A LONG TERM CAPACITY AND DEMAND ASSESSMENT MODEL FOR THE UK TRANSPORT SYSTEM

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1. INTRODUCTION AND BACKGROUND

1.1 The UK Infrastructure Transitions Research Consortium

This paper describes a transport modelling framework which is being produced by the UK Infrastructure Transitions Research Consortium (ITRC), a partnership between seven leading universities. In the UK, as in other advanced economies, National Infrastructure (NI) systems face serious and immediate challenges including the growing demand for such systems from a modern economy and a growing and ageing population, significant investment requirements to allow ageing infrastructure assets to meet this demand while providing reliable, cost-effective and high quality services, and the increasing complexity and interdependence of infrastructure networks (Hall et al., 2012). In order to help meet these challenges, ITRC has been funded by the EPSRC to develop and demonstrate a new range of system simulation models and tools to inform analysis, planning and design of a robust NI system for the UK. It involves a five year research programme, running from 2011 to 2015, which is structured around four overarching questions:

1. How can infrastructure capacity and demand be balanced in an uncertain future?
2. What are the risks of infrastructure failure and how can we adapt NI to make it more resilient?
3. How do infrastructure systems evolve and interact with society and the economy?
4. What should the UK strategy be for integrated provision of NI in the long term?

ITRC aims to explicitly account for interdependencies between infrastructure systems by developing an integrated framework of geographically explicit national-scale models of energy, transport, water, waste water and solid waste systems. These models will provide a virtual environment in which to test strategies for long term investment in NI and understand how alternative strategies perform with respect to policy constraints such as reliability and security of supply, cost, carbon emissions, and adaptability to demographic and climate change (Hall et al., 2012).

1.2 Model Rationale

Initial ITRC research involved undertaking a Fast Track Analysis (FTA) of UK infrastructure and a review of relevant data sources, in order to ensure that the programme is building upon existing knowledge and review and refine the scope of the ITRC research, and full details of the FTA are provided by Hall et al. (2012). This has been followed by the development of simulation models for the various infrastructure sectors, and this paper focuses on the ITRC Transport Capacity-Demand Assessment Model (CDAM). This is intended to be a strategic model, which will assess the transport demand-capacity balance at a national scale. It should be able to identify key zones and links where demand-capacity mismatches are likely to arise, allowing more spatially-detailed models to then be used to identify solutions to these mismatches.

Unsurprisingly, this is not the first attempt to produce a long term model of the UK transport system, and the Transport CDAM was initially planned to be developed based on outputs from relevant existing models, particularly those owned by the Department for Transport (DfT). A number of models were reviewed, including the Long Distance Model (URS/Scott Wilson, 2011), the National Transport Model (Department for Transport, 2009), the PLANET Long Distance model (HS2 Ltd, 2010), the National Trip End Model (WSP Group, 2011), the Great Britain Freight Model (MDS Transmodal Ltd, 2008), the rail Network Modelling Framework (Steer Davies Gleave & DeltaRail, 2007), the Air Passenger Demand Model (Department for Transport, 2011a), and the National Air Passenger Allocation Model (Department for Transport, 2011b). However, in practice these models either proved to be unsuitable for our purposes or could not be made available to ITRC researchers within a suitable timeframe. An alternative approach was therefore followed, with a bespoke ITRC model being developed based largely on open-source data. The remainder of this paper outlines the form and development of this model and discusses some issues which have arisen during its development.

2. MODEL STRUCTURE

2.1 Spatial Resolution

The model forecasts transport demand and capacity within and between 144 zones based on local authorities (with the London and Metropolitan boroughts aggregated into seven metropolitan zones), covering the whole of Great Britain. The first stage of model development involved producing a 'base year' representation of the transport infrastructure system in 2010, with usage levels for this system in the same year. The model infrastructure system is made up of link-based trunk road and rail networks (with actual network links aggregated to give a single link between each adjacent zone pair), along with nodes representing all major airports and major seaports. The key variable of interest is the level of traffic crossing zonal boundaries (as the best available proxy for infrastructure capacity utilisation), and therefore the model differs from most aggregate transport models in that it neither contains nor attempts to impute an origin-destination trip matrix. In addition to interzonal and nodal traffic, intrazonal road and rail traffic is also modelled based on total vehicle kilometres and passenger numbers.

2.2 Temporal Resolution

The model covers the time period from 2010-2100, which is a much longer time period than most other 'long-term' transport models, with forecasts provided at yearly intervals. The model does however consider much smaller time intervals when making forecasts, with for example road traffic disaggregated into hourly time periods across the day when estimating congestion levels.

3. DATA SOURCES

3.1 Road Transport

Data on road traffic was obtained from the Department for Transport's Average Annual Daily Flow (AADF) statistics. These are mainly based on approximately 10,000 manual traffic counts which take place over a twelve hour period on a 'neutral' day (a weekday between March and October excluding public and school holidays), which are supplemented by data from Automatic Traffic Counters to produce 24 hour AADF figures for all motorways and A roads disaggregated by vehicle types. For the purposes of this study we are only interested in those links which cross interzonal boundaries. In theory links are broken at local authority boundaries, meaning that each inter-authority flow will be represented using two links, but in practice it appears that in some cases links were not split in this way, or that the presence of junctions on authority boundaries complicated this splitting process. Interzonal flows were therefore estimated by summing the flows on the links either side of the zonal boundary and then averaging these two totals.

The road capacity measure used in the model was the total number of major road lanes provided between each pair of zones, with this data obtained by linking the AADF data to Ordnance Survey® (OS) Strategi® map data, supplemented by data from Google Maps. The usage and capacity data were then combined to give current capacity utilisation measured in passenger car unit (PCU) per lane, as shown in Figure 1.

