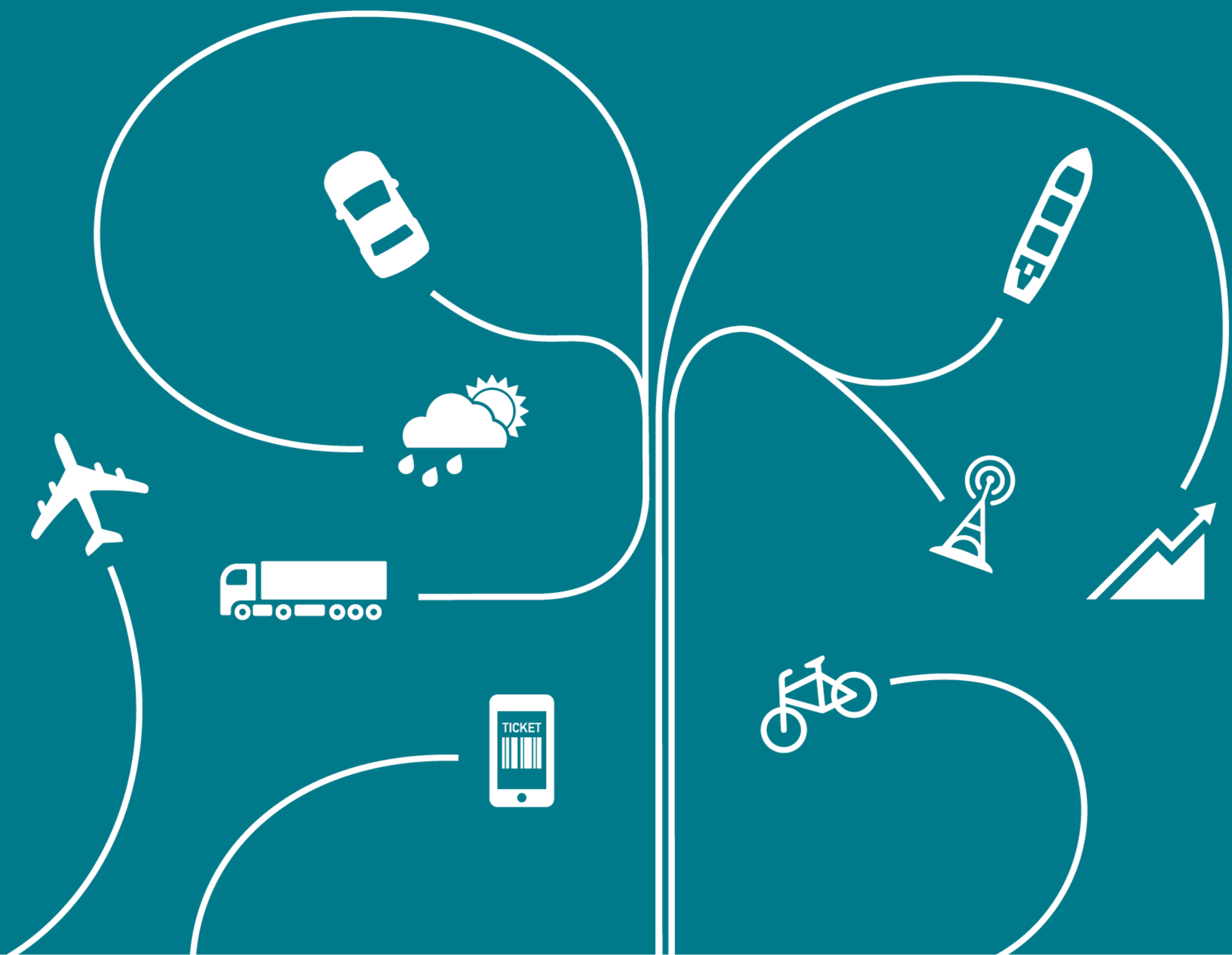
EXPLORING INTELLIGENT MOBILITY

CATAPULT Transport Systems

Modelling for Intelligent Mobility

February 2015



Contents

Contents 1

Document Control 2

Foreword 1

About the Transport Systems Catapult 1

Executive Summary 2

1 Introduction to the Transport Systems Catapult 3

Background 3

What is Intelligent Mobility? 3

2 Intelligent Mobility – the Opportunities 5

Scale of the Global Market 5

Reacting to the Opportunities 6

3 Modelling and Intelligent Mobility 7

New Realms for Transport Models 7

Examples of IM Models Today 8

Accessing this Market 9

4 The TSC Modelling Programme 10

Types of Models 10

Prospective Model Activities 11

Infrastructure and Activities to Support the Modelling Programme 12

5 Governance and Communication 14

Open Engagement 14

Opportunities 14

Appendices 17

Appendix 1 – Modelling Capability and Application areas 17

Appendix 2 - Prospective Model Activities 25

Appendix 3 – Transport Model Reference Architecture (TMRA) 27

Appendix 4 – A National Synthetic Population 28

Appendix 5 – A Data Clearing Centre for Transport 30

Appendix 6 - Reviewers 31

Document Control

Title Modelling for Intelligent Mobility

Authors H Neffendorf, G Fletcher, R North, T Worsley (1st&2nd draft), R Bradley (3rd draft)

Reviewers Model and Analysis Professional Advisory Group (MAPAG); 18 selected external experts; TSC staff

File Ref Modelling Intelligent Mobility – v5-8 – Feb 2015.docx

Issue History

1 – 23/5/14 Initial draft (green paper) – authors

2 – 29/5/14 Second draft – authors, MAPAG (see reviewers)

3 – 18/8/14 Third draft – TSC internal, MAPAG

4 – 16/10/14 Fourth draft – Selected experts, TSC Staff

5 – 24/2/15 Fifth draft – Paper prepared for publication

Foreword

This paper was commissioned to capture initial thinking at the Transport Systems Catapult regarding the challenges and opportunities associated with the adoption of emerging technologies in the design, delivery, operation and use of transport systems. It forms part of a series of documents designed to assist in catalysing UK research and industry to capture a significant share of the anticipated global market for 'Intelligent Mobility' where emerging technologies support the realisation of cost-effective movement of goods and people.

Within this context, there is a need to ensure that UK technology industries and the client bases they serve are well-supported by modelling tools that allow a full range of 'what if..?' questions to be explored. These tools must represent the importance of user, operator and regulator responses to increased availability of data and information and in many cases must go beyond traditional approaches if they are to provide accurate and trusted support for decision-making. This challenge of 'Modelling for Intelligent Mobility' has been identified as a key area where the Transport Systems Catapult can assist in accelerating the development and adoption of appropriate tools and methods for the benefit of UK industry.

The preparation of this paper has involved consultation with expert reviewers from across industry and academia. Our intent is that this forms an introduction to the opportunities in the field, outlines a number of the technical challenges we anticipate, and provides an overview of the initial activities being undertaken to address them. We welcome wider engagement around these topics and our purpose is to identify and develop opportunities to collaborate effectively.

About the Transport Systems Catapult

The Transport Systems Catapult is one of seven elite technology and innovation centres established and overseen by the UK's innovation agency, Innovate UK (previously known as the Technology Strategy Board, TSB)[1]. We were created to drive and promote the Intelligent Mobility market – using new and emerging technologies to transport people and goods more smartly and efficiently. We are helping UK businesses create products and services that meet the needs of the world's transport systems as they respond to ever-stretching demands. We help sell UK capability on the global stage, while also promoting the UK as a superb test bed for the transportation industry. With a clear emphasis on collaboration, we are bringing together diverse organisations across different modes of transport, breaking down barriers and providing a unique platform for meeting the world's most pressing transport challenges.

The Transport Systems Catapult is working in partnership with industry, government authorities and research bodies to champion innovation in transport. We work across all major forms of transport, with an emphasis on seeking solutions that can be applied to multiple modes. The main focus areas include automated transport systems, modelling & visualisation, customer experience and information exploitation. We seek to provide a translational infrastructure including facilities and technical expertise.

The Transport Systems Catapult is a not-for-profit organisation. All Catapults obtain their funds from a combination of core Innovate UK support and competitively won business and public sector funding. In addition, the Transport Systems Catapult is receiving substantial funding from the UK's Department for Transport. When fully established, Catapults are expected to generate their funding broadly equally from three sources:

- business-funded R&D contracts, won competitively;
- collaborative applied R&D projects, funded jointly by the public and private sectors, also won competitively; and
- core public funding for long-term investment in infrastructure, expertise and skills development.

For more information on the Catapult programme, please visit www.catapult.org.uk.

[1] In this paper we generally use 'Innovate UK', notwithstanding the fact that some initiatives and activities described were supported by the organisation under its former guise.

Executive Summary

The opportunities presented by the Intelligent Mobility market and innovations in transport are vast. Market analysis indicates worldwide revenues of over £900bn per year by 2025. A healthy share of this will be open to UK businesses, while the innovation potential of new technology will also improve the efficiency of UK transport and will support economic growth, new jobs and competitiveness. The Transport Systems Catapult (TSC) has been created to help the UK to realise this potential.

Modelling, including data analytics, is a key element of structured transport planning and modern infrastructure management. The TSC recognises the importance of models in helping to promote development of the Intelligent Mobility market. Furthermore, there will be major direct business prospects in modelling itself, associated with the emerging developments. There is a strong UK background and skill in transport models but also much to be gained by new research and embracing techniques from other fields. This paper sets out principal domains and priorities of the Catapult for intelligent mobility involving advanced transport models, how these will be developed and illustrates some of the many opportunities that this can present to users, administrations, researchers, operations and businesses, at home and abroad.

The Transport Systems Catapult is one of a network of elite technology and innovation centres established by Innovate UK (formerly the Technology Strategy Board) as a long-term investment in the UK's economic capability. Applying business-led research, Catapults help businesses transform their ideas into valuable products and services to compete in the global markets of tomorrow.

In the same way that technology is rapidly transforming the conventional view of lifestyle, commerce, product development and customer behaviour, the potential for major and rapid change in transport is being recognised. The emerging Intelligent Mobility (IM) market presents new challenges and opportunities in transport, mainly involving the development and application of emerging technology. It concerns a wide range of transport topics, many of which have so far received limited attention, or are in need of revisiting in light of technological and societal changes.

The IM market needs a range of models to support its development. In turn, models need skilled analysts, data and tools. Some applications are in areas familiar to the mainstream of transport planners but many are not; a wider body of modelling specialists will also participate. The TSC intention is to focus on the use and application of new technologies and insight to areas of modern transport that are most promising but are sometimes less well understood, or where persistent barriers to adoption remain.

Everything the TSC does is to be designed to lead to market growth, jobs and better transport. The emphasis on models will be in areas that are likely to yield high benefits in terms of the TSC objectives. The TSC does not intend to be specifically active in well-established, conventional areas of transport modelling and scheme appraisal, although naturally there will be interactions. It will complement and build on promising areas of innovative research by providing a translational infrastructure of software, hardware and data facilities, with the technical expertise to assist in the development of commercially-deployable tools. The TSC wishes to engage actively with modelling specialists to pursue the opportunities together and to accelerate market adoption and penetration.

The TSC plans for modelling have been developed through consultation with leaders in academia and industry. We will focus most strongly on development of synthetic environments (simulations) and use of real-time data feeds, together with data sources and standards to support innovative, integrated models and analytical approaches. It aims to share the benefits of this work with the wider community and to pursue and facilitate projects to involve other professional modellers.

