ITRC mistral

multi-scale infrastructure systems analytics

From household to global: simulating national infrastructure to inform decision-making

18 April 2018

Institution of Civil Engineers, London

Infrastructure Transitions Research Consortium – Multi-Scale Infrastructure Systems Analytics (ITRC- MISTRAL)

EPSRC
Engineering and Physical Sciences Research Council

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Welcome

Welcome to **From household to global: simulating national infrastructure to inform decision-making**. We will give you a glimpse of cutting-edge research which will be yielding results and new capabilities over the coming months.

Today we will show how ITRC-MISTRAL's work is giving decision-makers new resources and new opportunities to explore innovative and radical solutions to infrastructure questions.

For those of you who are new to ITRC-MISTRAL, we are a consortium of seven UK universities bringing together over 35 researchers with expertise that includes infrastructure sectors and systems, risk analysis, economics and governance.

We are using innovative modelling techniques to create tools that can be used by the infrastructure community to assess the impact of policies, technologies, construction and investment.

At the half-way mark in our project, we are demonstrating how our work is already influencing the way that infrastructure decisions are being made. Today you will hear examples of how ITRC-MISTRAL outputs are being applied, for instance, in our work with the National Infrastructure Commission and the United Nations Office for Project Services.

For the first time we are also giving you a close look at the models in action, with eight demonstrations to show different applications at work. ITRC-MISTRAL researchers will be on hand to guide you and answer your questions.

I hope that you will find today stimulating and engaging. We look forward to responding to your questions and hearing your feedback.

Jim W Hall FREng

Professor of Climate and Environmental Risks

Infrastructure Transitions Research Consortium (ITRC-MISTRAL)
Director, Environmental Change Institute
University of Oxford

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Participants

Rob Adam, Infrastructure and Projects Authority

Natalyn Ala, Copper Consultancy

James Angus, Network Rail

Alastair Atkinson, WSP

Stuart Barr, Newcastle University

Khesraw Bashir, Student

Mike Batty, University College London

Guy Beaumont, Turner & Townsend

Paul Beckford, University College London

Keith Binding, Spirit Consulting

Simon Blainey, University of Southampton

James Britton, HSBC

Manuel Buitrago , University of Southampton

Adam Cambridge, Articulate Futures

Kate Canning, ARUP

Natalie Carolan, Skanska UK

Adrian Carro, INET, University of Oxford

Jonathan Chapman, Environment Agency

Modassar Chaudry, Cardiff University

Samuel Chorlton, Science and Technology Facilities Council

Joseph Clarke, Jacobs (formerly CH2M)

Christine Cole, Nottingham Trent University

Nicolas Cote-Colisson, HSBC

Ian Dabson, Infrastructure and projects authority

Anes Dallagi, EDF Energy R&D UK Centre

Chris Dent, University of Edinburgh and Alan Turing Institute

John Dora, John Dora Consulting Limited

Matt Edwards, Anglian Water

Sven Eggimann, Oxford University

Mark Enzer, Mott MacDonald

Jarmo Eskelinen, Future Cities Catapult

Neil Fleming, AIG

Alistair Ford, Newcastle University

Victor Freeney, Independent consultant

Lena Fuldauer, University of Oxford

Ben Gardiner, Cambridge Econometrics

Vassilis Glenis, Newcastle University

Nils Goldbeck, Imperial College London

Denis Golovenko, Streamliner

Silje Merete Gronning, IFM Investors

Lijia Guo, University of Cambridge

Jim Hall, University of Oxford

James Hardy, Rail Safety and Standards Board

Tony Hargreaves, University of Birmingham

Sarah Hendel-Blackford, Navigant

Adrian Hickford, University of Southampton

Simon Hodgkinson, University of Birmingham

Rollo Home, Ordnance Survey

Bianca Howard, Loughborough University

Ruth Hughes, Natural Environment Research Council

Huaihai Hui, University of Leeds

Basharat Hussain, Thomson

Ohis Ilalokhoin, Network Rail

Boulent Imam, University of Surrey

Matthew Ives, University of Oxford

David Jaroszweski, University of Birmingham

Lahiru Jayasuriya, Cardiff University

Kay Jenkinson, ITRC-MISTRAL, University of Oxford

Kay Johnstone, Environment Agency

Paul Jowitt, Heriot Watt University

Elco Koks, University of Oxford

Aleksander Kowalski, Consortiq

Rob Lamb, JBA Trust / Lancaster University

Joanne Leach, University of Birmingham

Charlotte Leonard, Whellock Consulting

Roald Lemmen, University of Oxford

Bianca Letti , National Infrastructure Commission

Henry Leveson-Gower, Department for Environment, Food & Rural Affairs

Nik Lomax, University of Leeds

Kat Lovell, Science Policy Research Unit, University of Sussex

Milan Lovric, University of Southampton

Tim Marshall, Oxford Brookes University

William McGeehin, Frazer-Nash Consultancy

Julian McGougan, techUK

Francesca Medda, University College London

Miriam Mendes, ITRC-MISTRAL, University of Oxford

Juliet Mian, Arup / The Resilience Shift

Richard Moore, Anglian Water

Benjamin Mousseau, EDF Energy

Myriam Neaimeh, Newcastle University

Robert Nicholls, University of Southampton

Emeka Obiodu, GSMA

Peter Oliver, Science & Technology Facilities Council

David Orton, Sky-Futures

Martin Osborne, WSP

Edward Oughton, University of Cambridge

David Owen, Kelda Group & Yorkshire Water

Alessio Pagani, The Alan Turing Institute

Alan Plunkett, Karaka Limited

Maria Pregnolato, Newcastle University

John Preston, University of Southampton

David Quincey, Network Rail

Jamie Radford, Mott MacDonald

Nazanin Rashidi, Knowledge Transfer Network

James Richards, Anglian Water

Tristram Riley-Smith, Cambridge University

Keiron Roberts, University of Southampton

Craig Robson, Newcastle University

Adele Rodrian, Department for Transport

Trudie Roiz de Sa, KPMG LLP

Thomas Rushby, University of Southampton

Erica Russell, University of Surrey

Jessica Russell, techUK

Tom Russell, University of Oxford

Eric Salem, Infrastructure and Projects Authority

Matt Sanderson, University of Manchester

Raj Sivalingam, WHP Telecoms Ltd

Andrew Smith, University of Leeds

Ralph Smyth, Warwick University/ Highways England Design Panel

John Steed, JS Risk Management Ltd

Mike Steel, Environment Agency

James Stewart, KPMG LLP

Roger Street, Environmental Change Institute, University of Oxford

Vance Tan, University of Oxford

Scott Thacker, UNOPS

Alan Thomson, Arup

Michael Tran, National Infrastructure Commission

Peter Tyler, Cambridge University

Inara Watson, London South Bank University

Jim Watson, University of Sussex

Mark Workman, Imperial College London / Energy Systems Catapult

Chengxiang Zhuge, University of Cambridge

Chaher Zid, Universiti Tun Hussein Onn Malaysia

Conrad Zorn, University of Oxford

Programme

In the morning, there will be a series of short presentations to show how our findings are being used in government and business. In the afternoon there will be an under-the-bonnet look at ITRC-MISTRAL modelling, led by the research team.

10.00 Registration

10.30 Jim Hall, ITRC-MISTRAL programme lead, University of Oxford

Welcome and introduction

10.40 Keynote presentation

James Stewart, Vice Chair – Industrial Strategy, geo-politics & Brexit at KPMG/ ITRC-MISTRAL Client Group

Planning infrastructure investment in a changing world
Looking at the global picture, including the link to Sustainable Development Goals, the impact of technology and changing consumer behaviour; and creating alignment between payers, financiers and beneficiaries.

11.10 Jim Hall

Overview of ITRC-MISTRAL aims & progress

11.30 Highlights

Nik Lomax, University of Leeds

High resolution demographic projections for infrastructure planning
Population and household projections at a fine spatial scale using microsimulation techniques.

Stuart Barr, Newcastle University

New approaches to infrastructure data integration and management for national scale simulation modelling
A 'Big Data' database-approach for the storage, management and analysis of national infrastructure data in the UK, and how computer models of household structure and building stock can be used for improved understanding of infrastructure demand.

Simon Blainey, University of Southampton

NISMOD national transport model: road network capabilities
Modelling the impacts of intervention & interdependencies with other infrastructure systems.

Edward Oughton, University of Cambridge

Towards 5G
Assessing the capacity, coverage and cost implications of future mobile telecommunications infrastructure

Scott Thacker, United Nations Office for Project Services & University of Oxford

Transforming national infrastructure choices worldwide
How national infrastructure systems modelling is being used to support evidenced-based infrastructure development in a variety of countries and contexts

12.15 Questions to our panel of speakers

13.00 Buffet lunch and networking

See the modelling, meet the experts: demonstrations, posters and conversations

14.00 Jim Hall

Introduction to the afternoon: a quick overview of the demonstrations and posters on offer.

Please note that coffee will be available throughout the afternoon session

14:20 Demonstrations – summaries on pages 10–23

National Infrastructure Commission & ITRC MISTRAL partnership – using high performance computing to scrutinise uncertainty around infrastructure decisions
ITRC-MISTRAL's NISMOD and the National Infrastructure Commission working in partnership, using the high-capacity computing of the Data and Analytics Facility for National Infrastructure (DAFNI).

