ASSESSING LONG TERM CAPACITY AND DEMAND IN THE RAIL SECTOR

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ABSTRACT

This paper describes research which aims to model British rail network demand and capacity up to 2100, as part of the Infrastructure Transitions Research Consortium (ITRC). ITRC is developing models and decision support tools to enable analysis and planning of a robust national infrastructure system in an uncertain future, and the research discussed here forms part of the transport model. This is a simulation model forecasting travel within and between 142 zones, with rail traffic measured on both a link and zonal basis. The rail link model forecasts the total number of trains per track between each pair of adjacent zones, with delays acting as a brake on demand as capacity utilisation increases. Total consumption of electric and diesel fuel will also be estimated, allowing interactions with the ITRC energy model. The rail zone model forecasts the number of passengers per station within each zone, with capacity enhancements incorporated via the addition of new stations. Together these models can be used to predict rail traffic, capacity utilisation and energy consumption under a range of future scenarios, and can thus help identify which strategies for future transport infrastructure provision have the best chance of being effective in practice.

Keywords: Rail, infrastructure, modelling, futures, scenarios

1) INTRODUCTION

1.1 ITRC – An Overview

Railway systems face a number of serious challenges over the coming years and decades, including (in many countries) growing demand from both passenger and freight users, changes to the size, spatial distribution and mobility patterns of the population, significant investment requirements to allow ageing infrastructure assets to meet this demand while providing reliable, cost-effective and high quality services, and increasing levels of interdependence with other complex infrastructure systems (Hall et al., 2012). This paper describes the development and use of a model which forms part of a suite of modelling tools designed by the UK Infrastructure Transitions Research Consortium (ITRC) to help transport and other infrastructure systems meet the many future challenges they face. 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 National Infrastructure (NI) system for the UK over the remainder of the 21st century. It involves a five year research programme, running from 2011 to 2015, which is structured around the following 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?

As well as transport, ITRC is also considering the energy, water, waste water, waste and ICT systems, and is making use of a range of future demographic and economic scenarios as a deterministic input to the analysis being undertaken.

1.2 The ITRC Modelling Approach

In order to address the first of the four overarching questions it is necessary to understand and predict how infrastructure capacity and demand will change over the next 90 years. Initial ITRC research was centred on a ‘Fast Track Analysis’ of UK infrastructure and a review of existing models and data sources, to refine the scope of the project and ensure that it complemented rather than repeated previous research (Hall et al., 2012). This has since been followed by the development of four sector-specific simulation models for energy, water, waste and transport systems in Britain with the modelling described here forming part of the transport model. This was designed to be a strategic model capable of assessing the transport demand-capacity balance at a national scale, while also taking account of local variations in demand and supply and identifying particular zones and links where demand-supply mismatches were likely to arise.

1.3 Long-Term Transport Modelling In Britain

When this research commenced the project team were aware that a number of long-term models of British transport systems already existed, and to avoid repeating previous work the original plan was that the ITRC model would be based on outputs from these existing models, particularly those owned by the Department for Transport. Relevant models in the rail sector include the PLANET Long Distance Model developed as part of the planning for the proposed HS2 railway (HST Ltd, 2010), and the Department for Transport’s National Transport Model (Department for Transport, 2009) and National Trip End Model (WSP Group, 2011). However, in practice these models either proved unsuitable for the purposes of the ITRC project or could not be made available within the project timeframes. It was therefore necessary to develop a bespoke transport model for ITRC, based almost entirely on open-source data.

1.4 ITRC Transport Model Structure

The ITRC model forecasts transport demand (and its relationship with transport capacity) by road and rail within and between 144 zones (based on local authorities) covering the whole of Great Britain. Interzonal traffic is allocated to an infrastructure system made of single aggregated links connecting each pair of adjacent zones, with intrazonal traffic modelled at the aggregate level. The model differs from most aggregate transport models in that it neither contains nor imputes an origin-destination matrix, as the key point of interest is the volume of traffic on particular links or within individual zones. Seaborne freight traffic is represented via a set of seaport nodes, and air passenger traffic is modelled on the basis of inter-airport links for domestic traffic and airport nodes for international traffic. The model produces forecasts on a yearly basis for the period 2011-2100, but considers much smaller time intervals during the forecasting process (for example to allow a more accurate representation of road congestion). Capacity enhancements can be incorporated in the modelling process, but must be specified in the model inputs prior to the commencement of a model run. The remainder of this paper examines the rail submodels in more detail by first outlining the model data sources and structure, and then examining some initial results.