UK modelling professionals are encouraged to recognise the new range of opportunities, to interact with the TSC and to adapt their research programmes and market activities where necessary to be among the international leaders in the field. Please contact us at modellingforIM@ts.catapult.org.uk.

1 Introduction to the Transport Systems Catapult

Background

The Transport Systems Catapult (TSC) was announced in March 2012, with the overall goals of accelerating commercialisation of new technologies, helping businesses to grow by benefiting from UK research and hence enhancing UK growth in transport systems markets.

When opening the new TSC Intelligent Mobility Innovation Centre on 12 June 2014, Dr Vince Cable, Secretary of State for Business, Innovation and Skills (BIS), said:

"Our network of Catapult centres brings together the very best of the UK's businesses, scientists and engineers, to work side by side on research and development, transforming ideas into products and services that people will want to buy and sell. This new innovation centre will ensure the UK is well placed to profit from the increased demand for high-tech transport solutions - creating jobs, supporting businesses, and driving economic growth."

The TSC has agreed with BIS four critical success factors. These are, broadly:

- improvement in the efficiency of UK transport infrastructure;
- growing the UK presence in international Intelligent Mobility (IM) business;
- increasing UK jobs in IM; and
- securing a self-sustaining future for the TSC.

All of the TSC activity can be considered in relation to these success factors. The TSC was set up with a fundamental aim to support and help grow UK activity in transport, with a focus on the IM market. While they must be self-sustaining, the overall working principle for all the Catapults is one of collaboration and sharing. The TSC is embarking on suitable programmes of work in an open and inclusive way and wishes to cooperate with UK businesses, administrations and researchers to align a wide range of interests to support and be involved with IM.

What is Intelligent Mobility?

Over recent years, the global demand for transporting people and goods has increased significantly, opening up new opportunities and substantial challenges. Emerging technologies, including mobile devices, the internet of things, open data and wireless communications are becoming increasingly important in supporting the transport and mobility demands of the future. New service offerings are being developed, with new characteristics requiring innovations in all areas of the transport system.

While the UK is well positioned to take advantage of the opportunity through its expertise and capabilities in transport system modelling, design, planning and testing, there is scope to do much more to ensure we create and maintain a world-leading position. The TSC describes these concepts as 'Intelligent Mobility' (IM) and further defined this through its vision to:

"Drive UK global leadership in intelligent mobility promoting sustained economic growth and wellbeing through integrated, efficient and sustainable transport systems"

Intelligent Mobility explores new and different ways of increasing the efficiency of moving people and goods. It demands greater integration with, and cuts across, multiple industry sectors and systems wider than just transport. It helps shift consumer, industry and government behaviour towards more appropriate and efficient user-led and demand-led strategies; impacting commercial, social, economic and environmental strategy and planning.

Within this, there is specific attention to the role of innovation, emerging technology and information services. The focus, as stated, is on enhancing the movement of people and goods, together with advanced management of infrastructure and assets. All modes of transport are in scope.

Some of the early challenges that will be addressed through the TSC include seamless journey systems, remote asset management and monitoring, innovative traffic management and control systems, real-time journey assistance systems, infrastructure integrity and security, advanced/autonomous vehicles, and novel economic and business considerations.

Longer term issues will also be important. Among those already identified are the impact of transport system innovations on land use (and vice versa), consideration of transport with other domains (e.g. health, climate), whole life asset management and introducing principles of systems engineering.

The use of mathematical models pervades these activities. Many new concepts are unproven or face challenges in moving from ideas or proof of concept stage to full-scale deployment and market adoption. For these reasons, a platform to provide sound planning and evaluation of simulations and forecasts is essential. Modelling such challenges has been difficult but we now have access to data and tools that were previously unavailable and much more is now possible.

The market potential for Intelligent Mobility worldwide has been estimated to grow to over £900 billion per year between now and 2025 (see next Chapter). While this includes a wide spectrum of activities, it is clear that there will be vast business opportunities, including many new projects over the coming years. There will be considerable work for researchers, suppliers and consultancies, including those involved in modelling.

The TSC seeks to lead the way in unlocking local, national and global economic and social benefits across a wide range of connected markets for UK-based businesses to lead and exploit. TSC intends to serve as the unifying entity supplying the translational infrastructure that can provide the focus for innovation in the emerging Intelligent Mobility market as needed to ensure the UK continues to lead the way. The TSC will also continue to maximise the opportunity afforded by Innovate UK and Department for Transport (DfT) grant funding to deliver benefits to the wider UK community.

2 Intelligent Mobility – the Opportunities

Scale of the Global Market

The Transport Systems Catapult (TSC) vision is to "drive the UK's global leadership in intelligent mobility, promoting sustained UK economic growth and wellbeing[2]". In order to pursue this vision the TSC seeks to focus the market on the worldwide IM opportunities that the UK can exploit. It will identify the global markets within transport systems which will grow and provide the greatest opportunity for UK exports. This information is to be shared with UK stakeholders.

To begin with, the TSC has undertaken a market review[3]. The global transport market has been estimated to be between £2.6 and £5.2 trillion (World Bank, 2013) and, while it is expected to grow in real terms, the proportion of the worldwide economy spent on transport is not expected to change significantly.

There are, however, global trends that highlight a need to obtain more for less and develop:

- user focused transport systems - to meet the needs of an ever connected world and an aging population;
- integrated transport systems - to maximise the capacity of transport;
- efficient transport systems - to meet global resource demands; and
- sustainable transport systems - to address global social, environment and economic risks, particularly climate resilience.

The market review explores the factors that enable this view of transport systems to develop. Intelligent mobility cuts across and goes beyond the traditional transport sector. It utilises the emerging technological trends to support these user-focused, integrated, efficient and sustainable transport systems. These enabling markets are estimated to grow from £137bn globally in 2014 to £907bn in 2025.

In particular there are large markets and growth in the areas of:

- mobile-commerce[4] from a 2014 value of £52bn to a 2025 value of £296bn;
- customer experience[5] from £0.3bn in 2014 to £91bn in 2025;
- transport 'internet of things'[6] market from £5bn in 2014 to £41bn by 2025;
- passenger information systems from £3bn in 2014 to £35bn by 2025; and
- data management and opportunities around open data from £9bn 2014 to £32bn by 2025.

Within the estimates are global figures of £15bn growing to £60bn for data, modelling and analytical tools & techniques.

The market review is the first stage in what we envisage as a continuous process of refreshing our understanding of these markets as they evolve. This process will involve engagement across all sectors.

---

[2] Transport Systems Catapult 5 year Delivery Plan (2013)
[3] Intelligent Mobility Market Review, April 2014.
[4] **Mobile commerce** – offering opportunities to engage in commercial activities while mobile (or pre-journey)
[5] **Customer experience** – combining real world activity with computer generated enhancements (e.g. augmented reality).
[6] The **internet of things** consists of things/objects/machines that interact with each other via the internet over fixed and wireless networks (MarketsandMarkets, 2012). With the internet of things, everyday objects fitted with sensors and devices will process information and act on this information independently of direct human control. They will initiate the transactions and influence each other.

Within this we anticipate ongoing engagement with industry to develop a series or future market projection scenarios to assist in identifying priority actions for UK industry, and to ensure that TSC activities remain well-focused.

Reacting to the Opportunities

We are clearly in a rapidly changing world where organisations can thrive if they adapt to the opportunities. There are already clear signs that conventional views of many markets are not sustainable and are being replaced by new types of services and products. To a large extent, we are moving into a monitor and respond mode in an environment that will be rich in real time data (a data-driven paradigm). These are concepts that will resonate with decision-makers keen to find more compelling evidence and methods in a field where advances in *info*structure are going to be at least as important as continued investments in *infra*structure, especially given typical timescales for infrastructure delivery. It is increasingly necessary to address what is on the mind of policy-makers rather than answer yesterday's questions. As planners and analysts we must change our game to usefully inform the debate on the issues identified in order to remain relevant.

The message from this analysis is to adapt and take advantage. It is acknowledged that there are already appropriate skills available and there has been much discussion of the IM issues. The challenge now is to accelerate their development and practical adoption. Organisations are encouraged to prepare actively, to engage and embrace the vision. Where R&D budgets are available these should be aligned or directed to these new horizons – this naturally also applies to academic research. Collaboration will be essential to avoid fragmentation of the opportunities, and to ensure that all the necessary resources are brought to bear.

In particular, it is recognised that the market projections, while impressive, do not translate automatically into benefits. Public authorities and the private sector alike require very strong business cases for any investment and a generalised picture will not suffice. Consultants have an important part to play in showing clients how the high level numbers can be translated into direct and profitable ventures. Researchers must explore and develop the pipeline of concepts, providing a sound theoretical grounding. The TSC role is to foster promising innovations, taking suitable initiatives to advance technology readiness levels and working with the transport community to seek growth and new jobs.

The emerging Intelligent Mobility markets represent an enormous (£900bn per year in 2025) opportunity for the UK. The TSC role is to provide the translational infrastructure necessary to foster technology development for rapid market uptake of innovative products and services. It will thereby help to influence international developments and to illustrate the benefits that are attainable.

3 Modelling and Intelligent Mobility

New Realms for Transport Models

Modelling involves the use of mathematical expressions and digital data to design, build and manage planning (forecasting) tools, real time linkages and simulation systems. These are used to test and evaluate alternative system management methodologies and to examine alternative future supply and demand scenarios to improve system efficiency, cost-effectiveness and resilience.

Projects built using emerging technology capabilities need to be assessed. If the IM market is to grow as predicted such projects must sometimes compete with traditional schemes as well as other investments for scarce public and private funds. The sponsors or developers of these systems will often need support from the transport modelling community, looking for the expertise to justify and support their policies or businesses. However, the potential market for ways in which transport modellers can help is changing; new elements of the IM market do not necessarily know that these modellers are there or even what can be done. The TSC will publicise the advantages of models while encouraging the modelling community to adapt and promote itself more with an appreciation of IM market opportunities.

Criteria used to appraise the merits of model-based forecasts provide a critical means of determining the customer base for any modelling. Businesses with consumer-oriented technologies will be interested in using modelling for such matters as demonstrating to themselves and others the efficacy of their systems, and understanding likely levels of market penetration. At the same time there are established processes for evaluating whether transport infrastructure changes offer adequate societal, economic and environmental benefits. For some cases the customer base has distinct private and public interests, each with distinct appraisal criteria. However, many technological developments for transport will require or benefit from the engagement of both public and private sectors and the modelling outputs will consequentially need to be relevant to both public and private sector appraisal criteria. By giving more attention to how appraisals of new transport technology are undertaken, the TSC will help modellers to gain a clearer view of understanding and broadening the potential customer base.

Modelling these systems involves much more than traditional transport planning models. It extends to such topics as working with data in real time, simulating synthetic environments[7], modelling human behaviour and interactions, connections with land use and the economy, the environment and climate. IM systems can be about changing the customer experience and thus will affect travel decisions, sometimes during the course of a journey. This might alter how travellers perceive their journey and the value placed on time savings. Interventions using emerging technologies might not only affect the amount of congestion, but also the impact of the congestion on the economy and thus the viability of a scheme.