United Nations Office for Project Services (UNOPS) & ITRC-MISTRAL partnership – supporting evidence-based planning for sustainable development worldwide
Demonstration of the National Infrastructure Model for International Contexts (NISMOD-Int) – the United Nations Office for Project Services (UNOPS) and ITRC-MISTRAL partnership

Household & building characterisation for infrastructure demand modelling
A visualisation to show how we create a household-level picture of UK infrastructure demand, and exploring infrastructure interdependencies

The next generation national infrastructure modelling database: NISMOD-DB++
New ways of handling data to fully characterise and understand infrastructure demand at the intra-urban building scale.

A decision-making tool to inform planning of water resources at a national scale
Understanding national scale uncertainties in the water sector

Road capacity utilisation and road traffic – modelling the impacts of policy interventions
Looking at the impacts of policy on vehicle demand, inter-zonal travel times and road capacity utilisation in an area in South East England.

Future demand for mobile telecommunications: comparing and costing 5G infrastructure deployment strategies
Exploring how ITRC-MISTRAL's modelling of future demand, technology and costings can inform government and industry.

Risk and resilience from local to global

We will show how local disruption of the electricity grid can have impacts on multiple infrastructures across local, national, and global scales. We will also show the impact of different recovery approaches.

Posters – summaries on pages 24–30

National Infrastructure Systems Model (NISMOD): improving performance and scalability

Urban water infrastructure transition: simulation and analysis of sewer networks

Solid Waste Infrastructure Modelling System – a full life cycle analysis & material flow analysis based on environmental impacts & costs

Energy demand: socio-technical energy demand simulation with a system-of-systems modelling approach

Energy supply: multi-scale modelling of integrated energy supply systems in Great Britain

Modelling the actions and interactions in the transport and housing sectors – whole system analysis for better infrastructure investment choices

Economics: assessing the impact of infrastructure on local economic performance

Infrastructure governance: understanding current arrangements and how future changes could affect infrastructure decisions

16.00 Jim Hall

Closing remarks

Summaries of demonstrations

National Infrastructure Commission & ITRC MISTRAL partnership – using high performance computing to scrutinise uncertainty around infrastructure decisions

The National Infrastructure Commission (NIC) recently launched its interim National Infrastructure Assessment. Much of the modelling work for this assessment was conducted through an application of ITRC's National Infrastructure Systems Model (NISMOD) alongside the use of established model simulations already used by government departments. By using a portfolio of models, the NIC hope to provide decision-makers with a better understanding of uncertainties within different model structures; of the range of likely outcomes for different future scenarios; and of the robustness of the evidence they are using to develop infrastructure policy.

Following the success of this work, the NIC is now working with ITRC to develop recommendations for infrastructure provision that will be fit-for-purpose under a range of futures. This second piece of work will inform the full National Infrastructure Assessment that is due later this year.

One major piece of this work involves understanding the vulnerability of England to drought at a national scale. The NIC is uniquely-placed to take a broad view of England's water supply and as the government's infrastructure adviser it needs to understand the risks and challenges that the water networks will face, and to provide a national perspective on the best infrastructure solutions for the future.

To do this, the NIC are utilising ITRC's NISMOD water model to investigate the best way to limit drought risk through investment in alternative water supply infrastructure assets including building new reservoirs, expanding existing reservoirs, recharging aquifers, building new desalination or effluent reuse plants and transfers between companies.

One of the key goals of this applied research is to determine the most affordable strategies of water infrastructure provision for making England drought-proof. Such an analysis depends on the accuracy of cost estimates for the various investment options. However, any cost estimates will be based on current projects, those provided by the water companies as part of their water resource management plans. Applying such cost estimates to future investments entails accepting an unavoidable amount of uncertainty that has implications for the recommendations provided by the NIC using this modelling work.

In order to explore the implications of this uncertainty the ITRC-MISTRAL team have developed a sensitivity analysis capability within NISMOD that makes use of the high computing throughput capability of the Data and Analytics Facility for National Infrastructure (DAFNI).

Using DAFNI and the capabilities of NISMOD we are able to run the water model many times against a full spectrum of possible cost estimates to explore the implications of these assumptions.

A reporting tool has also been developed to allow users to explore the results of this analysis including the discovery of "cross-over" points[1] at which changes in costs can make one strategy more desirable than another based on system performance indicators (e.g. total cumulative cost or final water balance in 2050).

This capability provides the NIC with further insights into the sources of vulnerability associated with their preferred strategies. This can either guide further research into improving their cost estimates or result in modifications to the strategy to increase its robustness to this uncertainty.

The presentation for the showcase event will feature an overview of the NISMOD tool, the use of NISMOD for the NIC National Infrastructure Assessment, the use of DAFNI's high computing throughput capability, and the reporting tool which audience members will be able to interact with using an installation on a computer provided at the event.

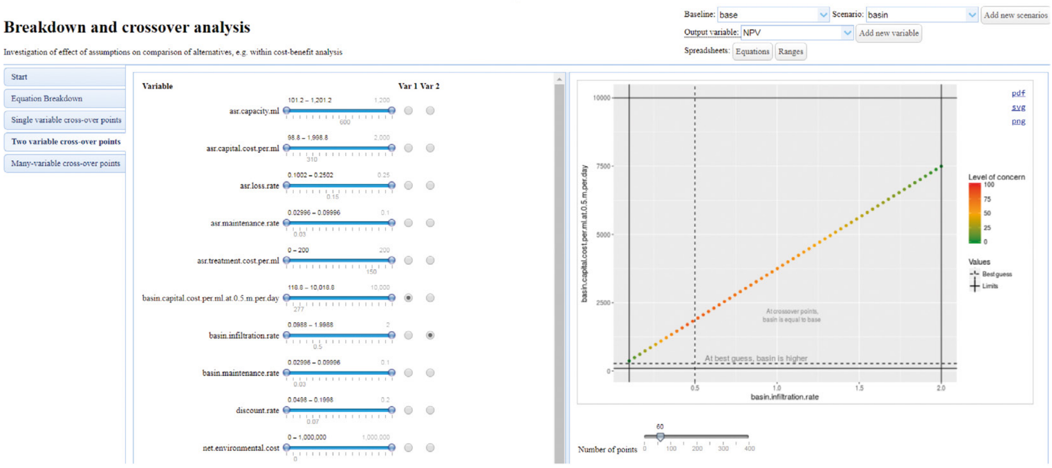
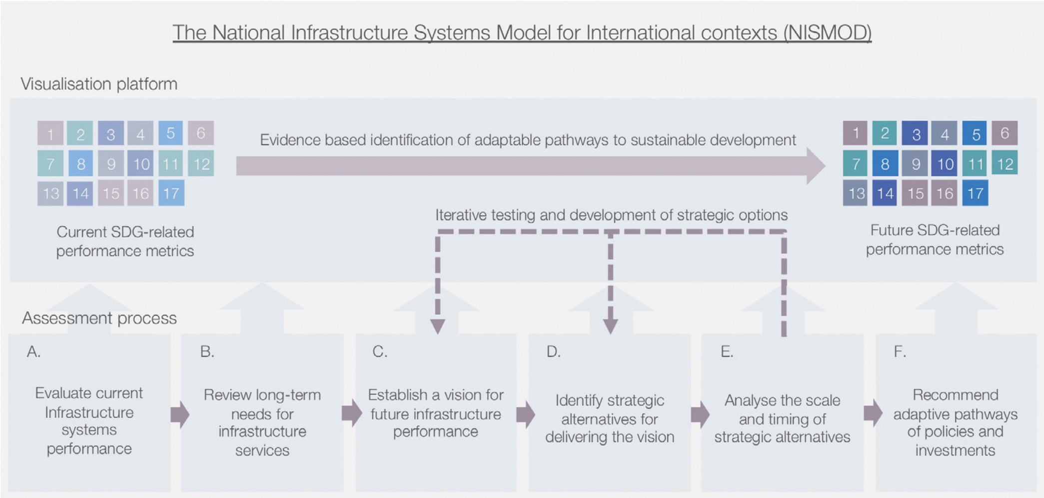


Figure 1: An example application of the reporting tool, developed by Guillaume et al. (2016)1 that allows users to explore the "cross-over" points associated with changes in key variables to examine at what point different strategies become more or less desirable based on performance indicators (e.g. total cumulative cost).

1 Guillaume, J. H. A., Arshad, M., Jakeman, A. J., Jalava, M. & Kummu, M. Robust discrimination between uncertain management alternatives by iterative reflection on crossover point scenarios: Principles, design and implementations. Environmental Modelling & Software 83, 326-343, doi:https://doi.org/10.1016/j.envsoft.2016.04.005 (2016).