A measure of intrazonal road capacity utilisation was also calculated, based on data from DfT road traffic statistics on total motor vehicle kilometres by local authority. While no comprehensive data on the number of lanes on each road link exists, a combination of OS Strategi® and Meridian® data were used in ArcGIS to estimate the total number of lane kilometres within each local authority zone. It was assumed that all motorways had six lanes and that all minor roads had two lanes, as while this is not in fact correct in all cases, the number of road segments involved made it impractical to manually check the number of lanes on each link. These calculations gave the traffic densities shown in Figure 2. In reality, of course, congestion does not occur at an average level across all links or lanes within a zone, but is concentrated on particular links. However, there are no comprehensive data available on such interlink variation, and analysis at such a detailed level is in any case beyond the scope of this study.

Figure 1: PCU per lane per day, 2010

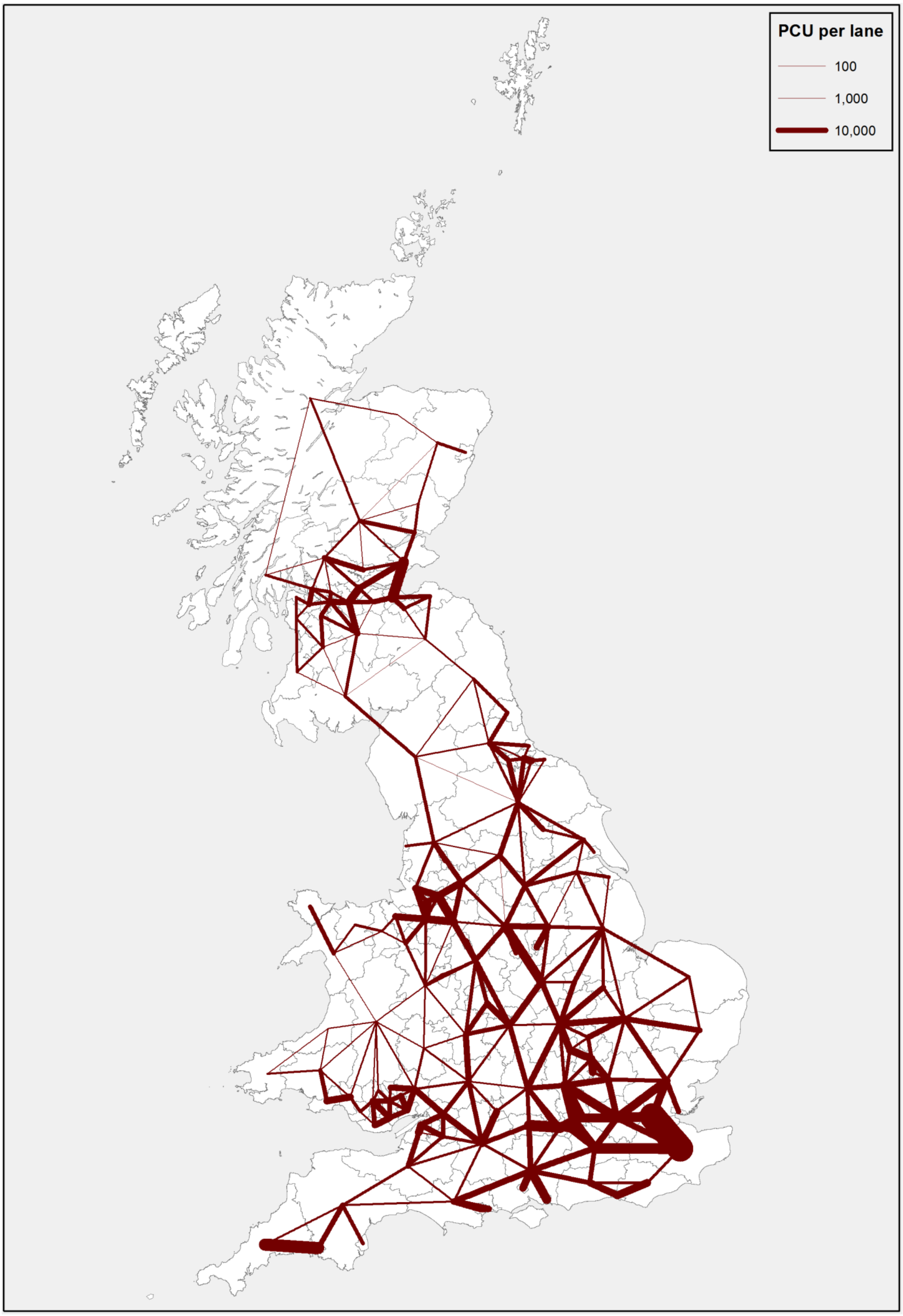
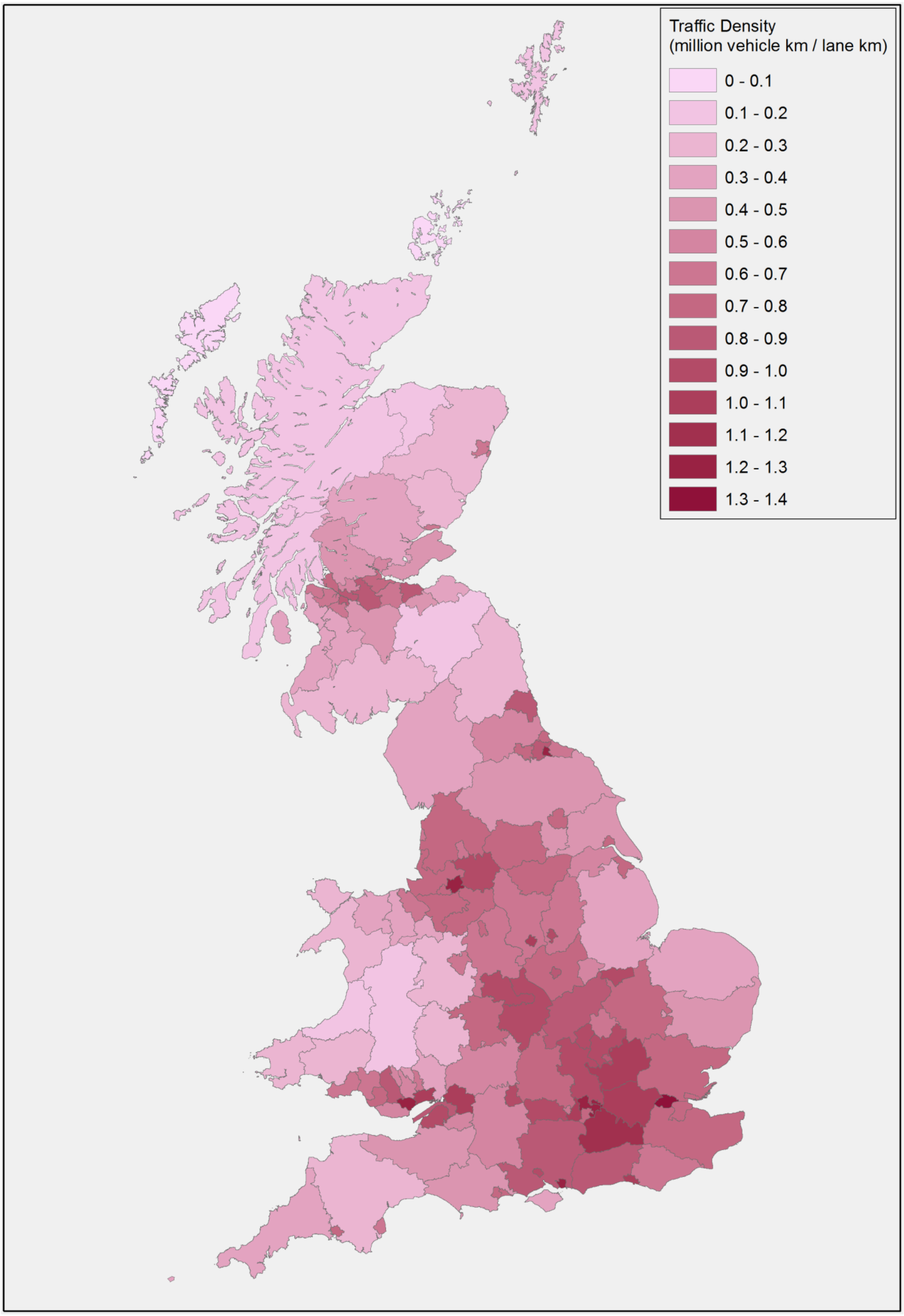