With its brief of "creating jobs, supporting businesses, and driving economic growth", the TSC will operate in a different, more technological domain than the policy and infrastructure-oriented world of much current transport analysis and modelling. However, there will be many cases when the two must overlap.

Transport models are relatively well developed for some applications in the UK and the TSC does not intend to focus where there is already sound activity. In particular, this would apply to techniques using aggregate trip models for scheme appraisal (as portrayed in the Department for Transport WebTag guidance), traffic micro-simulation, vehicle scheduling & routeing and conventional freight delivery logistics. While these naturally could be improved with more attention, they do not seem to be a priority for intelligent mobility, although IM research and development will gain from and have spin-off benefits

---

[7] 'Synthetic environments' refers to a set of technologies that seek to join up advanced models and simulations in order to facilitate experimentation, concept exploration and product development. They enable existing computational models, virtual environments and simulations, people, objects and equipment to interact in a virtual world. For further explanation in a transport context see:
http://webarchive.nationalarchives.gov.uk/20091204071822/http://www.dft.gov.uk/pgr/scienceresearch/futures/synthetic/syntheticenvironment.pdf

for conventional models. There will, however, be a focus on integration across model types and levels in order to support coherent analysis. New applications of models will also require standards and guidance, and these logically should reflect established guidance, where appropriate, to support common evaluation.

There have, of course, been previous attempts to tackle modelling in new environments – perhaps the TRANSIMS initiative in the USA is the most often cited. It is also noted that models are used widely in most other domains, some very advanced, and that there is much to be learned from such experience. The TSC will consider lessons learned in such approaches as we seek to develop our modelling activity.

In summary, we are facing an ever more complex and evolving world in which modelling of cause and effect becomes more challenging. The TSC wishes to help to harness more strategically the UK's existing modelling capability in pursuit of innovation that can deliver benefit to those participating.

Examples of IM Models Today

Modelling is not an end in itself but is a support activity to enhance understanding, appraisal or design of initiatives. It appears in many forms and ranges from relatively simple formulae of cause and effect to elaborate representation of complex synthetic environments. Since the interests of the TSC are broad, covering such diverse topics as autonomous vehicles in traffic, behaviour responses of travellers with interactive information, intermodality (person and freight) and the application of real time and 'big' data, all forms of model can find a role. Appendix 1 describes a set of initial classifications for modelling capabilities and application areas. The box here contains just a few existing examples of model developments that indicate the variety relevant to the TSC:

Highway Control – Innovate UK's SBRI[8]-sponsored development of an interactive visual environment to simulate Managed Motorways for training and the testing of operational concepts.

Airport Security – A security supplier engaged a computer games firm to create a visual model of person behaviour at baggage check operations at airports.

Air Traffic Arrivals – The TSC is working with the air industry to develop a whole-flight model to assist with better timing of departures in relation to external factors and desired arrival times.

Maritime freight – the TSC is investigating improved integration of land and sea-based container movements for greater efficiency, with modelling of implications for port and road infrastructure.

Driverless Vehicles – The TSC is supporting experiments with autonomous vehicles to include impacts on traveller behaviour, considerations of data exchanges and their impact on other traffic.

Journey Planners – All types of modern journey planner (including en route tools) involve models but many lack cross-modal integration and any reflection on how information affects travel decisions.

Rail franchising – The value of investments in technology is challenging for estimation and evaluation. The TSC is developing methodologies to support innovation in rail franchising.

Synthetic Population –A detailed synthetic model of individual people and households for the whole population of Great Britain can support a variety of applications, including travel studies[9]. The TSC is pursuing this concept to underpin new types of behavioural models and research.

Big Data – New datasets (including mobile phone and SatNav sample data) open new opportunities for the transport sector and are being widely investigated. However barriers exist. The TSC seeks to work with all elements of the supply chain to understand the issues and facilitate their resolution.

[8] Small Business Research Initiative

[9] For example, the University of Leeds-developed MOSES Project implementation – see Appendix 4.

The transport modelling world being envisaged is one where data is exchanged seamlessly (between people, vehicles and infrastructure and all combinations – i.e. models in the loop with live data feeds). This is a world where real life can be reflected virtually and experimental interventions introduced to immediately understand their impacts – where data trends can be used to predict impending issues and operational decisions can be proposed. Thus, the conventional views of demand and supply become somewhat blurred by personal availability of mobile technology. There is a challenge to appraise new types of initiatives in the context of new technology so that they can compete for investment and deliver meaningful benefits.

New technologies can be transformative of traveller behaviour, although basic habits, interests, and constraints can also mean that some behaviours remain entrenched over time. It will also be relevant to predict the decision *not* to travel due to the requirement being replaced by technological advances. This balance and transition of behaviour needs to be reflected fully in the models and associated appraisal methods.

Practical experimentation will also feature, along with modelling. A particularly important case, mentioned above, is that of autonomous vehicles. The TSC is involved actively in trials of such vehicles and sees that the planning and policy issues raised will test the boundaries of modelling. Person behaviour, impacts on land uses, vehicle interactions and safety are all factors that need research and development if the potential benefits of autonomous vehicle developments are to be realised.

Accessing this Market

We believe that to lead global development of this emerging market, modelling specialists will need expertise on the use and application of new technologies and insight to areas of transport that are less well understood. Similarly, non-specialists will need to trust the outputs of these methods to support decision-making.

The TSC is building and facilitating a portfolio of projects in IM, many of which will require models. The TSC aims to actively seek out opportunities for the UK industry and to help bring together sources of funding to support development and investment to exploit those opportunities. Our message for the research and consultancy community is:

> The large, emerging Intelligent Mobility market needs new, innovative modelling to fully reach its potential. The TSC is committed to helping to make that market grow for the UK to exploit. The TSC wants to work with modelling professionals from academia, industry and government to build a strong capability to assess these new types of projects.

4 The TSC Modelling Programme

Types of Models

The issues raised by intelligent mobility require use of the full range of modelling and visualisation tools, as depicted in Figure 1 below.

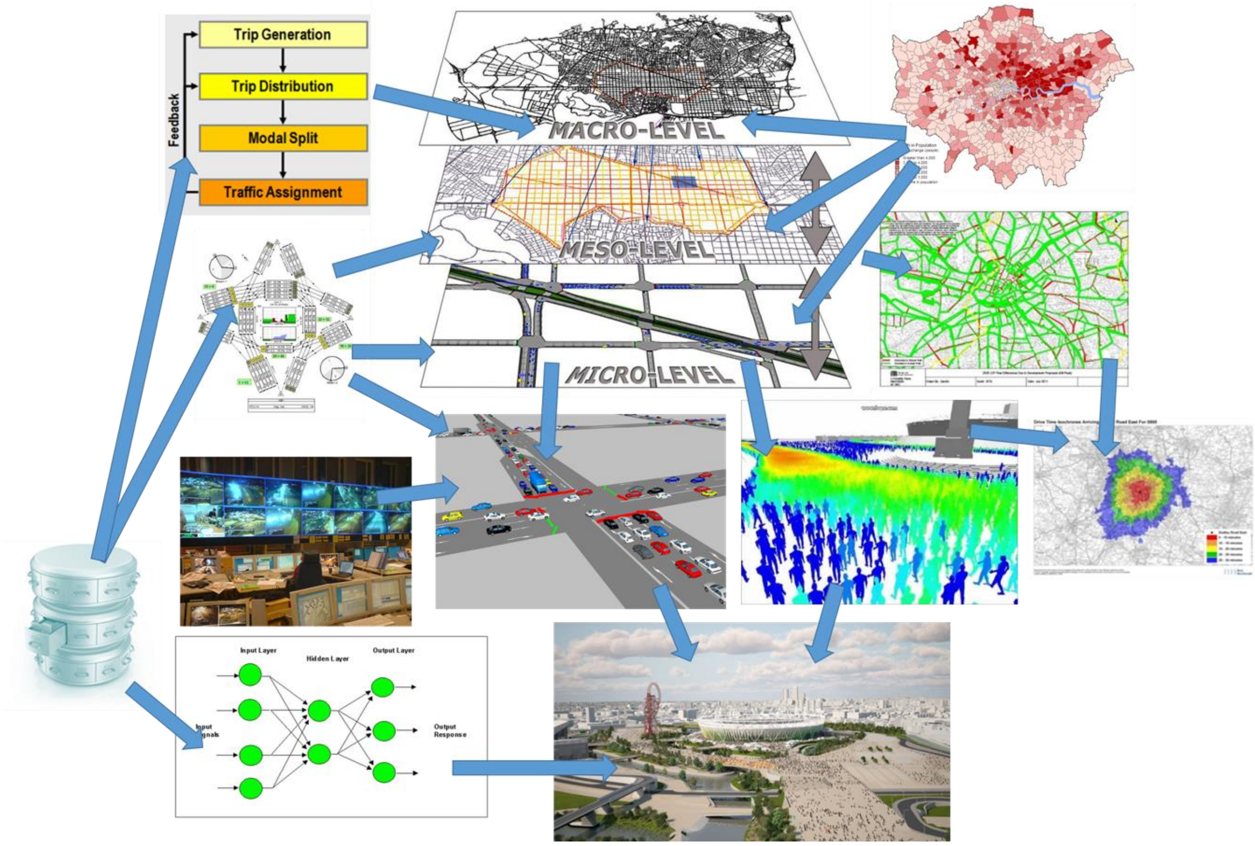


Figure 1: Simplified overview of interlinks between model types[10]

Some of these images represent planning methods that have a long history of development and application in transport and will be used in accordance with best practice. Others, involving real time data and behavioural representation of people or vehicles as modelled agents, are less extensively utilised in general practice and will be the focus of research and demonstrations. Some types of models from systems engineering or from other domains are not indicated explicitly in the diagram. But it is clear that a broad approach will integrate types of models and that attention to standards and interoperability is key to success for a multi-faceted modelling programme.

Models will be applied appropriately for varied applications. There needs to be attention to the granularity of the methods that is suited to the issues under consideration and the quality of data available. Uncertainty of model outputs and associated risk will receive particular attention. Demonstrating an ability to portray the relative robustness of likely outcomes can provide a distinctive aspect to the TSC-

[10] This figure uses a composite of images sourced from other publications. With thanks to The Greater London Authority, Transport for Greater Manchester, Mott Macdonald, ARUP, Transport Simulation Systems (TSS), JCT Consultancy, Electrosonic, The University of Sheffield, University of Leeds, Hofstra University, Italian Symposium on Advanced Database Systems, and the Centre for Traffic Research.

supported modelling and can exploit advances made in other fields in respect of handling uncertainties in computer modelling.

Prospective Model Activities

The TSC model activities will take shape as projects develop and as methods are identified or proposed. Some of these will not yet have been considered thoroughly by the TSC, so the process will be flexible and additional input is welcome. However, based on early thoughts and discussions with many stakeholders, a preliminary, if currently partial, list of topics of most interest is presented in Appendix 2. These interests are associated fundamentally with IM project and research issues rather than the much broader conventional activities of concern to transport planners.

Appendix 2 contains a very substantial 'wish list'; more than an organisation can develop fully within its own resources. However, recognising what already exists, working actively with others and seeking to prioritise realistically can achieve much. Of course, there is substantial good research and development work going on elsewhere in most of these areas and the TSC does not wish to duplicate but rather to provide the translational infrastructure necessary to support rapid progress from proof of concept to industrial adoption at scale. Continuing dialogue and collaborative activities will be managed to ensure joined-up projects. Figure 2 (below) illustrates areas that we see as requiring support in the coming years.