United Nations Office for Project Services (UNOPS) & ITRC-MISTRAL partnership – supporting evidence-based planning for sustainable development worldwide

In partnership with the United Nations Office for Project Services (UNOPS), ITRC-MISTRAL is evolving the National Infrastructure System Model (NISMOD) into a generalised process and platform to support the evidence-based identification of adaptable pathways to sustainable development, worldwide: NISMOD-International (NISMOD-Int). The figure below provides an overview of NISMOD-Int:

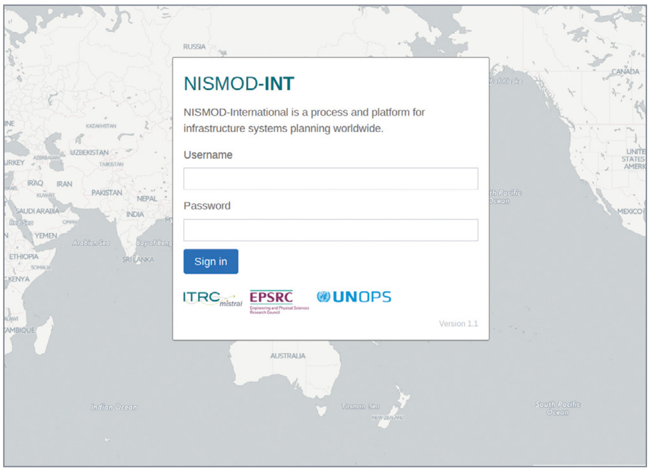


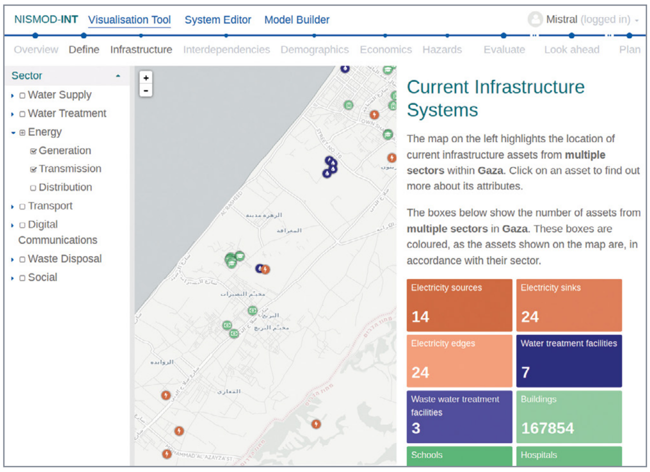
At the heart of NISMOD-Int is a methodological process (Steps A-F of figure above) that has been designed to systematically evaluate future infrastructure needs and provide strategies for how those needs can be met in accordance with a pre-defined development vision. Accompanying the process is the NISMOD-Int platform, an open source visualisation and decision support tool, that guides decision makers through NISMOD-Int process, facilitating the iterative identification of robust strategies for future infrastructure provisions. The figure below provides a selection of screenshots from the current (prototype) version of the platform, with a full release expected in mid 2018 – following further development and in-country testing.

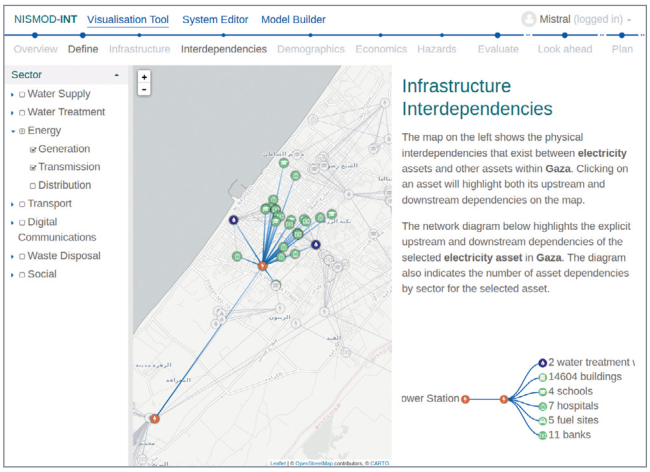
NISMOD-Int in practice

Through UNOPS' programme on Evidence Based Infrastructure EBI and partnership with the ITRC, NISMOD-Int is being applied to number of different countries and contexts, worldwide. This includes in Palestine, where NISMOD-Int is being used, with the Palestinian Authority, to highlight how infrastructure interdependencies can be managed to reduce the short-term risks of failure whilst providing for the long-term needs for infrastructure supply. In partnership with the government of Curaçao, NISMOD-Int is enabling the identification of pathways to a sustainable future, which consider the major drivers of demand on the Island, including population and tourism growth and the risks of sea-level rise and sea-surges. The demonstration will focus on the Curacao application.

Further applications of NISMOD-Int. are currently being explored in a range of political and geographical contexts including in post-conflict, post-disaster and developing economies, rapidly developing city-states and small island nations from South and Central America, to Africa, the Middle East and Asia.


NISMOD-INT
NISMOD-International is a process and platform for infrastructure systems planning worldwide.
Username
Password
Sign in
ITRC mistral
EPSRC
UNOPS
Version 1.1


NISMOD-INT Visualisation Tool System Editor Model Builder
Mistral (logged in)
Overview Define Infrastructure Interdependencies Demographics Economics Hazards Evaluate Look ahead Plan
Sector
Water Supply
Water Treatment
Energy
Generation
Transmission
Distribution
Transport
Digital Communications
Waste Disposal
Social
Current Infrastructure Systems
The map on the left highlights the location of current infrastructure assets from multiple sectors within Gaza. Click on an asset to find out more about its attributes.
The boxes below show the number of assets from multiple sectors in Gaza. These boxes are coloured, as the assets shown on the map are, in accordance with their sector.
Electricity sources 14
Electricity sinks 24
Electricity edges 24
Water treatment facilities 7
Waste water treatment facilities 3
Buildings 167854
Schools
Hospitals


NISMOD-INT Visualisation Tool System Editor Model Builder
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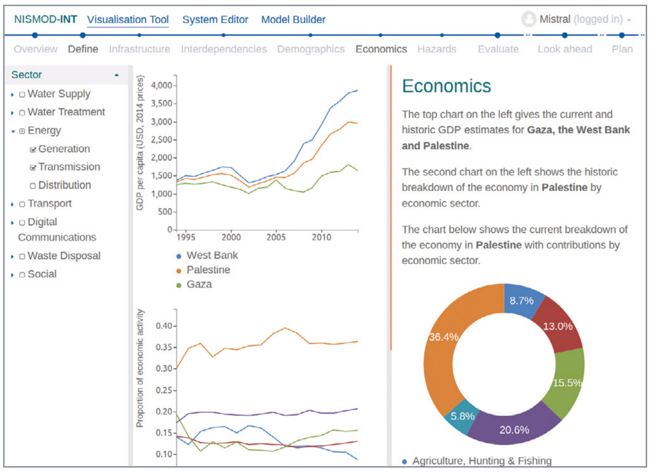
Sector
Water Supply
Water Treatment
Energy
Generation
Transmission
Distribution
Transport
Digital Communications
Waste Disposal
Social
Infrastructure Interdependencies
The map on the left shows the physical interdependencies that exist between electricity assets and other assets within Gaza. Clicking on an asset will highlight both its upstream and downstream dependencies on the map.
The network diagram below highlights the explicit upstream and downstream dependencies of the selected electricity asset in Gaza. The diagram also indicates the number of asset dependencies by sector for the selected asset.
ower Station
2 water treatment
14604 buildings
4 schools
7 hospitals
5 fuel sites
11 banks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Overview Define Infrastructure Interdependencies Demographics Economics Hazards Evaluate Look ahead Plan
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Generation
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Distribution
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Digital Communications
Waste Disposal
Social
GDP per capita (USD, 2014 prices)
West Bank
Palestine
Gaza
Proportion of economic activity
Economics
The top chart on the left gives the current and historic GDP estimates for Gaza, the West Bank and Palestine.
The second chart on the left shows the historic breakdown of the economy in Palestine by economic sector.
The chart below shows the current breakdown of the economy in Palestine with contributions by economic sector.
8.7%
13.0%
15.5%
20.6%
5.8%
36.4%
Agriculture, Hunting & Fishing

Household and building characterisation for infrastructure demand modelling

Planners and policy makers across a range of scales require information on the current day and future population, household and building stock in order to plan investments around infrastructure resources such as energy, transport, ICT, and water. The ITRC-MISTRAL consortium have been developing the next generation of multi-scale models that characterise the current day and predict future population, resulting household composition and the dwellings that they occupy in order to inform multi-sector infrastructure demand models (Figure 1).

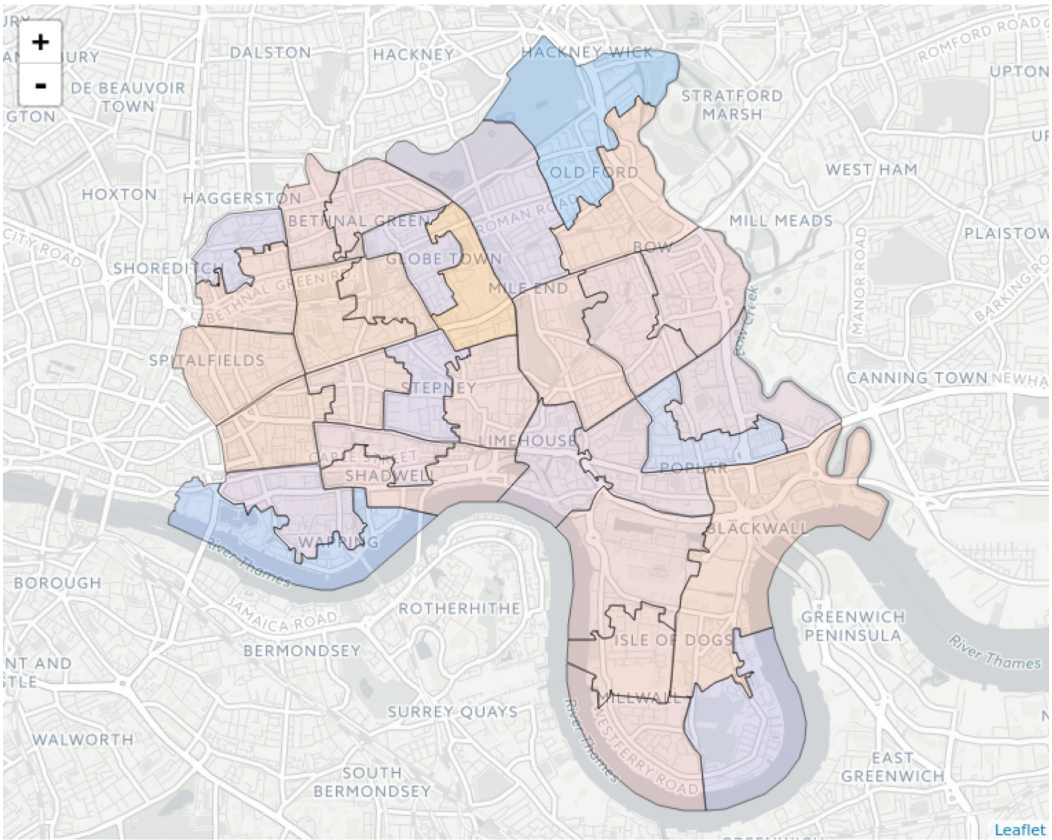


Figure 1. Projected population growth at MSOA level for Tower Hamlets, 2011-2021. Low growth is blue and higher orange. Map tiles by Carto, under CC BY 3.0. Data by OpenStreetMap, under ODbL.