Figure 2: Traffic Density By Lane Within Local Authority Zones, 2010



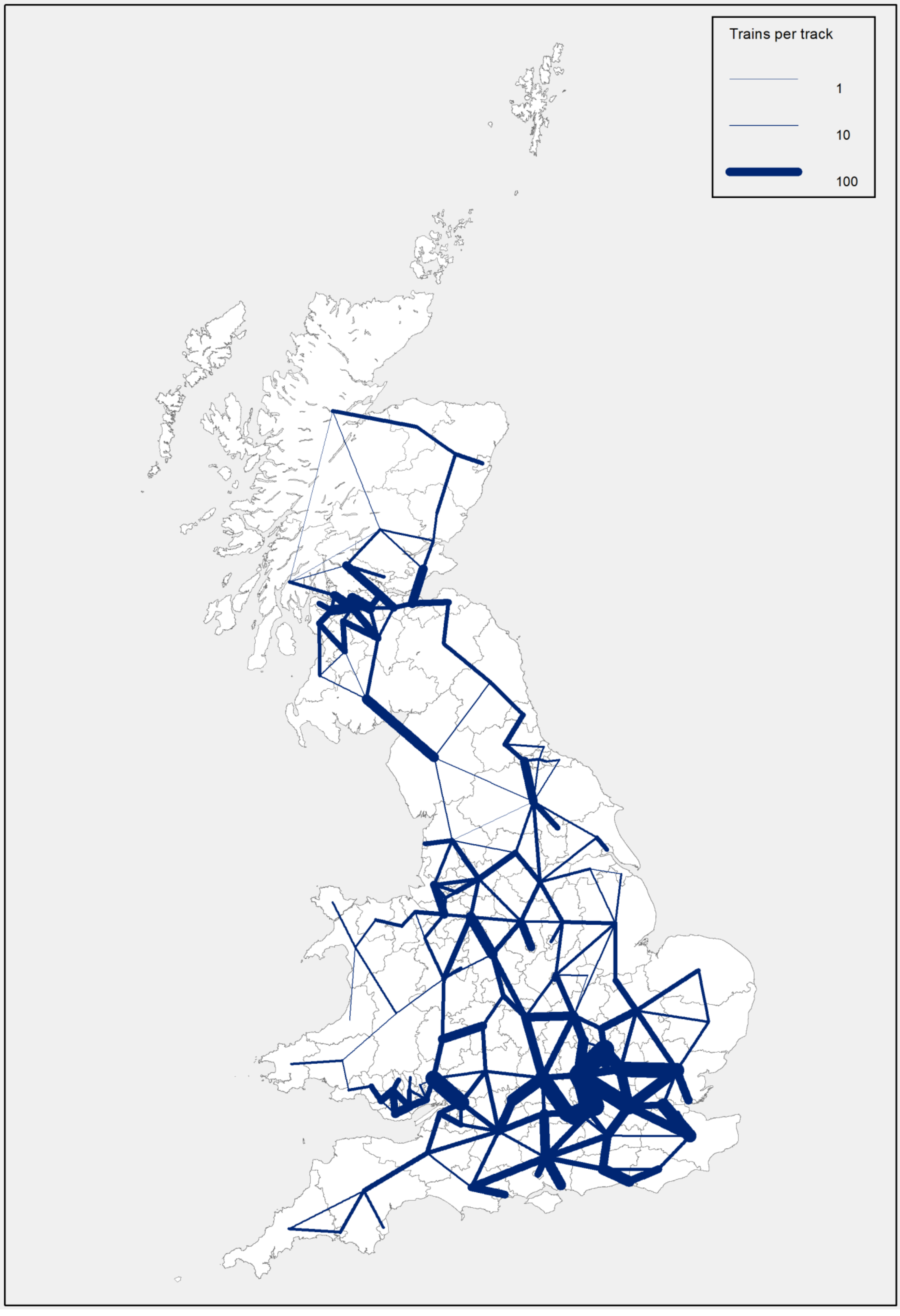
3.2 Rail Transport

Rail traffic tends to be measured in passenger numbers rather than in terms of vehicle numbers, and it was initially planned to follow this approach for the modelling work described here, making use of the rail passenger counts contained in the TOAD ('The Oxera Arup Dataset') dataset. This is based on LENNON/CAPRI ticket sales data, and gives the total number of passengers travelling between station pairs over annual periods, disaggregated by ticket type. However, in order to model inter-zonal infrastructure utilisation it is necessary to know the number of passengers travelling over particular stretches of line, and because TOAD contains at best extremely crude routing information (for example 'not via London') there was no straightforward way to convert it into the required spatial format. An alternative approach was therefore adopted, which involved calculating the number of trains using particular stretches of line based on rail passenger timetable data in CIF format. VB scripts were used to interrogate this data and obtain the total number of trains operating on 11,424 station to station (or junction) links. Links crossing zonal boundaries were then isolated and aggregated in the same way as for road data, and estimated freight train counts (based on (Rawlinson, 2011) added to the interzonal totals.

The measurement of rail capacity is an extremely complex topic, as there is effectively no single level of capacity for any given element of the rail network. Capacity is instead a variable and somewhat intangible quantity, affected by a large number of factors including the number of tracks, train frequencies, train speeds, the relative speeds and acceleration/braking capabilities of different trains, timetable patterns, train stopping patterns, signal spacing, speed restrictions, and station and junction layouts. The simplest (and consequently rather crude) representation of capacity is the number of tracks on particular routes, and this measure is easily aggregated across links to give a measure of total interzonal capacity. It was though not possible to source an electronic dataset which provided information on the number of tracks on particular links, and data therefore had to be collected manually from several sources. It was then necessary to identify links from timetable data which shared the same tracks (for example Southampton Airport Parkway – St Denys and Southampton Airport Parkway – Swaythling), to avoid double-counting of these tracks. The total number of tracks for each inter-zone pair could then be calculated, followed by the number of trains per track per day. This data is mapped in Figure 3, which gives an indication of inter-zone rail network capacity utilisation.