2) INTERZONAL MODEL

2.1 Data Sources

The main constraint in developing the ITRC transport model was data availability, and the rail sector was no exception in this regard. Rail traffic is most commonly measured in terms of passenger numbers, and a detailed origin-destination matrix is available for British passenger rail traffic. This is called TOAD (‘The Oxera Arup Dataset’), is based on electronic ticket sales data (Arup & Oxera, 2010), and gives the total number of passengers travelling between station pairs. However, one of the main aims of the ITRC modelling process is to estimate infrastructure capacity utilisation levels, and in order to do this it is necessary to know the number of passengers (and ultimately the number of trains) travelling over particular sections of line. As unfortunately there was no available methodology for assigning routes to each of the station pairs an alternative means of representing rail traffic was used. This involved representing rail traffic in terms of number of trains rather than number of passengers, with electronic timetable data used to calculate the number of trains using each link of the rail network. The complete GB rail timetable was obtained in text file format from the Association of Train Operating Companies, and a VB script was written to interrogate this text file and produce separate csv files for each of the 11,424 timing point to timing point links on which trains were recorded as operating and a summary file giving the total number of trains operating on each link. These totals were also broken down into electric and diesel trains, allowing for later estimation of fuel consumption. The resulting rail links are mapped with their service frequencies in Figure 1.