Household projection models provide information on the number of households and their composition for the entire UK; information that is matched to individual residential buildings in Ordnance Survey MasterMap data. MasterMap data along with AddressBase also provides a classification of the non-domestic building stock. The result is a national data-set where the use of each building is known along with key physical attributes relating to infrastructure demand (Figure 2).

Figure 2: Example building stock classification (Contains OS data © Crown copyright and database right 2017).

This unique national coverage of building stock and household composition represented at the level of individual buildings allows current infrastructure demand to be understood at a range of planning and governance scales; at the level of neighbourhoods for SMART-grid applications, through to understanding city, regional and national demand. The household-building stock national data-set generated by the MISTRAL team has been within the MISTRAL energy demand model which requires information on physical building characteristics such as dwelling type and floor area. Using such data the energy demand model calculates energy demand at a local authority (LAD) scale (Figure 3).

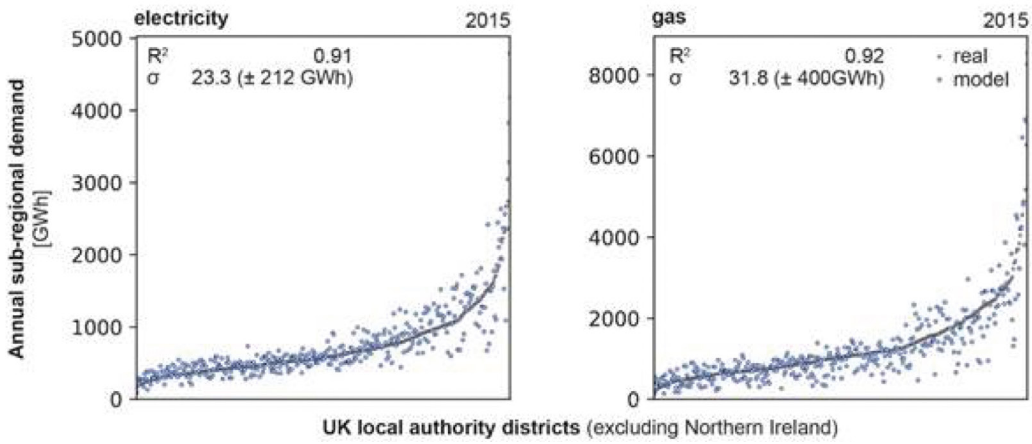


Figure 3: Spatial disaggregation of national energy demand down to ~400 regions for the UK using household-building stock floor area data.

Current is extending this current day characterisation of the UK household-building stock composition to simulate future household composition and building development due to population growth out to 2040. The development of a coupled future household-building stock model will allow government organisations such as the national Infrastructure Commission and infrastructure providers to target spatially where new infrastructure assets and networks are required to satisfy future demand.

NISMOD-DB++: The next generation national infrastructure modelling database

The ITRC-ISTRAL consortium, between 2010-2016, developed the first ever national infrastructure database designed to underpin and support national scale infrastructure modelling (NISMOD-DB). This database comprises of over 600 national scale datasets that were used in infrastructure models to predict the long term infrastructure investment requirements for the UK and also to model infrastructure risk and vulnerability (Figure 1).

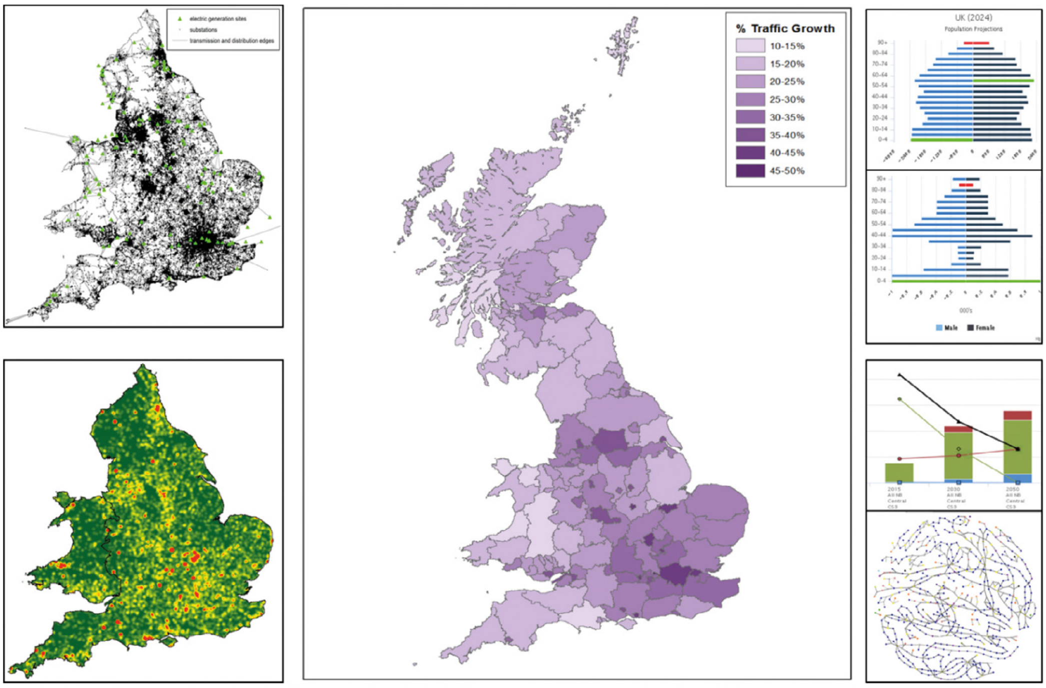


Figure 1: Modelling outputs produced via and represented in the first generation of NISMOD-DB.

The MISTRAL project is extending this existing capability to handle the Big Data challenges of developing a national modelling and analytics capability that is down-scaled to the level of representing infrastructure demand at the level of individual buildings. The development of such a database requires new ways of handling the huge volume of highly heterogeneous data required to fully characterise and understand infrastructure demand at the intra-urban building scale.

The resulting database, NISMOD-DB++, approaches this task by employing a federated hybrid database architecture, where different physical databases are used to optimally store, structure and mange different types of data. However, from a user's perspective they only request data or perform analysis via a single data management system. Figure 2 shows the basic configuration of NISMOD-DB++.

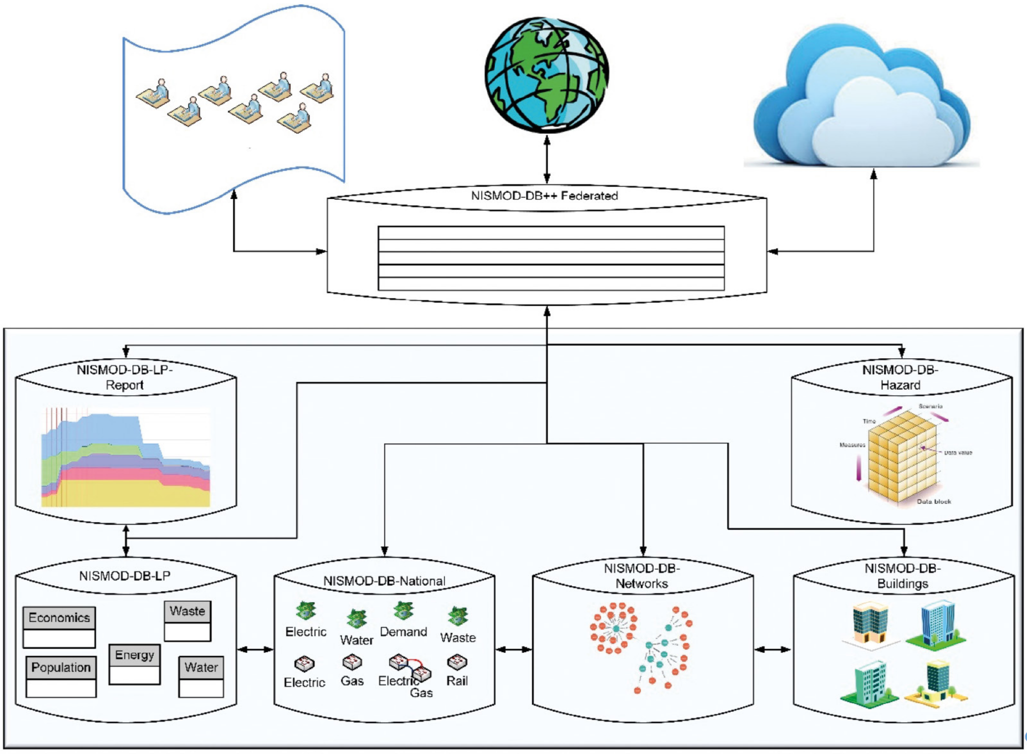


Figure 2: The basic architecture of NISMOD-DB++.