Intrazonal passenger rail travel was modelled based on the number of passengers boarding and alighting within each zone. All stations were allocated to zones, and ATOC station usage data used to give the total number of passengers for each zone in the year 2010/11. While there have been some suggestions that this data underestimates demand around major urban areas (see Roberts (2012) for a discussion of this issue), no more accurate dataset is currently available. No capacity constraint is applied to intrazonal rail traffic in the current model form.

Figure 3: Rail Track Capacity Utilisation by Interzonal Passenger Trains 2011



3.3 Air Transport

Highly-detailed data on traffic to and from UK airports is available from the Civil Aviation Authority, and this forms the basis for modelling air travel in the Transport CDAM. This gives details of the total number of passengers using 51 airports in the UK and the quantity of freight shipped via 40 UK airports, along with passenger numbers for 242 domestic inter-airport flows. This allows air traffic to be represented in the model on a nodal basis for freight and international passenger traffic, and on a flow basis for domestic passenger traffic. Airport terminal and runway capacity data was however only available for 28 UK airports, and therefore the ITRC model is restricted to modelling total international traffic at a nodal level from these airports, along with 223 domestic flows to/from these airports.

3.4 Sea Transport

Base case data on waterborne traffic was obtained from the DfT's maritime statistics, which provided disaggregate data on sea-going freight traffic for 104 individual ports which handled freight traffic in 2010. Ports are treated as nodes in the Transport CDAM, as while there is also considerable traffic between these ports which could be represented as flows, these flows travel almost entirely via the sea. For the purposes of the model it is assumed that this has an effectively infinite capacity. Waterborne freight capacity is therefore constrained only by the limits on accommodation provided at terminals.

3.5 External inputs

The model also makes use of data on a number of external explanatory variables, including population, GVA, and fuel costs. Base values for these variables were obtained from the ONS (via Neighbourhood Statistics) and from the Automobile Association, with values for future years varying by scenario (see section 5.2) and generated by other elements of the ITRC modelling framework.

4. MODEL SPECIFICATION

4.1 Road Transport

The interzonal road model is based on a simple elasticity-based model which forecasts the change in demand over time as a result of changes in population, speed, cost and income, and the basic form of this model is given by equations (1) and (2). This is not in itself sufficient, because as demand (and thereby capacity utilisation) increases, congestion may begin to occur and speeds will drop. Equation (3) was therefore added to the model, allowing speed to be adjusted as capacity utilisation changes, with the model iterating between equations (1) and (3) in order to produce forecasts. The capacity constraint (equation (3)) will only apply when traffic exceeds a certain level, with data on maximum free flow lane capacities for different road types obtained from WebTAG unit 3.9.5.

