 It should be noted that there has always been a much stronger social science component to transport research in France (Benwell, 1980).
break between growth in GDP and growth in travel is contrary to what has traditionally been observed, and has major implications for forecasts of future transport growth and the likely levels of traffic congestion and CO₂ emissions. It is an open question as to whether this phenomenon can be explained through one or more of the existing paradigm expansions, or whether addressing it will require further outreach – perhaps through engaging with anthropologists or historians.

At the beginning of this paper I raised the rhetorical question: how different would transport-related research and policy now be if we had followed a Khunian paradigm shift, rather than the actual path of evolution and accretion, with the original vehicle-based approach as its core? Whilst I can only speculate, I suspect that there would be more emphasis on the activity-based and attitude-based perspectives, and the active involvement of a wider range of social scientists. The performance of the road network would be just one area of interest that spanned broad issues of movement, communications and accessibility. Without the vehicle-based legacy, there would probably be much more emphasis on behaviour patterns and lifestyles, well being and the facilitating role of movement in the economy and society. There would probably be a greater attention to more subjective factors, and a stronger concern with meeting a set of broader aspirations of the population, both through travel and other means of interaction.

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