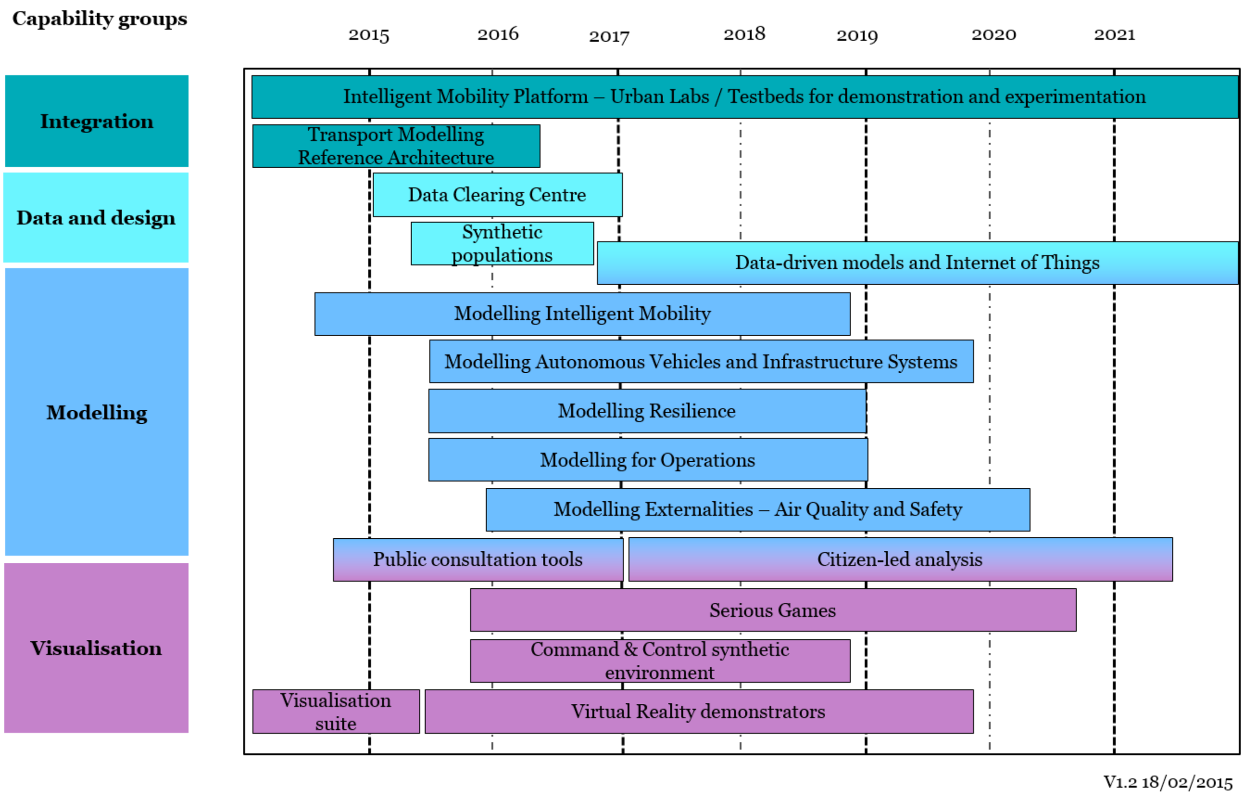


Figure 2: Illustrative roadmap for TSC modelling and visualisation translational infrastructure.

With collaboration in mind, priority developments are to:

- Review technology readiness and key capabilities for IM modelling in the UK.
- Assemble the TSC translational infrastructure to include software tools and visualisation suite.
- Developing with industry a number of data interface standards to improve the integration and interoperability of models and modelling data (see Appendix 3).

- Develop a synthetic population for activity and simulation models (see Appendix 4).
- Create a Data Clearing Centre to facilitate access and use of transport-related datasets (see Appendix 5).
- Create reference implementations of innovative approaches to demonstrate new capabilities

In some cases, pilot proof-of-concept work is required to support subsequent developments. Further details are described in the Appendices, and will be the focus of future activity and events where we will seek to engage with representatives from the transport modelling community from all sectors.

Infrastructure and Activities to Support the Modelling Programme

Innovation in transport systems modelling, and in the assessment of the implications of Intelligent Mobility faces many barriers. The development and adoption of new solutions can be accelerated by the provision of consistent platforms and associated technical support in a translational infrastructure. To support this concept, investments are being made in acquiring and configuring hardware, software and technical expertise internally at the TSC.

Simulation modelling is seen as a key capability. As well as a focus on standards, the TSC intends to obtain tools and data, with access to state-of-the-art computer resources, to support the emphasis on synthetic environments and their visualisation.

There is a growing attention to simulations in many domains and while there are several attractive principal benefits, simulation approaches also face challenges and limitations including those summarised in Table 1.

Table 1: Summary of benefits and challenges of simulation models

Benefits	Challenges
Allow representation of a real life situation in laboratory simulation when it would be more costly, difficult or impossible to create the experiment in the field	Data input can be hard to obtain, interpret or integrate
Explicitly represents process models of sub-systems and their interactions	Links in the model chain can be weak
Create data for analysis or publication	Computing power is often demanding and data output can be voluminous
Facilitate interactive models where human or system decision-making can be represented, tested and developed	They can be demanding of domain expertise and attract scepticism (is it just a game?)
Support excellent visualisation that helps explain the simulation to decision makers (or to the public) and to involve a range of people in decisions	Validation is sometimes difficult (particularly when allowing human inputs!)

These limitations can be treated but must not be ignored. The TSC will apply and demonstrate simulation techniques in ways that illustrate their advantages while managing their potential restrictions. In so doing, we seek to collaborate with existing expertise within and beyond the traditional transport modelling community.

To support this activity, we are initiating work to design a basis for behavioural modelling involving a zone-free national microsimulation of population, household and job details at local levels. This will be a synthetic demographic base on which to build a variety of tactical and strategic transport models, supporting game simulations and aggregate models, also linking with Smart Cities initiatives. It will facilitate research into activity-based modelling and simulation demonstrators that will showcase the potential. More information on the concept of the synthetic population appears in Appendix 4.

The TSC also plans to offer project resources to support modelling professionals. These include such activities as:

- forums, workshops, seminars and conferences;
- opportunities to experiment with state-of-the-art techniques, models, data and hardware;
- facilities to test integration through trials and prototyping;
- standards development and publication;
- training; and
- a web library of reports, papers and articles.

These will involve collaborative working and relationships with existing providers where appropriate and to avoid duplication.

These components of the programme are squarely in the domain of modelling intelligent mobility. They concentrate on collaboration, integration, reuse and open access. The TSC is not reproducing the expertise of existing consultancies and researchers, nor does it intend to compete to their detriment. It wants to work with others to find the correct way to explore and pursue these new opportunities and to help develop transferable methods and efficiencies that might not happen from other programmes. The TSC also sees that adoption of standards approaches from other domains is a key enabler to promote collaboration with a wider industry. Our platforms are being built to not only deliver the modelling needed for our own projects, but to trial and demonstrate these procedures and open standards in transport.

To a large extent, we are witnessing a switch in focus from building infrastructure with 50+ year lifespans to continually evolving market-driven services and pricing solutions that dictates a fundamental shift in our approach to forecasting. Strategic planning will remain important, but with a greatly increased tactical emphasis that focuses on operating existing systems more efficiently. Data mining and pattern recognition, coupled with gaming of alternative futures, are far better suited for such pursuits. A deep understanding of the factors that we think influence current choices will be matched by being able to better understand and track the choices that are being made.

Modellers are able to adapt to these emerging challenges and researchers or consultants often will innovate when required by a project. It would be wrong to imply that people in the transport sector are not doing the kind of things set out in this paper – they are, and have the capability to do more if asked.

Significant expertise already exists; the technical capacity and ingenuity are there, but addressing IM issues has been *ad hoc* to date. The TSC aims to support the industry to identify potential barriers to development well in advance through independent horizon-scanning activity, industry and academic engagement, and clear communication. Through this we seek to influence the research agenda as it evolves and to leverage support for key issues faced by those actively addressing the IM market.

5 Governance and Communication

Open Engagement

The TSC approach will be open and consultative, as befits an entity supported by public investment. The management structure will ensure good practice, with an aim to engage support and participation. Links will be maintained with the Department for Transport, Highways Agency, Network Rail, Transport Research Laboratory as well as other industry or research bodies and local authorities where appropriate.

In particular, the TSC maintains close liaison with Innovate UK and the DfT regarding details of its work programme, since these bodies fund elements of the work. An independent Model and Analysis Professional Advisory Group has been established with a core and floating membership to provide expert input and assurance to the programme. That group has participated in the preparation and review of this paper.

In developing these activities, the TSC is conscious of the need to properly treat collaborator background IP, and to suitably protect and develop foreground IP for the parties concerned. The TSC is adopting a flexible approach to IP rights, which will be addressed on a case-by-case basis. Our own IP is not anticipated to be a primary source of TSC income, but will nevertheless support our long term sustainable business model. We will seek to support SMEs and collaborators through provision of commercialisation services and to facilitate access to funding sources for new ventures.

The TSC will participate actively in (and will sponsor) modelling conferences and seminars, arranging its own as appropriate. It will provide a forum for constructive challenge to orthodox thinking as well as a medium through which existing (sometimes competing) capabilities in the UK can work together for mutual advantage. Periodically, thought pieces will be written or commissioned from external specialists to stimulate professional discussion. We intend to clearly communicate our progress and to publicise opportunities for organisations to become involved in developments or consultations.

Importantly, there is also considerable activity around the world in the Intelligent Mobility market – international relations are important. The TSC will maintain a vigil, scanning for innovation, and will seek involvement and liaison with international experts and activities. Project participation (e.g. EU research and development) will be sought, working with UK and foreign partners as appropriate.

Opportunities

Efficient transport systems are essential to the health and wealth of the UK, its businesses, its economy and its citizens. The key challenge is how to innovate to increase mobility: the efficient and cost effective movement of people and goods. The TSC will support UK industry in exploiting the massive global market for new products and services that will drive the integration of transport and its systems by providing a translational infrastructure to accelerate the development and adoption of innovations.

The work of the Catapult will be developed in liaison with those that can benefit most – private sector firms that can exploit the techniques, researchers that can be part of the concept, consultants who can provide project expertise and public sector bodies that are seeking best practice and efficiencies and the authorities responsible for ensuring appropriate levels of rigour in appraisal. Collectively, we can innovate and accelerate the development of tools and techniques that may take much longer to gestate in the 'normal' world of modelling.

There are three main routes by which we seek to increase technology readiness levels in industry from proof of concept (at level 3) to best practice market adoption (at level 8) as illustrated in Figure 3;

- **Facilitation** where industry is investing effectively in delivering new technologies and innovations to market. The TSC role lies in facilitating the adoption of such methods through showcases of capability, hosting training or briefing events, brokering relationships and accelerating market growth.