Model elasticities were obtained from previous research, with the elasticity of demand with respect to population set at 1. For the purposes of this model, the cost of road travel was assumed to be related to the cost of fuel, allowing the fuel price elasticity of -0.215 (the National Transport Model mean of high and low growth first round own price elasticities) to be used for passenger transport, with an elasticity of -0.1 (from De Jong et al. (2010)) used for road freight transport. Similarly, GDP was assumed to be a proxy for GVA, meaning that the GDP per capita elasticity of 0.63 from the NTM could be used for passenger traffic and a slightly higher elasticity of 0.7 for freight traffic (Shen et al., 2009). Finally, the Department for Transport's Long Distance Model gives an elasticity of journey time with respect to traffic (assumed to be equivalent to capacity utilisation in congested conditions) of 0.3, which is equivalent to an elasticity of speed with respect to traffic of -0.3 (because speed varies in inverse proportion to journey time), along with an elasticity of demand with respect to journey time of -0.41, and hence an elasticity of demand with respect to speed of 0.41.

It seems reasonable to assume that if congestion exists only during a particular timeslot, the existence of that congestion will only affect average speeds in that timeslot, and that these reductions in speeds will therefore only feed back to act as a brake on demand during that timeslot, rather than the consequent reduction in speed averaged over all journeys in a day feeding back to give a smaller reduction in demand for journeys made in all timeslots during the day. The question of whether congestion on one type of road affects road speeds on all types (in other words whether for modelling purposes flows should be aggregated across all roads linking a particular zone pair) also needs to be considered. Some level of switching between roads to avoid congestion would be expected, but this will obviously depend on the extent to which roads serve the same origins and destinations (and therefore whether they are directly substitutable), to simplify the model speeds were initially only averaged across all speed categories for each road type for a particular timeslot rather than across all road types.

$$\left(\frac{F_{ijt+1}}{F_{ijt}}\right) = \frac{\sum_h F_{ijht+1}}{\sum_h F_{ijht}} \qquad (1)$$

$$\left(\frac{F_{ijht+1}}{F_{ijht}}\right) = \left(\frac{P_{it+1} + P_{jt+1}}{P_{it} + P_{jt}}\right)^{\eta_P} \left(\frac{I_{jt+1} + I_{it+1}}{I_{jt} + I_{it}}\right)^{\eta_I} \left(\frac{S_{ijht+1}}{S_{ijht}}\right)^{\eta_S} \left(\frac{C_{ijt+1}}{C_{ijt}}\right)^{\eta_C} (2)$$

$$\left(\frac{S_{ijht+1}}{S_{ijht}}\right) = \left(\frac{Cu_{ijht+1}}{Cu_{ijht}}\right)^{-0.3} \qquad (3)$$

Where:
F_{ijt} is the average daily flow (in passenger car units) between zone *i* and zone *j* in year *t*
F_{ijht} is the flow in an average day in year *t* (in passenger car units) between zone *i* and zone *j* during hour *h*
P_{it} is the population in zone *i* in year *t*

P_{jt} is the population in zone *j* in year *t*
I_{it} is the GVA per capita in zone *i* in year *t*
I_{jt} is the GVA per capita in zone *j* in year *t*
C_{ijt} is the average cost of travel between zone *i* and zone *j* in year *t*
S_{ijht} is the average speed of travel during hour *h* between zone *i* and zone *j* on an average day in year *t*
CU_{ijht} is the level of capacity utilisation during hour *h* between zone *i* and zone *j* on an average day in year *t*
η_p is the elasticity of demand with respect to population (and similar)

Average speeds for different vehicle types on different road types are available from DfT Transport Statistics (Table SPE0101), and these were used to allocate traffic by vehicle type to s set of speed-based categories for each road type (motorway, dual carriageway and single carriageway). The speed variable used in the model is therefore defined by equation (4).

$$S_{ijht} = \frac{\sum_{SCr}\left(S_{SCr}F_{ijhtSCr}\right)}{F_{ijt}} \quad (4)$$

Where:
S_{SCr} is the average free-flow speed for vehicles in category *SC* on road category *r*
$F_{ijhtSCr}$ is the flow (in PCU) of vehicles in category *SC* on road category *r* during hour *h* between zone *i* and zone *j* on an average day in year *t*

The base PCU data for each road type are distributed across 24 hourly periods based on evidence from the National Travel Survey (Table NTS0501) which shows the number of car driver trips in progress per hour over a typical day. Average speeds were then estimated for each vehicle type for each flow, with free-flow speeds applied if the traffic flow was below the maximum value from WebTAG, and the elasticity of speed with respect to traffic used to adjust speeds if the traffic flow was above the average lane capacity (with the base traffic level set at the free flow capacity and the new traffic level set at the observed traffic flow).

The intrazonal road model is similar to the interzonal model, but because there was no way, given the available data, for congestion (or by implication capacity utilisation) to be represented the model does not include a capacity constraint. Estimation of road speeds was of necessity somewhat coarse, as no data were available on observed speeds on all road links. The roads in each zone were therefore split into urban and rural roads based on data from DfT Transport Statistics (Table RDL0202), with rural average speeds taken from the same source as for the interzonal model, and urban average speeds obtained from DfT Transport Statistics Table SPE0102. The model form is given by equation (5).

$$\left(\frac{Vkm_{it+1}}{Vkm_{it}}\right) = \left(\frac{P_{it+1}}{P_{it}}\right)^{\eta_p} \left(\frac{I_{it+1}}{I_{it}}\right)^{\eta_I} \left(\frac{S_{ijt+1}}{S_{ijt}}\right)^{\eta_s} \left(\frac{C_{t+1}}{C_t}\right)^{\eta_c} \quad (5)$$

Where:
Vkm_{it} is the total road vehicle km in zone *i* in year *t*
S_{it} is the estimated mean speed of road traffic in zone *i* in year *t*
C_t is the average cost of travel in year *t*, given by the cost per litre of fuel

These (and all other) model elements were implemented via VB scripts, based on a number of standardised csv input files. Model run times are currently negligible in all cases.