This new approach to managing infrastructure data at unprecedented spatial and temporal levels has been used to develop an integrated urban-infrastructure implementation for the city of Newcastle upon Tyne, where a database on household composition is linked with building stock footprints and infrastructure networks and assets to understand the final spatial scale dependency of households on infrastructure assets. Figure 3 shows the results of this showing the local electric feeder networks that connect sub-stations to different types of households.

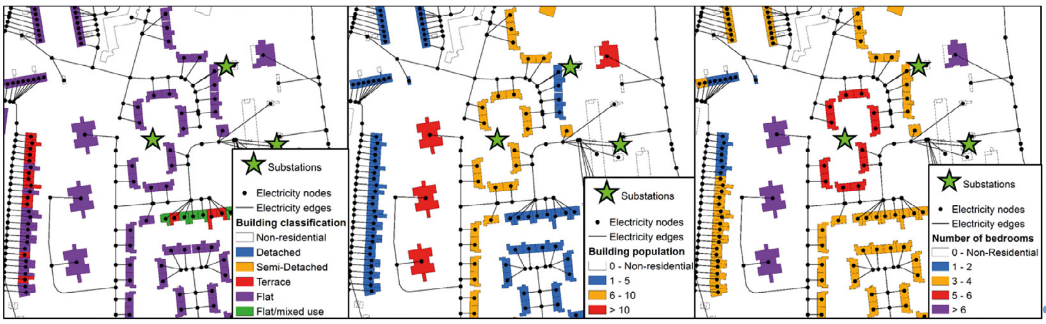


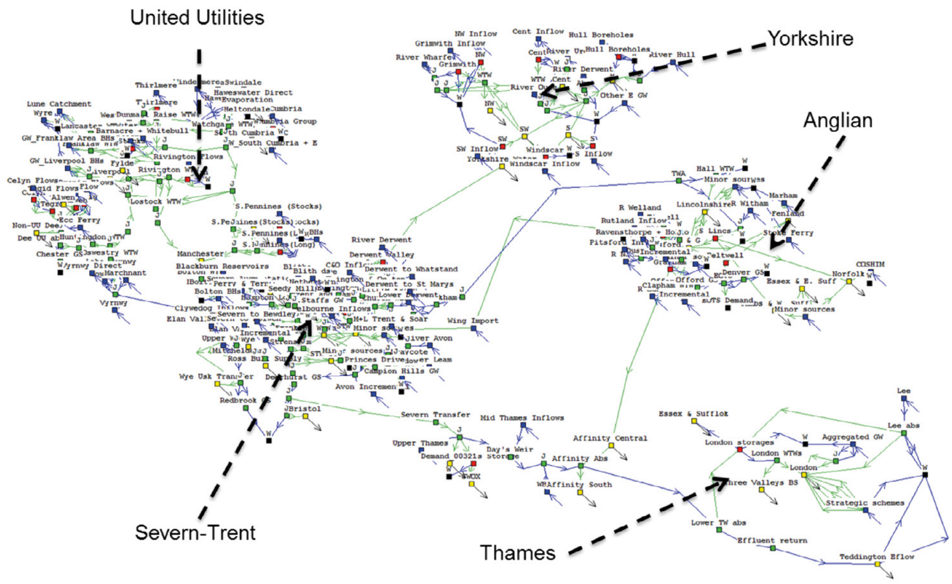
Figure 3: spatially related household, building and electricity networks retrieved from NISMOD-DB++.

Current work is extending NISMOD-DB++ to allow users to easily query, analyse and extract data held in the multiple internal databases. NISMOD-DB++ is also being used a the prototype architecture for the development of the National Infrastructure Database on the £8m EPSRC DAFNI national infrastructure data and analytics facility being developed by the Science and Technology Facilities Council (www.dafni.ac.uk/).

A decision-support system for national scale water resources modelling and planning

The WATHNET model is a high-resolution representation of the national water supply system in England and Wales. Decision-makers in the water sector face a number of uncertainties in future infrastructure planning such as climate change and population dynamics, as well as unknowns from other critical sectors such as energy and food. Decision support systems facilitate the decision making process by providing insights about the consequences of implementing various options. In particular, they assist in answering "what-if" questions. There are two main components of such decision-tools for the water sector: (1) system simulation and (2) optimising the outcomes that are important to the decision-maker.

Such simulation and optimisation models are used widely to support decision-making in the water sector. However, owing to the regulatory structure of the water sector in the UK, it has to date been difficult to develop the tools necessary to optimise future infrastructure portfolios under deep uncertainties at a national scale.

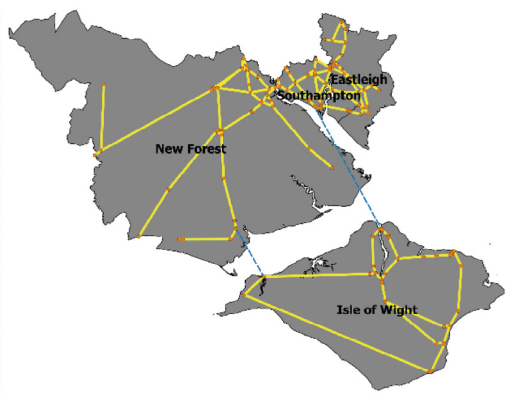


We have developed the national scale WATHNET model of water supply systems in England and Wales to fill this gap as part of the Marius (Managing the Risks, Impacts and Uncertainties of drought and water scarcity) and ITRC-MISTRAL (Infrastructure Transitions Research Consortium – Multi-Scale Infrastructure System Analytics) projects, and in collaboration with Atkins for Water UK. The first of its kind, WATHNET model connects certain major water companies in England (e.g. Thames Water, United Utilities, Severn Trent Water, Anglian Water, and Yorkshire Water) and is validated against the water companies' own models and datasets. In its current state, the national model consists of over 600 arcs and 380 nodes, as presented in the figure above. Within WATHNET, nodes represent supply sources, transfer points, and demand centres, whilst arcs represent physical flows of water between points. The WATHNET model has three key advantages: (1) it comprises robust future climate change scenarios, (2) it benefits from fast computation speeds allowing it to handle a highly complex decision space, and (3) it can be coupled with other sector models to conduct multi-sector impact assessments.

The presentation for this showcase event shall provide an overview of the WATHNET tool; taking the audience through the theory behind the model, as well as the usage and functionality. We shall demonstrate the WATHNET software through running simulations of the models developed as part of ITRC-MISTRAL. Finally, we shall explore the outputs from the model such as the future system reliability under climate change, as well as key trade-offs involved in investment portfolios.

Road capacity utilisation and road traffic – modelling the impacts of policy interventions

This showcase demo demonstrates the impacts of three policy interventions on road traffic on the UK's major roads using the newly developed ITRC-MISTRAL transport model. The study includes four local authority districts in South East England (Southampton, Eastleigh, New Forest and Isle of Wight).



Two of the policy interventions focus on building new infrastructure (road expansion and road development), whilst the third policy focuses on road pricing (a congestion charging zone implemented in the Southampton city centre). Policies are compared with the baseline ("before intervention") scenario for the same year, to disentangle the policy impacts from the impacts of yearly changes in demand predictors such as population size and income. The goal is to allow the users to experiment with different policy interventions and to explore the interdependencies between transport infrastructure, policy interventions and demand.

Policy Interventions

The user will be offered a choice of policy intervention(s) to run via a graphical user interface with three buttons. Each intervention will then open up as a separate dashboard displaying the results of a default policy, and will also allow the user to design and run custom policies using the controls included on each dashboard.

1. **Road expansion** – expanding existing road links with additional lanes.
   To design a new policy, the user can select a road link via its start and end node, and specify the number of lanes to add per direction.
2. **Road development** – building completely new road links between existing intersections.
   To design a new policy, the user can select two nodes (road intersections) between which a new road should be developed, choose the road class (A-road or motorway), and specify the number of lanes in each direction and the road length (the minimum feasible length is used as the default).
3. **Congestion charging** – implementing road tolls in a pre-defined policy area, distinguished by time of day.
   To design a new policy, the user can specify the amount that will be charged to each vehicle that enters the zone. Two charges can be selected, one for the peak period (7am-11am & 4pm-7pm) and the other for the off-peak period (everything outside the peak period).

Outputs

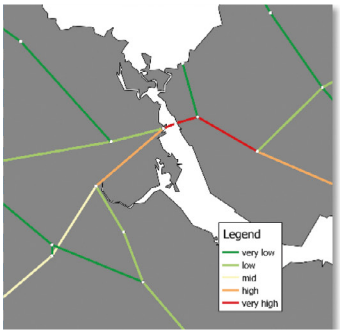
To understand the impacts of these policy interventions, the user can compare road capacity utilisation shown on the "before" and "after" maps, the origin-destination tables with vehicle demand (number of vehicle trips) before and after the intervention, and average inter-zonal travel times before and after the intervention.

Capacity utilisation is calculated as peak-hour flows divided by the maximum capacity of each road link (which depends on the road class and the number of lanes). This is classified into quintiles and colour-coded from the lowest (dark green) to the highest (red) capacity utilisation. Links coloured red indicate a potential capacity "pinch point". In general, new infrastructure provides more capacity, so it is expected to reduce the capacity utilisation. However, new infrastructure may also change the demand by reducing travel times.