- **Collaborative Research and Development** where technologies and innovations are developed jointly. Here, TSC activity is configured to address barriers to wide-scale market adoption, to assist in de-risking the transfer of new techniques into transport applications, for example through the deployment of reference case experiments, access to prototyping data feeds, or high-grade computer and visualisation facilities.
- **TSC Research and Development, then Technology Transfer** where industry barriers are high, or the development process is perceived to be too risky. The TSC will work in conjunction with academic and research collaborators to increase the technology readiness level of innovative solutions. As these reach maturity, we will seek opportunities to transfer the technology into industrial practice.

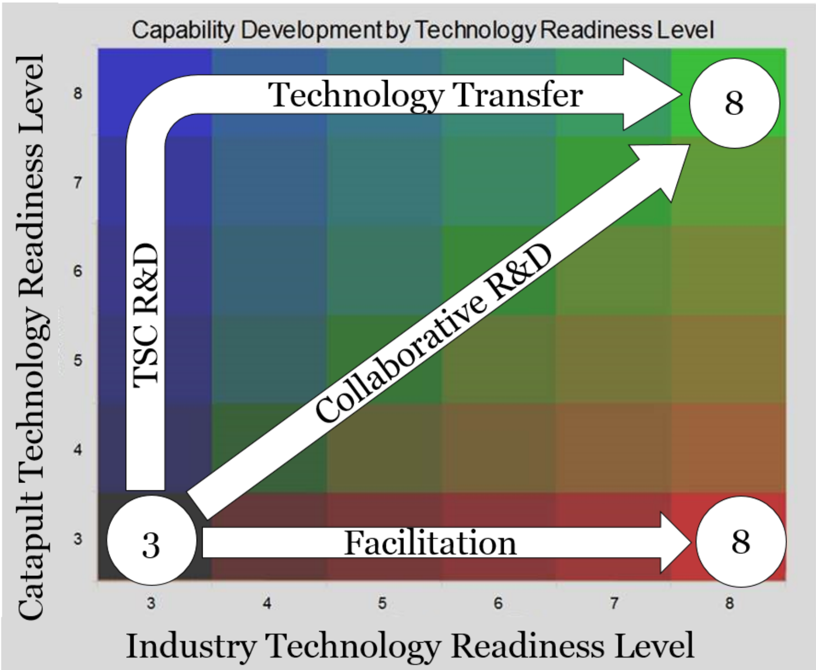


Figure 3: Mechanisms for engagement to enhance Technology Readiness Levels in industry

A given innovation development programme may interface with TSC activity in different ways, at different times. We will seek to co-ordinate and prioritise our projects and collaborative bidding activities in order to provide appropriate input on a case-by-case basis.

Wide engagement with industry and academia is essential and the TSC has been engaged actively in both academic and practitioner forums. This activity will be continued and extend over time.

With academic partners, in most cases the TSC will focus on exploitation, integration and dissemination activities with the university undertaking the fundamental research. Academic engagement to date has included:

- Collaborative R&D bidding and project delivery (e.g. the University of Oxford on the LUTZ[11] Pathfinder Programme; The University of Cambridge, Open University and the University of Oxford on the UK Autodrive project);

[11] Low-carbon Urban Transport Zones, an initiative supported by the Automotive Council to examine the potential of driverless pods as an urban transport system.

- Support for research grant applications, studentships and staff placements;
- The Universities Partner Programme (UPP)[12], which will assist in creating 'fuzzier' boundaries between academia, innovation development and industrial practice through the movement of people and skills between the universities, and between them and the TSC Intelligent Mobility Innovation Centre to break down barriers to collaboration.

Some of the new model work and tools will be capable of being used more widely in industrial practice, at home and in support of exports. As prototypes and reference cases are developed, the Catapult will be a showcase for UK ingenuity and capability.

Consultancies, in particular, can benefit from the opportunities of the IM market. For example, they can:

- Promote Intelligent Mobility concepts in project evaluation. This will help to create the market for these evaluations and establish the UK a leader in this field, capturing the value for its businesses.
- Help to define the tangible benefits from IM in support of business cases for investment.
- Seek to integrate transport systems modelling with adjacent domains. Intelligent Mobility is about more than transport and there is already much relevant work elsewhere. We need to be able to integrate with other modellers from outside the transport field.
- Aim to reuse. We need to be able to re-task models to answer all sorts of new questions. There is a need to make our modelling tools and data more flexible.
- Continue to innovate. The UK should adopt business and technical structures that make innovation faster and more effective. This domain will move quickly so, to keep up and even lead, it is necessary to be more innovative, not more protective.

Interfaces to software and data providers will also be of great importance. The TSC translational infrastructure will use a variety of software tools and has already begun to acquire some of these. It is interested to liaise and work with software providers (necessarily including those from other countries) to enhance their offerings in an inclusive manner. However, the focus will be on an open approach to standardisation and developments, so the TSC will avoid being tied to any proprietary tools or data formats.

In all cases, the TSC will seek to stimulate opportunities to access funds and support for collaborative project opportunities for organisations that have skills and interest in model development, application or research. This is expected to include a range of industrial parties, Small-Medium Enterprises (SMEs), government and academia. In addition to examples cited above, the TSC is able to engage experts for advice and to help with development of methods. Activities will be facilitated through liaison with other client groups and funding bodies – particularly in cases where the TSC is not in a position to pursue direct contracts.

In summary, it is hoped that all participants in UK transport will seek to engage and to explore the opportunities, bringing forward ideas or responding to the proposals of the TSC. We seek to support the development and adoption of world-leading methods to model Intelligent Mobility innovations. We welcome your feedback and input. Please contact us at modellingforIM@ts.catapult.org.uk.

12 The TSC University Partner Programme (UPP) includes 14 universities in eight partnerships. These universities were selected following an open request for proposals. Initial partnership agreements are for up to three years to encourage long term relationship building. Current members of the TSC UPP are: The University of Leicester and The University of Nottingham; The University of Sheffield and Sheffield Hallam University; University of Leeds; Loughborough University, Nottingham Trent University, De Montfort University and Coventry University; University of Aberdeen and Heriot Watt University; University of Cambridge; and University of Southampton.

Appendices

Appendix 1 – Modelling Capability and Application areas

Chapter 3 gave some examples of IM projects today that involve modelling. Here, we provide more detail regarding areas of interest described in early TSC investigations and descriptions of capability and application areas for modelling[13].

Modelling capability areas

We propose initial definitions of eleven Capability Areas to cover the range of capabilities relevant for Modelling for Intelligent Mobility. Note that Capability Areas C6-C11 are concerned with cross-cutting capability that is relevant to modelling activity generally, and not just confined to transport. All of these areas are represented to some degree in transport modelling currently, but there scope for tapping into leading expertise in these areas, irrespective of whether it is presently connected to transport.

C1. Behavioural Economics: Demand, Route and Mode Choice

This lies at the core of the modelling that supports transport planning decisions. It incorporates (for example) estimation of existing Origin-Destination demands from travel survey / link-flow data and future demand predictions based on incremental changes in transport supply. Demands are fed into economic models of individual behaviour to solve traffic assignment problems, i.e. predictions of how demand will divide over different modes or (in the case of road) different routes. This area is thus an application of behavioural economics with the classical approach based on rational actor theory. New emerging directions include better behavioural models involving incomplete information or bounded rationality. Generally speaking, fully dynamic traffic assignment problems, where the demands within-day are strongly time-dependent and where, for instance, departure time may also be variable, are extremely challenging, and computationally intensive. The sensitivity analysis of the forecasted flows is also very poorly understood. Finally, the predicted flows should then be fed into more detailed modelling of the performance of links etc. (Capability Area C5 below). The utility that results then feeds back into the demand and choice modelling.

C2. Land Use and Long-Range Economic Modelling

This area is related to Area C1 above, but concerned more explicitly with the bidirectional feedbacks between transport supply and future land-use. Future provision of transport supply encourages new development, which feeds into economic activity and drives travel demand, which in turn requires the provision of further transport supply. Like Area C1, this area is concerned with supporting travel planning decisions, but over even more extended time scales (several decades at least). It is a very challenging area which is generally poorly understood. A topical example would be the benefit-cost calculation for HS2 – the forecasts range very widely. Associated to this area, some modellers are now concerned broadly with the long-term evolution of urban area and function. For example, do cities with particular spatial patterns of population and businesses operate more efficiently than others? Like Area C1, this area is associated with the evolution of the transport system over long time scales.

C3. Travel Behaviour Modelling

This is an emerging direction in travel demand modelling that is at the interface with the Social Sciences. Its rationale is that the classic behavioural economics of Area C1 oversimplifies the decisions involved in whether or not and how to travel. Topics that might be grouped within this area include activity-based modelling (i.e. demand is driven by requirement to perform a particular activity, rather than to go to a particular place), and the complex decisions involved in trip-chaining and the fitting together (for

[13] This appendix builds on initial analysis provided by the Smith Institute for Industrial Mathematics and System Engineering under contract to the TSC in February 2014. Further activity to refine these classifications is anticipated.

example) of the journeys of a given household and the shared use of their vehicles. Also within this area is Travel Behaviour Change, i.e. consideration of what external factors at the level of individuals drive changes in the modal split. This is often analysed by quite detailed ethnographic studies of individual households, although the National Travel Survey could also be viewed as belonging to this area. This theme often has a particular focus on the active modes (walking and cycling), health, lifestyle changes and life-long changes in travel behaviours, and modelling access to transport for the elderly or disabled. Traditionally, this area has not been as quantitative as some others, and perhaps not even considered as "modelling", but its inputs are crucial in understanding the response of travellers to innovative changes in the transport system.

C4. Human Factors

Like Area C3, this area is concerned with fine-scale modelling of individual human behaviour. However, the focus here is not on broader decisions of whether and how to make trips, but the factors that influence behaviour during journeys. For example, how do travellers respond to particular sorts of prompts, delivered e.g. via their satnav, smartphone or variable message signs. Hence there is an overlap with the academic area known as HCI (human-computer interaction). Also included here is how humans respond to other forms of automation, e.g. autonomous vehicles, and more broadly how attention is focussed during the driving task. On a different tack, we have also bundled in here some expertise associated with detailed engineering design / function, for example, how detailed design of space affects use, or for example, how seating arrangements on public transport influence accessibility. Like Area C3, this heading might not be viewed traditionally as "modelling", but its input can be considered and modelled in innovative transport solutions.

C5. Microsimulation and Tactical Forecasting Models

Like Area C1, this is core activity in traditional transport modelling work. Microsimulation (also known as Agent Based Modelling) is simulation where the motions of individual entities such as travellers and vehicles are explicitly represented, often with some simplified attempt to represent their decision-making processes (usually, in highly simplified form). It is connected to Area C6 below, because very often it is not at all obvious how the macroscopic outputs are related to and emerge from the interactions at the individual level. Well-known examples of microsimulation software include traffic flow simulation packages such as VISSIM, PARAMICS, AIMSUN, etc. However, the modelling capability is not the packages themselves, but in understanding how to use and adapt them, and in the ability to build simulations of new systems with different sets of agent-based rules. For example, pedestrian flow models are very often agent-based too, and also microsimulation models have been built to understand long-range land-use questions. However, the usual focus is on making forecasts / descriptions of the use of the transport system over within-day timescales. For this reason, we have also bundled here other types of modelling (e.g. continuous queue modelling and fluid dynamics modelling) that also consider traffic dynamics on within-day timescales.