4.2 Rail Transport

The basic form of the interzonal rail model is similar to the interzonal road model, with change in demand over a given time period predicted based on changes in population, GVA, and journey cost. As with the road model, the population elasticity was set to 1, and the NTM GDP elasticity of 0.55 was applied to GVA. The rail fare elasticity was set at -1 based on evidence from the Passenger Demand Forecasting Handbook (Association of Train Operating Companies, 2009). The speed variable from the road model was replaced by a delay variable with an elasticity of -0.34 (Preston & Dargay, 2005), and the NTM cross-elasticity of rail demand with respect to car fuel cost was also incorporated. The basic form of the model is given by equation (6) but, as with the interzonal road model, the model incorporates feedback between demand and capacity, with the level of delays on a particular link assumed to be an indirect function of the number of trains operating on that link, and therefore given by equation (7). The beta parameter was initially set to 2, based on evidence from Faber Maunsell (2007). Rail capacity utilisation is an extremely complex concept, but here an approximation is assumed to be given by equation (8). Because we are interested in total interzonal travel and in incremental changes over time rather than cross-sectional forecasts, we can assume that route km is equivalent to the number of tracks (one route km for each track), and that train km is equivalent to the number of trains operating between the zones (one train km for each train). Capacity utilisation is therefore given by the number of trains divided by the number of tracks. The model iterates between equations (6) and (7) until convergence is reached.

$$\frac{T_{ijt+1}}{T_{ijt}} = \left(\frac{P_{it+1}}{P_{it}}\right)^{1}\left(\frac{P_{jt+1}}{P_{jt}}\right)^{1}\left(\frac{I_{it+1}}{I_{it}}\right)^{0.55}\left(\frac{I_{jt+1}}{I_{jt}}\right)^{0.55}\left(\frac{D_{ijt+1}}{D_{ijt}}\right)^{-0.34}\left(\frac{C_{ijt+1}}{C_{ijt}}\right)^{-1}\left(\frac{F_{t+1}}{F_t}\right)^{-0.12} \quad (6)$$

$$\frac{D_{ijt+1}}{D_{ijt}} = \frac{e^{\beta CU_{ijt+1}}}{e^{\beta CU_{ijt}}} \quad (7)$$

$$CU_{ijt} = \frac{Tkm_{ij}}{Rkm_{ij}} \quad (8)$$

Where:
T_{ijt} is the number of trains
D_{ijt} is the level of delays for rail travel between zone *i* and zone *j* in year *t*
F_{t+1} is the car fuel cost (£ per litre) in year *t*

CU_{ijt} is the capacity utilisation between zone *i* and zone *j* in time period *t*
Tkm_{ij} is the number of train kilometres operating between zone *i* and zone *j*
Rkm_{ij} is the number of route kilometres between zone *i* and zone *j*

A problem with this model form is that the elasticities used relate more to passenger numbers than to train numbers, and passenger numbers and train numbers do not necessarily vary at the same rates. It is likely that in reality passenger numbers will grow until on-train crowding reaches a certain level, at which point additional trains will be provided. However, developing a model that works in this way is not straightforward, as no data were available on either the current number of passengers travelling between each zone pair, or the current level of crowding on trains between each zone pair.

A nodal passenger rail model was developed to accompany the interzonal rail model, but as with the intrazonal road model a lack of appropriate data means that this nodal model does not incorporate a capacity constraint. It was formulated to model the average number of passengers boarding and alighting per station within each zone based on changes in population, GDP, and cost. This allows future capacity enhancements (through the construction of additional stations) to be accounted for in model forecasts. In such cases an initial forecast is made for the station using trip end demand models previously developed at TRG (Blainey, 2010), with this figure then used to adjust the average number of trips per station within the zone. Speed was not included as a variable, as again no base level data was available. The same elasticities were used as in the interzonal model for population and GVA. However, it is known that fare elasticities are not constant across space. The Passenger Demand Forecasting Handbook (Association of Train Operating Companies, 2009) provides a range of fare elasticities for different trip categories, along with data on the number of passengers falling into each category, and these were used to estimate average fare elasticities for each zone. The model form is given by equation (9).

$$Tr_{it+1} = \left(\frac{P_{it+1}}{P_{it}}\right)^{1} \left(\frac{I_{it+1}}{I_{it}}\right)^{0.55} \left(\frac{C_{t+1}}{C_t}\right)^{\eta_C} T_{ist} S_{it+1} \quad (9)$$

Where:
Tr_{it+1} is the total number of rail trips in zone *i* in year *t*
Tr_{ist} is the average number of rail trips per railway station in zone *i* in year *t*
S_{it+1} is the number of railway stations in zone *i* in year *t+1*

4.3 Air Transport

The flow element of the air model (for domestic traffic) is similar to the interzonal road and rail models, although it was assumed that air travel times would remain constant over time, and therefore no speed variable was therefore included in the model (equation (10)). There are some limitations to this model, as it does not take account of the fact that airports will serve areas beyond the ITRC zone in which they are located, and that air passenger numbers may therefore be affected by changes in population and GVA in these wider areas. This flow model is accompanied by a nodal model for international traffic to/from airports. Government Office Regions (GORs) are used as the zones for calculating population and employment changes for this model rather than ITRC zones, because international air passengers will be drawn from a much wider area than passengers for other forms of transport, and therefore using ITRC zones would give an unrealistic picture of airport catchments. While it was initially assumed that the same set of airports would be available throughout the study period, it would in theory be possible to add new airports to the model in later years, although consideration would need to be given as to the methodology used for forecasting the usage of these airports as an elasticity-based approach would not be appropriate.