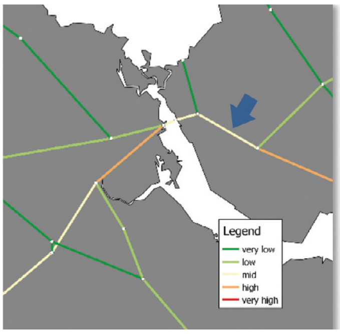
Travel time is calculated as the average travel time between each pair of zones. New road infrastructure is expected to reduce travel times. Congestion charging can increase travel times for vehicles re-routing around the congestion charging zone, but it can also reduce travel times by reducing the total demand.

Vehicle demand is the number of vehicle trips between each two zones. The demand after the policy intervention is calculated from the changes in travel times and travel costs using an elasticity-based approach. New road infrastructure is expected to increase vehicle demand via reduced travel times, while congestion charging is expected to reduce vehicle demand via increased travel costs.

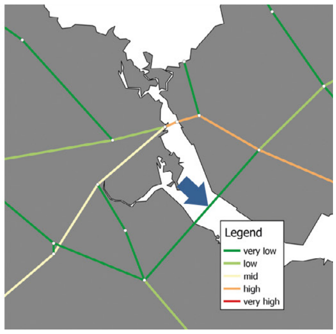
Examples of outputs



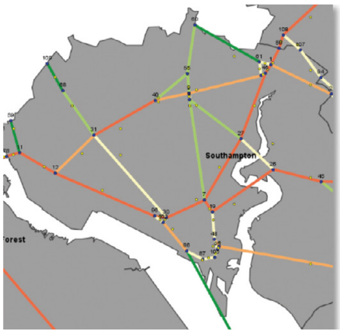
a) Before intervention



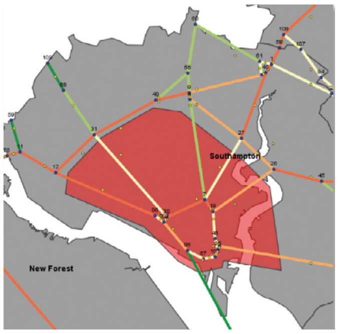
b) After road expansion



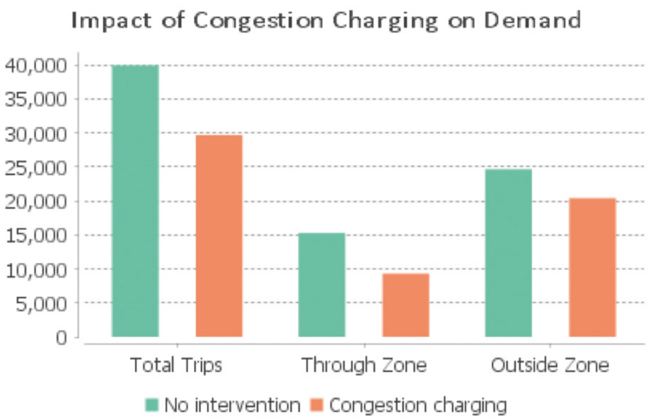
c) After road development



a) Before intervention



b) After congestion charging



Origin\ Destination	Southampton	Isle of Wight	Eastleigh	New Forest
Southampton	8.21	98.87	14.14	67.21
Isle of Wight	77.26	17.37	86.71	66.45
Eastleigh	14.10	109.11	10.78	81.08
New Forest	29.90	88.88	39.34	57.92

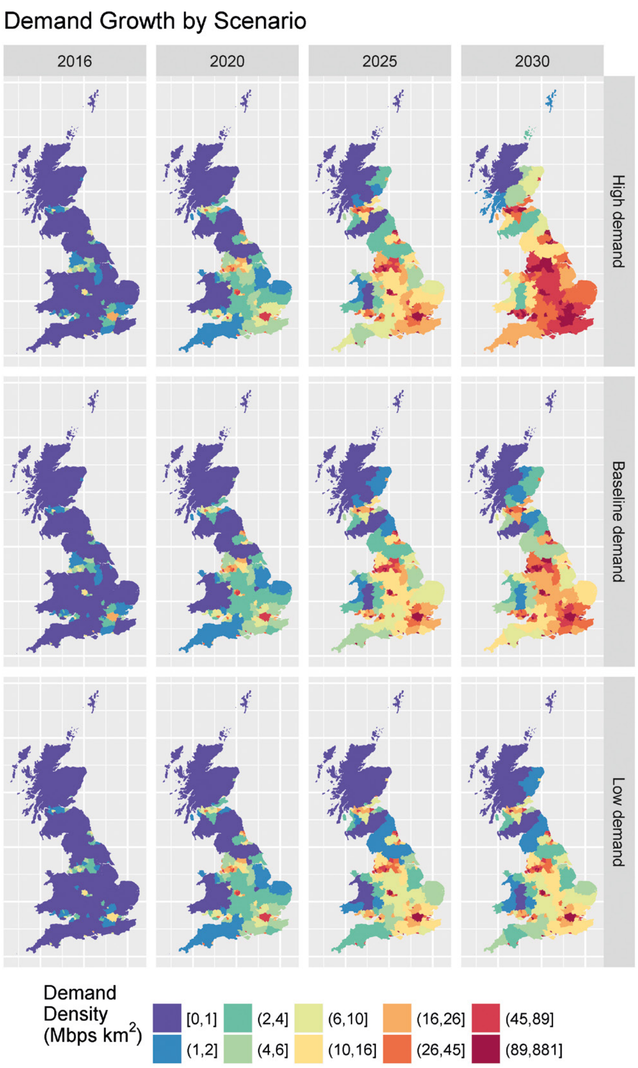
Average inter-zonal travel time [minutes]

Towards 5G: assessing the capacity, coverage and cost implications of future mobile telecommunications infrastructure

The UK has made an ambitious commitment to become a world leader in the deployment of 5G infrastructure systems. This showcase demonstration quantifies the uncertainty associated with the future supply and demand for mobile telecommunications infrastructure, by testing how different long-term infrastructure strategies perform. We draw on evidence used to support both the UK and the Dutch 5G strategies.

As 5G is not yet commercially deployed, we have taken an approach which extrapolates 4G LTE and 4G LTE-Advanced characteristics, the most recently deployed standard for mobile communications.

We test a spectrum strategy that integrates 5G frequency bands (700 and 3500MHz) on brownfield macrocellular sites, as well as a small cell strategy that densifies the network (utilising 3700MHz in TDD). A hybrid strategy is also explored which first deploys spectrum, and only small cells if more capacity is required.

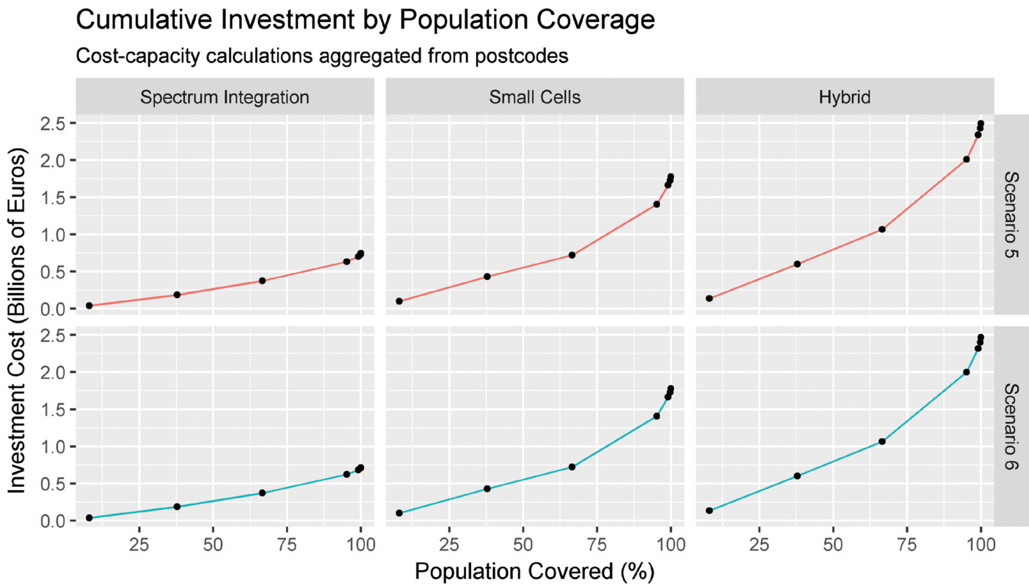


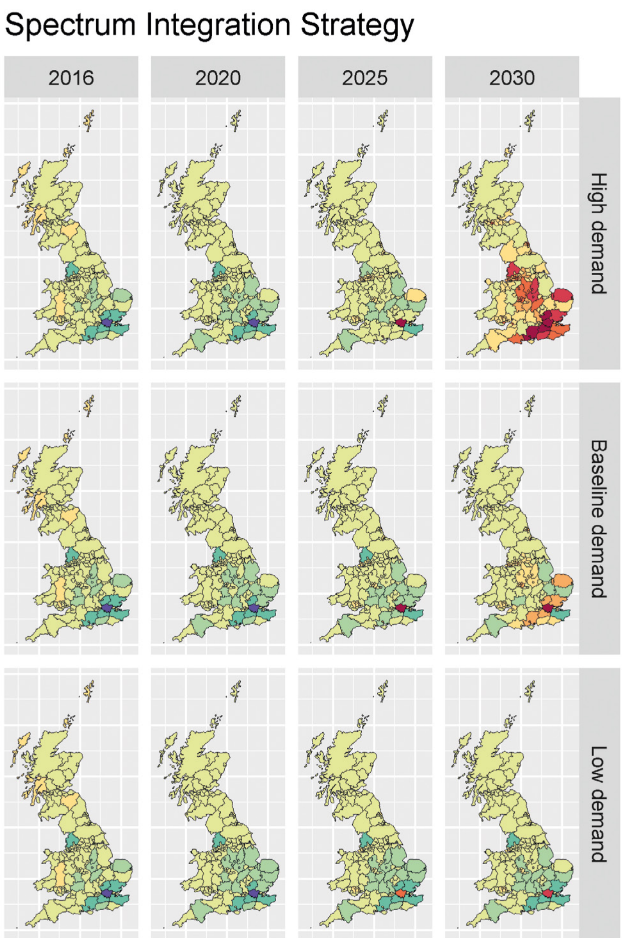
How does growing data usage and demographic change affect the demand for mobile telecommunications infrastructure?