C6. Model Integration and Complex Systems

This is a very broad area. At one end it incorporates Complexity Science: the study of emergent properties of systems based on microscopic rules, as a function of the connections between the basic entities, and which is rooted in Network Science and Statistical Mechanics. At the other end, it includes people who sometimes say that they work in Complex Systems or that they are Systems Thinkers – this is a less quantitative science but is involved in trying to understand very broadly the boundaries of very large systems and how their various components interact. (This is sometimes related to Systems Engineering.) We also include in this area general mathematical expertise in model fusion, model parametrisation and validation, uncertainty propagation, and black-box modelling techniques such as emulation and expert elicitation. We feel these are essential skills that must inform the development of successful large-scale modelling platforms.

C7. Control

By Control (or, as it is sometimes called, Control Theory or Control Engineering), we mean specifically expertise in understanding and building automatic control systems, or at least expertise in implementing them in relevant areas. For example, on motorways, Ramp Metering and Controlled Motorways speed limits would be examples of such systems; at an urban level, we have adaptive signal control. However, this area could also extend down to the low-level control of individual vehicles, be they trains or driverless cars. If there is an intention to couple models with dynamic hardware tests, in an approach sometimes called dynamic substructuring or hardware-in-the-loop, significant Control Theory expertise will be required. In some cases, where this area relates for example to dynamic (re)scheduling (e.g. of trains or aircraft), sometimes called "dynamic OR", there is an intersection with Area C10. Finally, as it relates to decision support systems, there is an intersection with Area C8.

C8. Artificial Intelligence

By this we mean quite narrowly the branch of Computer Science that develops machines and software with human-like intelligence. The particular relevance here is in replacing human controllers with automated ones – hence there is an intersection with Area C7, but here we mean that the controller is much higher level and probably in the form of a "black box" whose internal parameters might well have been trained from observations of human controllers (supervised learning). These "controllers" might replace or provide decision support for humans in traffic control rooms, provide more finely tuned control of traffic lights, or indeed drive automated vehicles in unconstrained environments (e.g. the Google car). Traditionally, Artificial Intelligence includes the field of Machine Learning, but where this relates to the extraction of knowledge from data, we have bundled it in Area C9.

C9. Data Science and Statistics

This is a very broad area. Here we mean everything from fundamental work in Statistics, including uncertainty propagation, extreme value theory (for consideration of extreme events) etc., through to large-scale data analytics or "Big Data" as it is often known, i.e. finding patterns in large (possibly unstructured) data sets (often a form of unsupervised learning). It includes expertise in novel data visualisation and manipulation techniques. We also bundle here expertise in sensor / data fusion, sometimes referred to as "developing a single representation of the transport network's state". Finally, we also take under this heading unique expertise in the nuts and bolts of particularly useful data sets, even if it does not include fundamental expertise in data science or statistics.

C10. Operations Research and Scheduling

This is the science of (discrete) optimisation with respect to constraints. In transport, the most relevant aspect is that of scheduling, e.g. of trains, aircraft and logistics operations. However "OR" is a field in its own right whose core expertise should be more strongly engaged in transport modelling, in our view. Note there is a distinction between "static OR" (in this context, finding best schedules where the future is assumed to be known at some level) and "dynamic OR", which is the problem of (re)-scheduling in the face of uncertainty. Dynamic OR is an extremely challenging area which should be used in future to inform transport systems operations at the tactical level, and design decisions at the strategic level. For example, the rail timetable's optimisation does not presently take into account that trains usually do not run on time.

C11. High-Performance Computing

For our purposes, we mean simply expertise in porting very large scale computations to cutting edge hardware platforms – be they implementing real-time algorithms that are coupled directly to a transport system's operations, or off-line computations that are used to inform planning decisions.

Modelling application areas

The capabilities summarised above can be applied to a wide range of application areas to inform alternative analyses. To facilitate discussion and market analysis a set of fourteen application areas have been initially defined (areas A1-A14 below). Their descriptions have been developed with reference to early thinking around priority opportunity areas in the Intelligent Mobility market;

A1. Parking

Modelling the use of parking facilities, their location, ease of access and availability/use has clear implications to improving traveller experience at interchanges, where adequate facilities play an important role in the operation of park-and-ride, airports, rail stations, etc, and may be seen to provide part of the first modal change point as part of a multimodal trip. Provision and encouraging adequate use of such facilities is also important in ensuring there are viable option available in the event of disruption and can encourage and incentivise travelers to use alternative transport networks, while appropriate availability and locations can improve the travelling experience and be incorporated into end-to-end mobility services which may increase whole journey accessibility. There are connections with several other applications where ITS can enable the dissemination of parking location and availability through mobile services or Variable Message Signs (VMS) in an urban network, making parking search faster and thereby minimising network congestion.

A2. Intelligent Transport Systems

Intelligent Transport Systems (ITS) allow the optimisation of transport systems by the collection and provision of information to decision makers, which may be individuals or traffic managers, allowing them to make more informed choices regarding trip time and/or mode choice or in the case of managers to optimise system operation by control systems such as traffic signals. The provision of such information leads to a better traveller experience at interchanges. Comparing information from different modes according to personal circumstances and needs improves the travelling experience and allows choices to be made whether or not to use alternative networks in the event of disruption. The ITS mechanisms themselves can be constructed to increase the availability of end-to-end mobility services. Because much ITS is designed to minimise congestion, there are natural economic knock-on effects, not only for the individual traveller but for the freight industry, where just-in-time delivery is vital to success. ITS is broadly applicable to all transport modes, although focus is mostly given to road transport, where a far greater degree of individual variation can occur, leading to a system that is harder to model and control.

A3. Active modes

Active transport modes (e.g. walking and cycling) are by definition always used as some part of every journey, even if it is only walking to the bus stop or from the office to the car park, to and from a car park or through a leisure facility. Understanding the needs of these modes (and in particular what drives the individual) is important in the provision of safe and efficient streets, facilities and interchanges and allows alternative methods of movement such as short-term bicycle hire. For example, by enabling smooth passenger movements within a railway station or ensuring shopping facilities can be safely evacuated, one increases the attractiveness of these modes, leading to minimisation of car journeys with economic and health (not least exercise) benefits.

A4. Multi-modal

Understanding how to undertake a global optimisation of a transport chain consisting of trips taken on more than one mode (e.g. road-rail-road), is a core aspect of transport master planning with clear implications for investment and policy at the highest level, both for passenger and freight movements. Such modelling allows exploration of the design of end-to-end mobility while optimising the overall trip and ensuring the robust operation of the network, through the facilitation of a wider range of routing options for individual trips. Implementation of multi-modal strategies is made possible through the dissemination of information and recommendations through ITS, in particular journey planning applications, and sees its widest applicability in passenger transport, where decisions and modal choice can be made swiftly and more easily.

A5. Interchanges

The nodal points at which multi-modal trips change modes are critical in ensuring the efficient movement of people and freight and in ensuring that the user experience encourages further use of particular modes and facilities and multimodality. For example, a badly designed airport or rail station may cause travellers to consider using alternative interchange points, or to abandon using air/rail completely. Freight movements in particular may often be overlooked, but are a vital interchange activity when one considers, for example, air freight and the import of goods through ports from sea traffic, with optimised load/offload being vital to aircraft and ships observing strict departure windows.

A6. Metro and Rail

Rail and Metro operations form one of the primary modes of transport in the UK and their efficient and safe operation is vital to the movement of people and goods. Their operation and attractiveness (reliability, capacity, etc.) are vital in maintaining rail as a viable alternative to road transport, both as a normative transport mode as part of a multi-modal journey, and in the event of disruption, with immediate economic and health impacts. The movement of freight by rail is a particularly important issue and understanding its economics compared with road transport is a core issue affecting the industry. ITS has also affected rail use with online and mobile applications allowing travellers access to timely information about their trip, route, and their choice of how to use rail as part of a multi-modal journey.

A7. Freight

The specific modelling of freight movements and activities and logistic planning (e.g. of delivery chains) is critical to business delivery, consistency and resource planning. There is clear impact on trade and supply, but also on traffic congestion, in both the road and rail networks, where in the former case HGVs can reach 40% of traffic on particular links. Safety (for example HGV accidents in urban areas, particularly in conjunction with active modes) and emissions are further issues. The smooth movement of goods from source to delivery point may also require the use of a range of modes and well-planned interchanges, both in terms of access and operation, together with fall-back strategies to ensure on-time delivery in the event of congestion/accidents or other disruptions that may necessitate the use of re-routing. ITS has played a vital role in facilitating this information through the delivery of timely advice, while online delivery services benefit from widespread use of scheduling and delivery mechanisms.

A8. Road - urban

Urban road networks are the most commonly used infrastructure and their optimal management is vital in order to benefit the economy and increase quality of life, through the movement of people and freight, while minimising emissions and accidents. Ease of access through and within cities and towns is also a critical factor in delivering and enabling viable transport alternatives in the event of disruption, say to the local rail network, and in encouraging the use of other transport modes by providing quick and easy access to interchanges such as rail stations and ports. Freight movements within the urban road network can be particularly problematic and present safety problems, particularly in the presence of high flows of active mode travellers, and can be aided by specific routing and/or better urban design. ITS is a vital enabler for managing urban traffic, with information not only being drawn from a widespread sensor network, but control becoming possible through traffic signal control strategies that may include signal pre-emption for public transport and emergency vehicles.

A9. Road - highways

Highways form the connectors between cities and urban areas for road transport and are the main service provider along with rail. Operational norms of flows and speeds, and deviations from them, provide information that can be used in management and planning, for example in the detection of congestion. Strategic and tactical plans can then be formulated to manage traffic on a day-to-day basis, thereby minimising the impacts of congestion, and also to utilise both the urban and inter-urban networks effectively in the event of an incident. Many of these plans and strategies can be implemented through ITS, for example using the managed motorway paradigm of combining routing and speed advice through VMS with speed enforcement.

A10. Road - public transport

Understanding how to provide an efficient public transport service as an alternative to car-based travel can play an important part in keeping cars off the roads and minimising congestion, thereby aiding the economy and improving quality-of-life for the individual traveller. Understanding the operational service requirements, for example optimal timings, wait times, etc, provides a service which has the confidence of the public and better caters to their needs, allows synchronisation between services in different modes, and improves resilience when using alternatives in the event of disruption. Conversely, information on ridership and delays encountered can be used by ITS in order to monitor network performance and aid the optimisation in both the short and long term, through, for example, bus priority signalling. Delay times can be displayed to waiting passengers to increase confidence in the service and allow them to make more informed choices about whether to wait or use an alternative mode.

A11. Waterways

Waterborne transport, primarily sea, is critical to the delivery of freight into the UK and forms the first delivery point for incoming goods. While water transport enables international connection, it can also play a role in everyday passenger trips (e.g. the Thames RiverBus), thereby providing an alternative travel mode that can be used as a fall-back option to more conventional modes such as the Underground. Modelling of waterway traffic could be viewed as being more straightforward than road traffic (where human behaviour and choice plays a greater confounding role) or rail, where there are evident capacity issues requiring OR methods. Research is ongoing into the management of 'Motorways of the seas', where the inherent scale means that issues such as safety and emissions can be of far greater magnitude in terms of their repercussions.