Both models are constrained by airport capacity, with the constraint mechanism taking a different form to the road and rail models, as capacity constraints place an absolute limit on air passenger numbers. The constraint therefore means that if the capacity limit at a particular airport is reached, no further growth in usage can occur at that airport until capacity enhancement occurs. Capacity will be used by both domestic (interzonal) and international passengers, and therefore the interzonal and nodal air models are run simultaneously, with domestic and international passenger numbers calculated for each year and then summed and compared to terminal capacity to check if a constraint has been reached. If it has, then domestic and international demand is fixed at these maximum levels until investment in capacity enhancements is specified as an external variable. While the number of passengers using an airport is directly related to terminal capacity utilisation, its relationship with runway capacity utilisation is more complicated. This is because the number of passengers which can be accommodated per runway slot varies with both aeroplane capacity and aeroplane average load factors. Average aeroplane size and average load factor are therefore included as external variables in the model, giving the potential for changes in load factors and aeroplane capacities under some future scenarios. The model brings together unconstrained estimates of domestic and international passengers via equation (12), with average load factors (from the British Air Transport Association) applied to estimate the unconstrained number of flights via each airport, and a set of constraints (given by equations (13)-(17)) then used to scale these figures to give final forecasts of passengers and flights.

$$\left(\frac{F_{abt+1}}{F_{abt}}\right) = \left(\frac{P_{it+1}}{P_{it}}\right)^{\eta_P} \left(\frac{P_{jt+1}}{P_{jt}}\right)^{\eta_P} \left(\frac{I_{it+1}}{I_{it}}\right)^{\eta_I} \left(\frac{I_{jt+1}}{I_{jt}}\right)^{\eta_I} \left(\frac{C_{ijt+1}}{C_{ijt}}\right)^{\eta_C} \quad (10)$$

$$\left(\frac{T_{Iat+1}}{T_{Iat}}\right) = \left(\frac{P_{zt+1}}{P_{zt}}\right)^{\eta_P} \left(\frac{I_{zt+1}}{I_{zt}}\right)^{\eta_I} \left(\frac{C_{t+1}}{C_{t}}\right)^{\eta_C} \quad (11)$$

$$T_{atu} = \sum_{a} F_{abt} + T_{Iat} \quad (12)$$

$$A_{atD} = Al_{Dt} As_{Dt} \sum_{i} F_{ijt} \quad (13)$$

$$A_{atI} = Al_{It} As_{It} T_{Iat} \quad (14)$$

$$A_{atu} = A_{atD} + A_{atI} \quad (15)$$

Constraint 1 (16):

If $T_{atu} > T_{Ca}$

Then $T_{at} = T_{Ca}$

and

$$A_{at} = \frac{\left(\frac{\sum_i F_{ijt-1}}{T_{at-1}}\right) T_{Ca}}{Al_{Dt} As_{Dt}} + \frac{\left(\frac{T_{Iat-1}}{T_{at-1}}\right) T_{Ca}}{Al_{It} As_I t}$$

Otherwise $T_{at} = T_{atu}$

Constraint 2 (17):

If $A_{atu} > A_{Ca}$

Then $A_{at} = A_{Ca}$

and

$$T_{at} = \left(\frac{A_{at-1D}}{A_{at-1}}\right) A_{Ca} Al_{Dt} As_{Dt} + \left(\frac{A_{at-1I}}{A_{at-1}}\right) A_{Ca} Al_{It} As_{It}$$

Otherwise $A_{at} = A_{atu}$

Where:
F_{ijt} is the number of air passengers between airport *a* (in zone *i*) and airport *b* (in zone *j*) in time period *t*
T_{Iat} is the number of international air arrivals and departures at airport *a* in time period *t*
P_{zt} is the population of Government Office Region *z* (within which airport *a* is located) in time period *t*
I_{zt} is the GVA per capita in Government Office Region *z* (within which airport *a* is located) in time period *t*
C_t is the average fuel cost in time *t*
T_{atu} is the unconstrained number of terminal passengers at airport *a* in year *t*
A_{atD} is the number of domestic airport movements at airport *a* in year *t*
A_{atI} is the number of international airport movements at airport *a* in year *t*
A_{atu} is the unconstrained total number of airport movements at airport *a* in year *t*
Al_{Dt} is the average load factor for domestic flights in year *t*
Al_{It} is the average load factor for international flights in year *t*
As_{DT} is the average aircraft size for domestic flights in year *t*
As_{IT} is the average aircraft size for international flights in year *t*
T_{Ca} is the maximum terminal capacity of airport *a* in year *t*

A_{Ca} is the maximum runway capacity of airport *a* in year *t*
T_{at} is the constrained number of terminal passengers at airport *a* in year *t*
A_{at} is the constrained total number of airport movements at airport *a* in year *t*

4.4 Sea Transport

The sea transport model forecasts total container traffic measured in TEUs and total bulk traffic measured in tonnes via 36 UK ports at a nodal level. The model takes a very similar form to the air model, with container traffic forecast using equation (18), subject to constraint (19) and bulk traffic using equation (20). No data were available on seaport bulk freight capacity, meaning that the latter traffic could not be constrained in the model. As with the other models, the population elasticity was set to 1, with a GDP elasticity of 0.64 taken from recommendations by the Australian Bureau of Infrastructure, Transport and Regional Economics and a fuel price elasticity of 0.1 (De Jong et al., 2010).

$$\left(\frac{TEU_{st+1u}}{T_{st}}\right) = \left(\frac{P_{zt+1}}{P_{zt}}\right)^{\eta p} \left(\frac{I_{zt+1}}{I_{zt}}\right)^{\eta I} \left(\frac{C_{t+1}}{C_t}\right)^{\eta c} \quad (18)$$

If $TEU_{st+1u} > S_{Ca}$ then $TEU_{st+1} = T_{Ca}$; otherwise $TEU_{st+1} = TEU_{st+1u}$ (19)

$$\left(\frac{Bf_{st+1u}}{Bf_{st}}\right) = \left(\frac{P_{zt+1}}{P_{zt}}\right)^{\eta p} \left(\frac{I_{zt+1}}{I_{zt}}\right)^{\eta I} \left(\frac{C_{t+1}}{C_t}\right)^{\eta c} \quad (20)$$