We find that increasing per user traffic resulting from technological change has a major impact on future demand, whereas demographic change (fertility, mortality and migration) has only a minor effect. For example, in the baseline scenario only 8% of the growth in data for 2016 to 2030 resulted from demographic change, whereas 92% was from per user data demand. Consequently, researchers should focus on refining per user data demand, rather than devoting time to developing population projections, contrasting strongly with energy or transport systems.

How do different supply-side infrastructure options perform when tested against future demand scenarios?

The results indicate that spectrum strategies perform well in most scenarios up until 2025, and hence will play an important role in meeting mid-term demand. However, if demand growth is very high, spectrum fails to meet demand. This contrasts with small cell deployment, which provides huge increases in capacity, but at the expense of much higher capital expenditure due to limited coverage per cell. Unless new revenue can be obtained from the value created by the Internet of Things, Smart Cities, or other new technological developments, the investment appetite for rolling out small cells anywhere other than urban areas will be low. 5G small cell deployments are likely in urban locations, but more cost-efficient wide-area coverage solutions are required to meet lower density areas.





What are the cost advantages across strategies and scenarios?

We report a set of cumulative cost curves for two scenarios where we test the capex difference in 5G infrastructure deployment in the Netherlands for delivering 300Mbps per user. This focuses on comparing the difference between a mobile-only MNO (Scenario 5) and a converged fixed-mobile MNO (Scenario 6). Translating this into the UK context, O2-Telefónica is classed as mobile-only, whereas BT-EE is classed as a converged fixed-mobile MNO.

In theory, fixed-mobile operators have a more extensive fibre backhaul network that they can utilise for mobile backhaul, reducing cost. In the Netherlands, however, even mobile-only operators have accrued an extensive fibre network and therefore only a small fraction of the sites require backhaul upgrades. This was a surprising result. Future research needs to undertake similar analysis in low fibre density contexts, such as the UK, where the cost advantages in fixed-mobile convergence are likely to be higher.

Risk and resilience from local to global level

Introduction

Resilient critical infrastructure systems, such as energy, transportation, water, waste and digital communications are the backbone of modern economies and societies. Catastrophic failures of these systems can propagate across other systems that may result in large-scale economic losses and social disruptions. Recent examples of such events in the United Kingdom are the Gatwick flood event (December 2013) and the River Lune flooding event (Lancaster, December 2015). The Christmas Eve flooding at Gatwick disrupted over 13,000 airline customers. The bank overtopping of the River Lune resulted in a electricity substation flooding which led to 61,000 homes and businesses being without power for nearly 48 hours.

Our approach to risk and resilience

Due to the cascading nature of these critical infrastructure failures, understanding their widespread impacts poses a complex problem for policymakers, infrastructure operators, insurers, and other stakeholders. To progress understanding of such complex problems, the ITRC-MISTRAL project has developed methodological frameworks for risk assessments of critical infrastructure at multiple geographical scales.

Past events have demonstrated societal reliance on continuous electricity supplies. Therefore, central to our UK risk-modelling is a high temporal and spatial resolution power-flow and asset recovery model of the transmission and selected distribution grids, with connectivity based network models representing other dependent infrastructure sectors. Coupled to this model is a macroeconomic multiregional impact model, allowing for the estimations of economic impacts of asset failures and the societal-wide effect of their recovery paths. On a global level, we have developed an international trade model, mapping global trade flows on top of a multimodal transport network. Such a modelling framework allows the computation of a resilience metric for a country's economy to large-scale disruptions -- regardless of the initial impact area.

Case study

To demonstrate the ongoing work in this project, we apply a NaFRA-derived flood scenario across the River Orwell (River Gipping and Belstead Brook) catchment near Ipswich. We will demonstrate how a disruption of the local 132kV Bramford Substation electricity grid substation impacts local, regional, national, and global infrastructure networks. Additionally, we will examine how different approaches to recovering network outages affect: disruptions to local populations, impacts on regional economic trade, and global connectivity of the nearby Felixstowe Port.

Poster summaries

NISMOD: National Infrastructure Systems Model Improving Performance and Scalability

The National Infrastructure Systems Model (NISMOD) is the first national system-of-systems long-term planning tool for infrastructure systems, including energy, transport, water, waste and digital communications. The tool has reached a stage of maturity to attract a diverse, expanding user group from researchers to government agencies, such as the National Infrastructure Commission (NIC). This user group is using NISMOD's modelling capabilities to answer real-world questions for policymakers around planning the future of the UK's national infrastructure.

With this ever-growing user group has come increased demands for model runtime, and a need to understand the sensitivity of model results to the assumptions around key model parameters. To meet this demand the ITRC-MISTRAL development team has collaborated with the Science and Technology Facility to make use of their high-performance computing facility at Harwell: the Data and Analytics Facility for National Infrastructure (DAFNI).

This project began with the development of model performance indicators and automated regression testing to help select the software and hardware improvements most effective for performance while guaranteeing minimum impact on modelling results. The team then developed functionality to enable NISMOD to farm out multiple model runs on the DAFNI high-performance computing cluster. This new functionality has enable thousands of different combinations of model parameter values to be run against NISMOD to examine the sensitivity of model results to the parameter uncertainty. Prior to this project such wide parameter sweeps would have taken weeks to run but with DAFNI can now be completed in less than a day.

This capability is currently being used to inform the NIC's National Infrastructure Assessment (due for release mid-2018).

Urban water infrastructure transition: simulation and analysis of sewer networks

We are using the CityCAT (City Catchment Analysis Tool) hydrodynamic model to simulate the urban water system, as industry models cannot adequately represent the complex flows between pipes, surfaces and buildings, with a range of planned interventions.

In MISTRAL we are undertaking analysis of multiple cities across the UK, to cover a range of different sizes, ages, topography and rainfall climate. This means using the Cloud for computing at high resolution for large domains, and imposing a huge burden on the need for detailed information on the sewer networks. To reduce the data requirements, we are augmenting the real pipe network data from water companies with synthetic versions of the pipe and storm drain networks which can be generated from readily-available data of roads and buildings.

We plan to model the major cities in Britain to assess the overall capacity of the networks and flood risk associated, for the present situation and for future possible design interventions. The effects and cost of separated or super-sized pipe networks will be investigated.

Solid Waste Infrastructure Modelling System – a full life cycle analysis & material flow analysis based on environmental impacts & costs

Solid waste management (SWM) has gradually shifted from being a service which provides safe and cost effective disposal of unwanted materials to one predominantly involved with recovery of material resources and energy. Consequently, SWM has become more complex and analytical tools are needed to assist in the decision-makers in the development of SWM strategies.

There are currently a plethora of linear SWM models available, which often use basic assumptions about current technologies, waste materials and transport methods to determine infrastructure needs. The Solid Waste Infrastructure Modelling System (SWIMS) expands upon this by creating a non-linear, dynamic, LCA-based optimisation tool to determine infrastructure capacity and costs, together with environment impacts. SWIMS optimises the pathways through which waste can be collected, transported and treated and instead of simply classifying waste to single facility types and collection methods, the entirety of the SWM system is simulated with greater realism.

SWIMS simulates waste arisings and composition, and optimises waste collection and management at multiple scales, (e.g. regional, national and international), based on one or multiple user-defined optimisation goals and constraints. The environmental and economic costs associated with the management of wastes at different facilities are calculated by a series of life cycle process models based on those included in the LCA software, EASETECH. Possible treatment paths for each waste stream are identified using a depth first search algorithm and an evolutionary genetic algorithm is used to prioritise the order of these paths. SWIMS calculates waste arisings into the future and determines if it is possible to treat the waste using existing and planned capacity. If additional capacity is required, SWIMS will select the optimum infrastructure solution to meet this capacity demand. This also enables the system to be tested for its resilience as multiple facilities can be optimised to treat and receive multiple waste streams depending on the user's goals and the constraints set. SWIMS benefits from the ability to incorporate waste producer behaviours, material types and compositions, existing and new technologies, new policies and constraints. This, coupled with its multi functionality to work as both a stand-alone model and integrated into the NISMOD system of systems model, produces a powerful, adaptable, holistic decision support tool.

Energy demand: socio-technical energy demand simulation with a system-of-systems modelling approach

The energy demand model of the ITRC-MISTRAL framework allows the simulation of long-term changes in energy demand patterns for the residential, service and industry sector on a high temporal and spatial scale across the United Kingdom. Transport demand is modelled in a separately linked model. The energy demand model allows the parametrisation of innovative technologies and policies, and their diffusion across space and time, focusing on socio-technical trends and testing the effect of alternative infrastructure futures on energy demand for different energy vectors (e.g. hydrogen, gas, electricity).