A12. Emissions / energy modelling

Modelling of energy use enables long-term planning that emphasises routes, trip chains and indeed individual modes and links which consume minimal resources. Meanwhile, the modelling of emissions is critical more generally in understanding impact on quality of life, and particularly so for freight and air traffic, which produce disproportionately more pollutants. There is also a role in designing contingency plans for alternative network use and re-routing strategies in the event of disruption, the impact of which may also be assessed by emissions modelling as part of a holistic impact assessment including capacity and accident risk. ITS has been used to address emissions in terms of recommending 'green driving strategies' or 'green-wave' traffic control, where synchronisation of traffic lights can be used to minimise stop-go driving. Additionally, increased attention is also being paid to marine traffic, where recent modelling is revealing that international freight shipments may be contributing far more to emissions than previously thought.

A13. Accidents

The modelling of accidents encompasses models for their prediction, impacts, and repercussions, as well as strategies for coping with them by re-routing or through the use of alternative transport networks. Accidents have clear economic consequences, both in terms of loss of time through congestion and direct loss of life costs. Their probability may be reduced through the adoption of routing strategies that lead to the segregation of particular modes, for example HGVs and active mode travellers. Accidents themselves can also be reduced through increased use of ITS, such as collision warning and other in- vehicle safety systems, as well as modelling studies of accident causative factors enabled through data loggers.

A14. Air operations

Air transport provides an essential high-speed connection between the UK and (primarily) other countries and is a vital component in the multi-modal transport chain. The facilitation of strong international links brings economic benefits in terms of business and tourism, although set against this are impacts such as noise and emissions. Air operations include both air traffic management and airport ground management, the latter of which is important to the through flow and transferal of freight. The international ubiquity of air travel has perhaps aided in its development, because there is far less national variation possible than in all other modes, except perhaps shipping. This leads to faster adoption of improved operational principles and technologies, in turn allowing for more regulation and optimisation. Capacity increases are now often a function of operational economics and land availability.

Additional areas of interest

Some additional examples are summarised here to illustrate a small subset of further potential application areas of interest. This is intended to stimulate discussion rather than to represent a prescriptive list;

- Digital Profiling. Travellers who sign-up to IM services can co-curate their digital profile. Ideally cloud-based, this profile allows an individual's preferences to be used by IM services to tailor suggestions for improvements to their journey. It also allows the system to be self-learning for the individual, or the group that the individual represents. This data can then be later used in models to suggest better alternatives.
- Personal journey planners based on mobile devices are likely to be a key tool for IM users. Prior to travel, the location, timing and purpose of activities can be scheduled within the electronic calendar and the mobile app becomes a 'journey angel', providing advice to help optimise the activities during the day. Among other benefits is the richness of data collection from such apps. This has the potential to partly replace the collection of travel diaries and conventional intercept surveys. Furthermore, when an IM user is faced with a choice of alternative options following an event, the data collected reveals details of the individual's perception of travel, which could be used to calibrate models.
- Existing models generally assume perfect knowledge – or an approximation which is close to that state. One of the first steps in producing a model to show how seamless journeys supported by superb information available throughout the journey is to reconstruct models to more accurately capture the imperfect knowledge, poor/inadequate information, difficulties with connections and so on.
- Personal journey planning also represents a policy tool that could reward IM users for using certain options. An interesting example is the Rotterdam peak avoidance scheme in which travellers were paid to travel outside the peak. Modelling and preparing business cases for such schemes and policies is likely to be required.
- It would also be possible to model the reaction of transport providers to IM users. For example, models can be used to predict near-future spikes in demand for travel on local services, which could result in additional services being released in time or at least support planning for more active capacity. This is a familiar approach in the electricity industry, for example.
- On the supply side one could also simulate a tiered transport control structure to provide both tactical planning and near-future real-time modelling. This can be seen today with the National Traffic Information Service (NTIS) using dynamic traffic assignment to predict congestion and suggest alternatives. The HA operates this at a national level but a current revamp is expected to introduce more local diversions, which adds a lower tier of priorities for a regional or local authority.

- A powerful new tool for modellers is the cross-referencing of real-time data and modelling against static datasets. In near-future forecasts used by control centres, this could help to set priorities for different areas to help the operator choose the best option. Furthermore, in autonomous controllers, the particular needs of an area could influence the allocation of capacity. For example, capacity could be checked against known local air quality issues, or to give priority to goods vehicles under defined circumstances. Controllers can also be linked to models, such as traffic microsimulations, to support automated decisions and self-learning. It is feasible for modelling to be shrunk to operate automatically on customised circuit boards at in-stations (e.g. side of the road) or out-stations (e.g. control centres).
- Cross-referencing also includes real-time data with real-time data. An example might be to combine traffic data with information from vehicle computers, such as transmitting increasingly automated aspects such as headlights, temperature sensors, windscreen wipers or tyre pressure monitors to improve traffic control actions that also consider ambient weather, etc.
- IM extends to urban centres where mobile devices use beacons (Bluetooth, WiFi, etc.) to triangulate the IM user's position, providing accurate user locations to provide relevant information. This has clear uses in IM and again might provide modellers with some interesting data to help build models.
- Modelling has a great opportunity to provide a holistic view of an IM user's day. Increasingly, data is available on the use of smart electricity and gas meters and this type of indication of activity could be added to behavioural models to better understand decision making, for example trip timing.

Appendix 2 - Prospective Model Activities

In Chapter 4 it was noted that the TSC had begun to identify modelling topics of interest for near-term development. A selection of these appears in the box below with additional description.

Data for models, including big data and real-time data – Data is essential for modelling and has emerged as a priority throughout our investigations. The TSC will probably not hold extensive amounts of data itself but wishes to identify sources, facilitate access for modellers, support understanding and promote best practice, including a focus on standards and on visualisation. Open data and open source analytical tools are an important element and the TSC will maintain a vigil on relevant Open public sector information. Consideration of errors and biases in data is most important to appropriate sample expansion and application. Better ways of obtaining travel demand matrices and transport network data will also be pursued, in conjunction with others where appropriate. This has clear interfaces to the proposed *Data Clearing Centre (see Appendix 5)*.

Activity modelling behavioural studies – It is vital to improve our understanding of transport user behaviour, particularly in terms of the likely impacts of new technology, increasing information availability and innovative transport solutions. Framing person travel demand in the context of household structures and activities is a subject of growing importance. Personal access to immediate information is a new dimension for models of behaviour. However, dimensions of activity models can involve complexity and over-fitting and will often be better for exploring behaviour than for long-range forecasting.

Errors and uncertainty – appear in data, models, assumptions and externalities. The TSC will take care to be aware and explicit about these effects in applications and metadata and will seek to promote discussion on this important and somewhat neglected topic.

Synthetic environments/simulation/gamification/visualisation – large scale agent simulation will be a particularly prominent feature of TSC modelling.

Econometric microsimulation - can also be relevant to reflect the general and distributional impacts of policies over time. These can be spatially detailed and linked to the concept of a synthetic population.

Social/economic dynamics and 'what if?' modelling – better understanding of how transport links with changes in modern society will support IM model development at the macro and detailed levels.

Systems engineering (including systems of systems links with non-transport models in aspects such as health, weather, energy, finance, social, etc.) – The TSC wishes to integrate varied models to generate results that cannot be obtained from isolated views of society. Models that are not yet mainstream in transport will be considered in a pluralistic manner that considers the relative strengths of different modelling methods.

Land use/transport interaction - how transport shapes land use/economy/employment – Although there has been much work on LUTI models, it remains an underdeveloped field relative to the importance of the subject. It is clear that the dynamics of transport and land use require better understanding, particularly in a technologically enabled Smart/Connected world.

Freight movement forecasting – Given its importance, freight demand modelling has received relatively little attention and there is scant guidance on how to approach it. Models that reflect better the movement of commodities and the operations of the freight industry are required to help analyse and justify IM in freight.

Intermodal/multimodal modelling – The TSC objective for seamless journeys requires improved treatment of intermodality in models.

Demand management; asset management; network resilience – This topic relates largely to new technology in the operation and physical fabric of transport systems, where there is much impressive activity already, but with an increasing role for remote monitoring and action. Optimisation of networks involving a mix of standard and autonomous vehicles is becoming relevant. Simulation models with an ability to look ahead (sometimes near term or predicting in real time) have great potential.

Short term prediction – operational decision support can benefit from robust methods to predict forward over short time windows based on current network state information. Alternative control interventions can be assessed to guide and manage system performance. Increasingly, interfaces between transport systems.

Evacuation strategies – Simulation models are finding an important place in planning for emergencies and it is likely that some TSC model developments could find a role in this area.

Accessibility analysis – Current studies of accessibility tend to focus on travel time contours, but a greater range of factors can be considered. There is an interest in how the use of technology and information affects accessibility and even the need to travel.

Pricing – If pricing and revenue earning opportunities return to prominence in the transport agenda, their impacts will also become part of the online information mix for which IM models will be relevant.

New technology in operations – Many TSC initiatives are likely to be concerned with innovative transport operations and provision of information to travellers and system managers, including within-journey updates. Smart/autonomous vehicles are relevant here, as is operational pursuit of environmental objectives. Such interventions often require modelling to predict their impacts.

IT and transport in a wide sense, including the internet of things – Technical advancement and horizon scanning clearly pervade the TSC thinking, including simulation based on understanding of the huge growth in mobile and fixed-item communications.

Evaluating major technology interventions in transport infrastructure – Transport assessment and investment evaluation is currently undertaken in a fairly narrow framework, with many effects difficult to quantify. It is particularly necessary to gain better insight where interventions are unusual in scale or in their familiarity, such as those involving technological changes. This naturally extends to environmental and social impacts, where current appraisal methodology already provides a starting point.

Appendix 3 – Transport Model Reference Architecture (TMRA)

Data interface standards have the potential to improve the integration and interoperability of models and modelling data. A reference architecture in the field of software or enterprise development provides a template solution for an architecture for a particular domain. It also provides a common vocabulary with which to discuss implementations, often with the aim to stress commonality.

To support the TSC vision of activity in Intelligent Mobility markets, the intention is to foster development of a Transport Model Reference Architecture (TMRA) that can be made available to all transport modelling organisations, creating the conditions for wider participation, open competition, access to new providers, and the international marketing of UK skills and products. Such an architecture is common in other domains, notably defence, but not yet in transport, so it is described here with some technical background.

The objective of this TSC initiative is to introduce higher levels of interoperability across the transport modelling community and data suppliers. The proposed strategy is to establish an adaptable development environment within the broader TSC modelling facilities and allow stakeholders to benefit from shared data and models on a collaborative and commercial basis, providing incentive for all parties to work towards common definitions and formats. In due course, the programme can expect to be measured against its ability to drive cost efficiencies through improved access to reliable datasets, greater interoperability across data and models, and new export potential for the UK's transport related services. Ensuring sustained investment and maintenance of the initiative will be an important pre-requisite.

The TMRA has to be based on a design that is compatible with real time, simulation and planning models. Standards for this breadth of modelling have been developed in other domains but less so in conventional transport planning, notwithstanding efforts to provide practical guidance. The proposed backbone for TSC modelling capability combines the well-established High Level Architecture (HLA)[14] and Service Oriented Architecture (SOA)[15] concepts, primarily for real time management and linked simulations, and for planning models respectively. While simulation is a main focus for the TMRA, there will be elements of planning models involved, with recognition of the many internationally available tools and methods.