Where:
TEU_{st} is the volume of container traffic (measured in TEUs) via seaport *s* during year *t*
TEU_{st+1u} is the unconstrained volume of container traffic (measured in TEUs) via seaport *s* during year *t + 1*
S_{Ca} is the capacity in TEUs of seaport *s*
BF_{st} is the volume of bulk freight (measured in tonnes) via seaport *s* during year *t*

4.5 Interrelationships

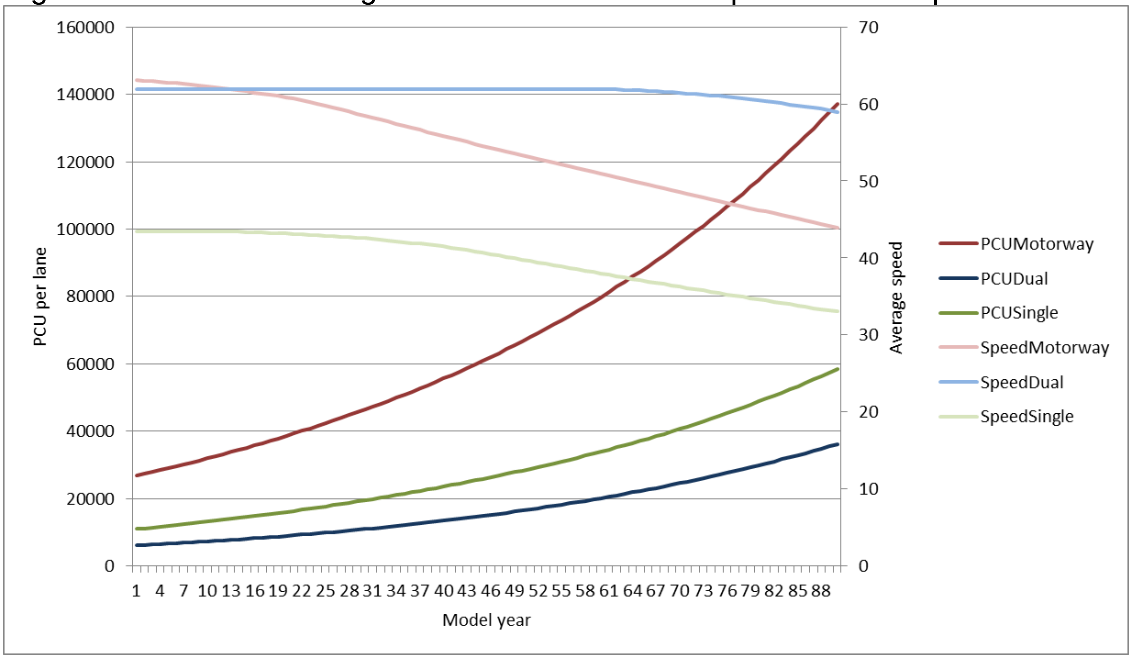
Currently, the only intermodal interrelationship included in the model is the cross-elasticity of rail demand with respect to fuel price. However, in reality there will obviously be other feedbacks between transport modes, and work is currently underway to expand the model to account for additional feedbacks, for example between levels of transport demand and capacity utilisation by different modes on the same interzonal flow.

5. MODEL OUTPUTS AND FUTURE WORK

5.1 Initial Outputs

The various elements of the model are currently being tested and validated, to check the consistency of model forecasts both with previously observed trends (via back-casting) and with forecasts of future changes from other models. This process is still ongoing, but an illustrative example of the model outputs is given by Figure 1, which shows estimated road traffic levels and speeds for a sample aggregated interzonal road link over the period from 2011-2100.

Figure 1: Estimated change in traffic volumes and speeds for sample road link



5.2 Next Steps: The Scenario-Based Approach

Once testing and validation of the various elements of the model has been completed, all sections of the Transport CDAM will be run simultaneously to estimate transport and infrastructure capacity utilisation throughout the remainder of the 21st century under a range of scenarios. This scenario-based approach is a central feature of the ITRC modelling approach, with the scenarios used being common to all infrastructure sectors considered in ITRC. These scenarios will include projected or potential changes in both transport and external factors. Examples of transport-related scenario elements might include developments in alternative transport fuels or the construction of new high speed rail lines, while external scenario elements might include a large and sustained increase in oil prices, or a rise in sea levels as a result of climate change. These scenario elements will impact on model outputs via associated changes in the levels of model external variables to reflect variations in (for example) GDP, population, employment, energy prices, fuel mix, fuel efficiency, public transport fares, taxation levels, speed limits (and other legal interventions), infrastructure capacity and inputs from other ITRC sector models. These changes may be either spatially homogenous or varying in magnitude and timing from place to place, depending on the expected characteristics of the scenario being modelled. Outputs from the transport model may then in turn form inputs to other ITRC CDAMs, with for example transport energy consumption forming an input to the energy model.

A major premise of the ITRC project (as emphasised in the Fast Track Analysis report (Hall et al., 2012)) is that the benefits of infrastructure can be more effectively achieved, and the systemic risks minimised, through the development of an integrated, long term strategic approach to infrastructure provision. This involves proposing an overall direction for NI systems and developing pathways to achieving the desired outcomes in the long term. In order to implement this approach in practice NI transition strategies should be formulated, these being cross-sectoral strategic plans for NI service provision, comprised of sequenced, sector-specific governance and technology options. The ITRC CDAMS will be used to test the results and effectiveness of these transition strategies in a range of future scenarios, providing a virtual environment in which the implications of these strategies can be assessed. The project will thus contribute to the development of new infrastructure decision-support tools, and inform the analysis, planning and design of NI in partnership with government and industry.

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