Energy demands are decomposed in different end-uses and sectors, based on national energy demand statistics. Demand is forecasted based on a set of scenario drivers such as population or temperature. Energy demands are spatially disaggregated to about 400 regions (local authority districts) with the help of different disaggregation factors such as floor area, being provided by the household model. Wherever possible, a bottom-up approach relying on measuring trial data is implemented for hourly energy demand modelling for specific technologies or end-uses.

While model validation is commonly neglected, our spatial and temporal disaggregation methodology is validated. Results show the importance of choosing appropriate disaggregation factors and the need for model calibration.

Most importantly, the calculated modelling results serve as crucial inputs for the energy supply model. The high spatial and temporal demand allocation is key for assessing peak demands or interlinking demand and supply with respect to highly variable renewables. Simulated energy demands are the basis for improved understanding of necessary regional resource availability and the need of regional system adaptation. Results show the importance of capturing the spatial and temporal dynamics of different energy futures. These modelling capabilities are innovative and have not been possible with previous models focusing on national and annual energy demand projections.

Energy supply: multi-scale modelling of integrated energy supply systems in Great Britain

The whole energy supply system is undergoing enormous change to deliver against all aspects of the "trilemma"- cost, security of supply and decarbonisation. Therefore, robust decision-making on infrastructure requires new tools to perform analytics across the entire energy supply chain – from supply, generation, transmission, distribution through to end use.

The energy supply model in the ITRC-MISTRAL programme is based on the Combined Gas and Electricity Network model (CGEN). The CGEN model is expanded to include representations of energy supply systems at both transmission and distribution scales. The energy supply model performs operational analysis over multi-time periods considering electricity, natural gas, heat supply systems and their interactions.

The modelling methodology chosen minimises total operational costs to meet energy demands across the whole energy supply system. The operational costs of the energy system are derived from energy supply, emissions and unserved energy. The cost minimisation is subjected to constraints which are derived from the operational characteristics of assets and the energy supply/demand balance of the entire energy system.

Energy transmission components in the model are based on electricity and natural gas transmission networks that interact through gas-fired power generators. Energy resource supplies, generation technologies and networks are explicitly modelled. Detailed modelling methods are used to represent storage operation, variable generation of renewables and operation of interconnectors. Energy supply at the transmission level meets demands from large industrial consumers and energy flows to the distribution networks.

At the distribution level, integrated electricity, natural gas and heat distribution systems are considered. To form the integrated framework of different energy carriers through energy conversion technologies, an "energy-hub" concept has been adopted. The energy hub uses available distributed energy resources and transmission grid supplies to meet electricity, natural gas and heat demands of residential and commercial consumers. Constraints from each technical component and energy flow capacities are considered in the model.

Key outputs from the model analysis include the energy supply mix at both transmission and distribution, total emissions from the electricity network, cost of operation and insights into infrastructure expansion and asset retirements.

The modelling approach in ITRC-MISTRAL offers a rich level of disaggregated temporal and spatial representation of energy supply systems. This allows detailed analysis of future energy supply systems under various strategies such as integrating high levels of renewables, expansion of community and distributed generation, benefits of electrical storage devices, greater consumer participation and the challenge of decarbonising heat and mobility.

Modelling the actions and interactions in the transport and housing sectors – whole system analysis for better infrastructure investment choices

Housing is the largest asset class in the economy, as well as one of its main drivers. In particular, the geographical distribution of dwellings and employment opportunities determine the need for transport infrastructure for commuting. At the same time, given a certain availability of employment opportunities and a certain distribution of transport infrastructure, only some commutes will be feasible, leading to a certain distribution of housing prices.

In order to model this complex relationship, we develop a spatial agent-based model of the interaction between housing markets and transport infrastructure. In particular, we develop a district-based model, i.e., we define a discrete set of locations, each of them characterised by a non-spatial housing market model, and a discrete set of commuting possibilities –transport infrastructure– between them. We simulate a large pool of households with realistic life-cycles and survey-calibrated consumption habits, buy-to-let investors, a banking sector providing mortgages under central bank rules, and detailed ownership and rental markets. The residential choice of households –where they decide to bid for housing and whether they do it in the rental or the ownership market– is based on a comparison of average costs and qualities among the different locations which takes into account the expected costs of commuting, both in the form of travel fees and travel times. Different transport infrastructure investment policies can then be studied by simply modifying the structure of these commuting fees and times, or, in a more nuanced way, by defining rules for their dynamic change during a given simulation.

The model is calibrated by combining a wealth of different data sources. For instance, census data and various ONS surveys are used for the calibration of the demographic and socio-economic characteristics of the pool of households, Land Registry and Zoopla data is used for the calibration of various pricing and market decisions of households, Council of Mortgage Lenders and Bank of England data is used for the calibration of various mortgage related parameters.

Economics – assessing the impact of infrastructure on local economic performance

In December 2017 HM Government published a White Paper **Building a Britain fit for the Future**. This identified five foundations of enhanced productivity growth for the UK: ideas, people, *infrastructure*, business environment and places (our emphasis).

The White Paper emphasises the importance of adopting a place-based approach to investment to deliver enhanced productivity growth, providing a series of local and national benefits. For 'infrastructure', one objective is to support investments in transport, housing and digital infrastructure by increasing the National Productivity Investment Fund. For 'places', a key focus is to use local industrial strategies to deliver economic opportunities based on local strengths, and to use a new Transforming Cities Fund to drive productivity by improving connections within city regions.

This White Paper offers an ideal time to consider how investment in infrastructure in specific cities and regions can help to deliver economic growth. However, current analytical tools for understanding the relationship between infrastructure investment and productivity/ output improvements in at the local level are relatively under-developed.

Thus, ITRC-MISTRAL's tools and frameworks have a key role to play in helping to guide infrastructure investment as part of a coherent industrial strategy. An interdependent world requires understanding of the changing functionality of infrastructure and the interdependencies that exist between infrastructure sectors at different spatial levels.

What is our work?

The ITRC-MISTRAL economics team is examining the empirical and theoretical relationship between infrastructure and the growth of productivity at different spatial levels, in particular how government policy for improving connectivity may also enhance productivity. We are developing better measures of the quality of local infrastructure for use our economic modelling of local growth and productivity. The research team has been building an extensive dataset to enable modelling of the impacts of enhanced infrastructure, particularly as it relates to connectivity, using historical data and projections for the UK's local authority districts. This includes Gross Value Added (GVA) and employment in 45-sector detail, for 2001-2015, with further augmentation of the data back to earlier years based on city analysis. Our model now contains measures of connectivity (road, rail and air) and ICT quality, as well as data on local skills (occupation-based), innovation, specialisation, capital stock and other variables that are important in modelling at the local level. A number of different econometric models are being tested.

What is the output of our work and how can it be useful for practitioners?

The ITRC-MISTRAL economics model enables practitioners and policymakers to investigate the impact of changes in infrastructure and non-infrastructure related variables on the growth of local productivity across Great Britain. The model will be able to use data inputs from other parts of the NISMOD modelling system and, in turn, provide inputs to other NISMOD models.

Infrastructure governance: understanding current arrangements and how future changes could affect infrastructure decisions

Optimisation of technical and economic factors presents a useful tool for infrastructure decision-making. However, the institutions and processes that govern infrastructure operation and development have important roles in shaping infrastructure and its performance. Both the structure and use of a tool such as the National Infrastructure Systems Model (NISMOD) should reflect its position within and interaction(s) with the structures, actors and processes of infrastructure governance.

Questions of central concern include: Who has the authority to make which decisions? Who will be consulted? At what scale(s) are priorities shaped and decisions made? Which functions and interests are prioritised? Whose voices are left out?

ITRC-MISTRAL's cross-cutting theme on infrastructure governance connects governance variables with NISMOD and its application. A five-phase model developed to link governance questions to techno-economic modelling is shown; each phase emphasises different combinations of existing knowledge and experience. This model has been developed and is being refined in conjunction with NISMOD and, within ITRC-MISTRAL, is designed to both inform modelling analyses and produce connected qualitative analysis.

The five phases can be traversed iteratively, with the starting point(s) determined by the context in which it is being applied.

Model phases

1. Mapping current governance: examines and records existing governance arrangements with reference to the key issues and actors of interest
2. Insert governance scenarios: identifies and applies alternative mechanisms of governance to consider how existing governance might change and be changed
3. Narrative development: quantitative and/or qualitative, descriptions of infrastructure governance and infrastructure development form the key communication and reference point between the applied governance thinking and modelling analysis
4. Translate into model framework: narratives and the parameters featured in the modelling analysis are connected and limitations identified
5. Model: the model is used to conduct analyses informed by governance thinking and/or that address governance questions

ITRC mistral
multi-scale infrastructure systems analytics

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The Infrastructure Transitions Research Consortium (ITRC) provides concepts, models and evidence to inform the analysis, planning and design of national infrastructure.

MISTRAL – Multi-scale Infrastructure Systems Analytics – is the second research programme of ITRC. The Engineering and Physical Sciences Research Council has invested £5.3 million in MISTRAL, which runs until 2020.

The aim of ITRC-MISTRAL is to develop and demonstrate a highly-integrated analytics capability to inform strategic infrastructure decision-making across scales, from local to global.

ITRC-MISTRAL partner universities

- University of Oxford
- Newcastle University
- University of Southampton
- Cardiff University
- University of Cambridge
- University of Leeds
- University of Sussex

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From household to global: simulating national infrastructure to inform decision-making

Infrastructure Transitions Research Consortium – Multi-Scale Infrastructure Systems Analytics (ITRC- MISTRAL)