A common information architecture is fundamental to this strategy and will provide the structure to develop and expand the many data definitions by which models will communicate across both the HLA and SOA. Key to this is an emphasis on standards for data exchange, including model outputs to achieve higher levels of interoperability and improved IM modelling services. TSC intends to provide leadership and resources, working with the profession, to promote such standards.

---

[14] A **High Level Architecture** (**HLA**) is a general-purpose architecture for distributed computer simulation systems. Using HLA, computer simulations can interact (that is, to communicate data, and to synchronise actions) with other computer simulations regardless of the computing platforms. HLA is an established interoperability standard for distributed simulation used to support analysis, engineering and training in a number of different domains.

[15] **Service Oriented Architecture** (**SOA**) is a software design and software architecture design pattern based on distinct pieces of software providing application functionality as services to other applications. This is known as service orientation. It is independent of any vendor, product or technology. A service is a self-contained unit of functionality and can be combined by other software applications to provide the complete functionality of a larger software application. SOA makes it easy for computers connected over a network to cooperate. Every computer can run an arbitrary number of services, and each service is built in a way that ensures that the service can exchange information with any other service in the network without human interaction and without the need to make changes to the underlying program itself.

Appendix 4 – A National Synthetic Population

Many of the 'Intelligent Mobility' issues of interest to the Transport Systems Catapult require a more insightful treatment of modelling. As new levels of journey information (prior to or within journey) become available, as car technology, ownership and usage within households evolves and technology changes the nature of and need for travel, it becomes increasingly necessary to move away from aggregate trip models to use of microsimulations of behaviour and links with real-time data. There is a therefore a desire to treat people more as individuals within household groups and to appreciate the interactions and decision processes involved with circumstances and life's activities rather than aggregate representations of group behaviour patterns.

The TSC wishes to explore such an evolution in a meaningful fashion. It will tackle significant issues without being constrained unnecessarily by convention. With a strong TSC focus on agent-based simulation methods, a synthetic environment treatment of personal transport modelling is entirely appropriate.

Concept

A synthetic transport modelling environment, usually involving simulation of chains of behaviour, needs to start with a good representation of individuals in the population. Such information is not available readily due to confidentiality of such data, but methods are available to derive very good estimates of the population and its characteristics.

It is fairly common in the USA to prepare very small area level family and person 'unit records' that are controlled to margin totals for the same small areas, typically from the population census. This has been done for some cities and states and is based on individual distributions of population characteristics derived from the Public Use Microdata Sample (PUMS) of anonymised unit census records. The distributions are built into a simulation that delivers very detailed and realistic demographic data for imagined individuals in households that comply with the small area controls. The method has proved powerful for studies that need to appreciate person and household level activity to develop more sensitive models. There are also examples available from other countries[16].

A similar approach has been applied in the Moses project[17] at the University of Leeds (Geography) – as a prominent UK example. This used the UK Sample of Anonymised Records (similar to the PUMS) along with controls of aggregate census data at Output Area level (some 240,000 small areas in the UK) plus additional sources of data to enrich or validate the simulation. Moses has led on to other relevant research projects and programmes.

Using such a population simulation, one can prepare a flexible transport model quite quickly and it could become an improved base for demand studies, forecasts, agent-based travel microsimulations, household activity-based research, gamification and localised, but nationally consistent, models extending to links with smart or connected cities initiatives. There are considerable benefits over conventional approaches, including the ability to work at a person or family level and freedom from incompatible zone systems. There are challenges with this approach, but it is believed that these are understood and manageable.

Approach

TSC intends to work with others to prepare an up to date process that is suitable as a base for transport modelling and research. This could produce outputs for use by the TSC but also by the wider modelling community. It is intended that the resulting data would be made generally available to modellers as Open Data in transport and other domains. For this reason, the Office for National Statistics and the Cabinet

---

16 http://www.researchgate.net/profile/Kay_Axhausen/publication/228973867_Population_synthesis_for_microsimulation_State_of_the_art/links/0deec517bbebb9606c000000.pdf

17 http://www.allhands.org.uk/2005/proceedings/papers/341.pdf

Office have expressed interest to be involved with the development.

Initially, this would be a proof of concept but, in time, it could grow into a national resource to support innovative models (not only for transport applications).

It would be desirable for the work to be compatible with the conventional population base and forecasts as represented in the Department for Transport's TEMPro database that is used as a standard source for transport models. The potential extent of compatibility will be explored.

Early work with the data would be to support home-based simulations of travel demand and research into travel behaviour from home. To be of greater utility, one needs to also consider the non-home end of journeys, such as employment, shopping, leisure activity, etc. So, the approach should also have an eye to the scope to create a simulation base for other land uses. A further extension could be to develop land use data to support freight modelling.

Appendix 5 – A Data Clearing Centre for Transport

Modelling tools of all types (see Appendix 1) have data requirements that significantly condition their applicability. A repeated request from the modelling community has been for the TSC to take a lead in collating resources through which access to data, meta-data and related guidance for transport systems modelling purposes can be provided. Through this activity, we would seek to facilitate the implementation of industrially-relevant research, and to provide for higher-quality, and more timely development programmes that are well-integrated with, and make best use of, emerging data sources.

As a key element, a Data Clearing Centre (DCC) is proposed, with a particular emphasis on supporting the data needs of modelling for intelligent mobility. This is conceived as a dedicated and trusted 'data acquisition broker' that will facilitate access to multiple datastreams and will process data to meet the demands of the various stakeholder groups. It will enable the scope, quality and price of data to be matched to its intended use and is intended to facilitate the testing and development of innovative modelling concepts and tools.

It is intended that this initiative is complementary to Open Data initiatives and does not seek to duplicate activity. We anticipate engaging with existing (and future) paid-for data provision services to improve understanding of how the modelling community can be best served by these developments. This may include hosting trial datasets or data feeds under suitable commercial arrangements to support prototyping and demonstration activities.

While it is anticipated that some national datasets will be held for convenience, in most cases, the TSC will provide a convenient access pathway to obtain suitable data (and sometimes local data) for specific applications. This can reduce a major barrier to the testing and adoption of new methods by different stakeholder groups and by streamlining the entire data acquisition process.

The TSC's role is to accelerate the development and adoption of technology innovations. Our focus will primarily be to provide guidance and advice on data, promote standards, support signposting and generation of metadata and foster the development of skills in appropriate data acquisition and application. It will also consider issues of data sharing, ownership and collective licensing to help users to obtain the right data more cost effectively and with less duplication of effort and a reduced scope for error.

Appendix 6 - Reviewers

We are grateful to the following people who offered feedback and commentary after reviewing draft versions of this paper. In alphabetical order;

Prof. Kay Axhausen

John Bates

Richard Bradley

Rick Donnelly

Nick Fenton

Andy Graham

Paul Hanson

Miles Logie

Prof. Glenn Lyons

Brian Martin

Prof. John Preston

Andrew Stoneman

John Swanson

Tom van Vuren

Tor Vorraa

Prof. Marcus Wigan

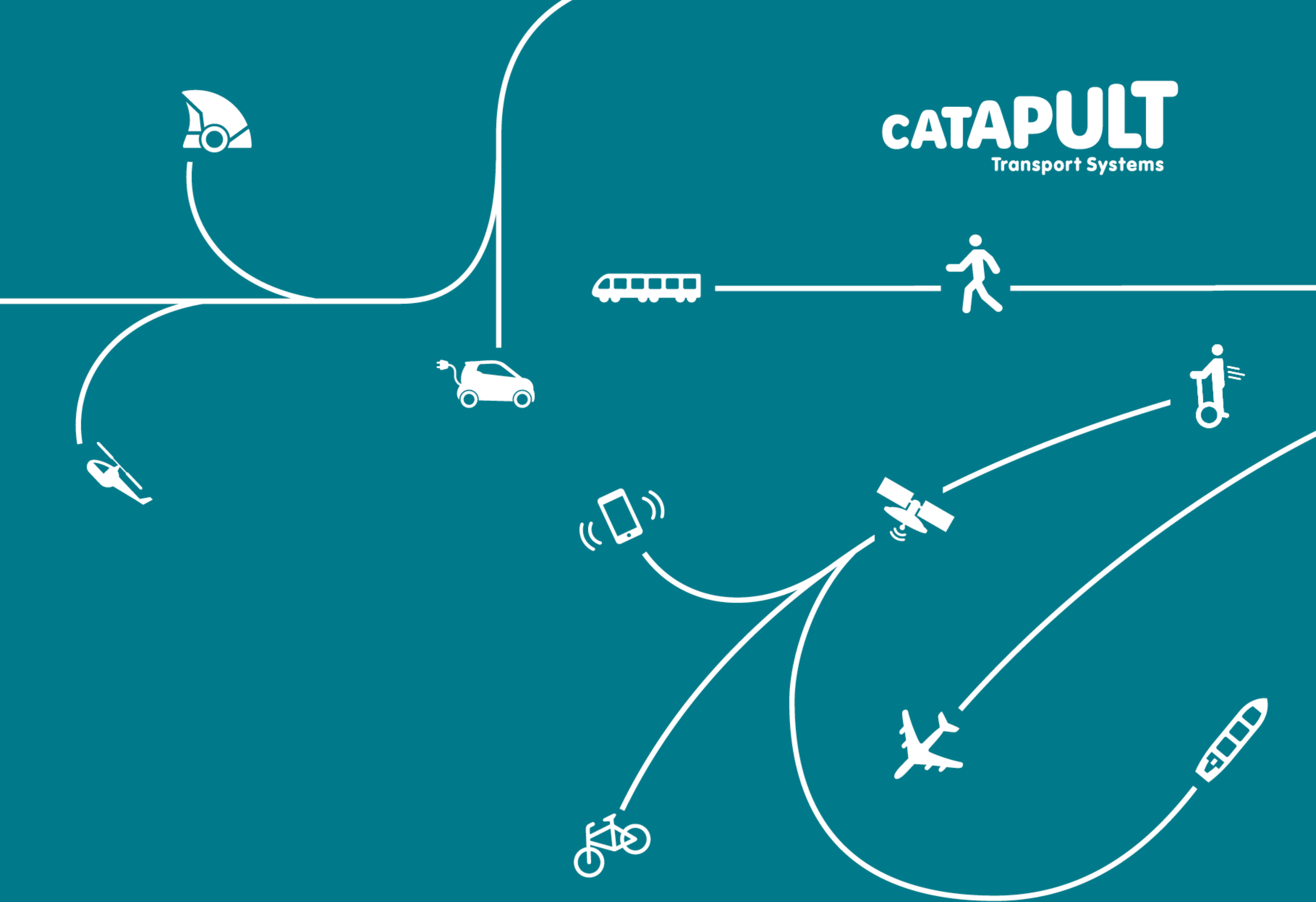
Ian Williams

Luis Willumsen

Prof. John Wootton

Tom Worsley

The paper has also benefitted from review and comment from members of the TSC staff, and in particular the Modelling and Visualisation team. We appreciate their contributions.



Transport Systems Catapult
The Pinnacle, 170 Midsummer Boulevard
Milton Keynes MK9 1BP

Tel: 01908 359 999

www.ts.catapult.org.uk
linkedin.com/company/transport-systems-catapult
Twitter: @TSCatapult

email feedback: modellingforIM@ts.catapult.org.uk