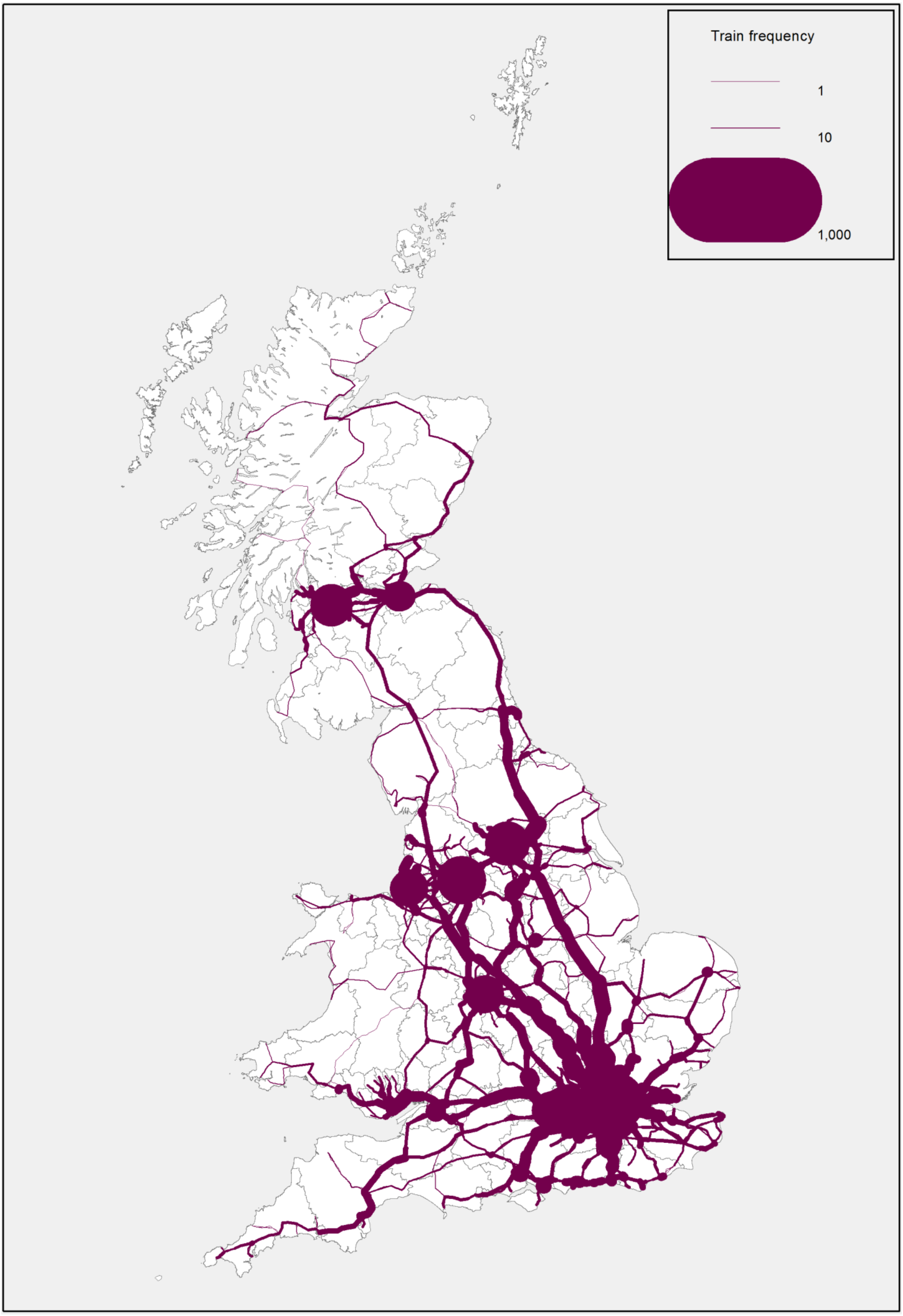

Figure 1: Rail Link Weekday Passenger Train Frequencies 2011

As the ITRC model is concerned with aggregate travel between 144 zones (based on local authorities), ArcGIS was used to select links crossing zone boundaries, split these links at the boundaries, join the resulting links to specific zones, and aggregate the links between adjacent zone pairs to give the total number of services operating between those zones on a typical weekday. This gave a total of 237 interzonal links for use in the model.

In addition to demand data, it was necessary to estimate base case data on the capacity of each of the interzonal links. The measurement of rail capacity is an extremely complex topic, as there is in reality 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 (but 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.

2.2 Model Form

Both rail modules were designed as simulation models, forecasting changes in demand over time. The interzonal model is a simple elasticity-based model which uses Equation (1) to predict demand response to changes in population, GVA (Gross Value Added, a proxy for economic activity), journey costs, car fuel costs and rail delays over a given time period. The elasticities used in the model were taken from the best available existing evidence, with the population and GVA elasticities from the Department for Transport's National Transport Model, the cost and delay elasticities from the Passenger Demand Forecasting Handbook (ATOC, 2009), and the cross-elasticity of rail demand with respect to car fuel cost again from the National Transport Model. An inherent problem with this model form is that the available elasticity values relate more to passenger numbers than to train numbers, and passenger and train numbers do not necessarily vary in parallel with each other. In reality it is more likely that passenger numbers will grow until on-train crowding reaches a certain level, at which point either additional trains will be provided or alternatively crowding will act to constrain growth in usage. However, it was not possible to develop a model which reflects this rather complex and unpredictable relationship, as no data were available on current levels of crowding or on the number of passengers travelling between each zone pair.

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

Where:
T_{ijt} is the number of trains between zone *i* and zone *j* in year *t*
P_{it} is the resident population of zone *i* in year *t*
I_{it} is the GVA per capita in zone *i* in year *t*
C_{ijt} is the average cost of rail travel between zone *i* and zone *j* in year *t*
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*

The level of delays on a particular link is an indirect function of the level of capacity utilisation on that link, and is given by Equation (2), which is based on evidence from a report by Faber Maunsell (2007). This means that the model includes a feedback mechanism between delays and capacity utilisation levels, and the model therefore iterates between Equations (1) and (2) until convergence is reached.

$$\frac{D_{ijt+1}}{D_{ijt}} = \frac{e^{2CU_{ijt+1}}}{e^{2CU_{ijt}}} \quad (2)$$

Where:
CU_{ijt} is the level of capacity utilisation between zone *i* and zone *j* in time period *t*

As stated previously, rail capacity utilisation is an extremely complex concept, and therefore a much simplified measure has been used here. 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). A train density measure is therefore given by the number of trains divided by the number of tracks, and the ratio of this train density measure to theoretical maximum capacity gives an approximation of capacity utilisation, shown here as Equation (3).

$$CU_{ijt} = \frac{\left(\frac{Tkm_{ij}}{Rkm_{ij}}\right)}{Td_{MAXij}} \quad (3)$$

Where:
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*
TD_{MAXij} is the maximum train density (trains divided by tracks) between zone *i* and zone *j*

This still left the problem that no data were available on the theoretical maximum capacities of different routes. An approximate estimate was therefore made, based on the assumption that all routes required a minimum headway of four minutes per track, following a check that this level of traffic is not currently exceeded on any interzonal links. However, these figures could easily be replaced with better data on actual maximum capacities if this became available in the future. Changes to infrastructure capacity (either in absolute terms through the addition/removal of tracks, or alternatively through changes in maximum train densities) over the modelling timescale are described in one of the model input files, and can be altered to represent different future scenarios before commencing a model run.

3) INTRAZONAL MODEL

3.1 Data Sources

In order to give a complete picture of British rail travel it was necessary to model traffic within zones as well as between zones, and a separate model module was therefore developed to represent such traffic, based on the number of passengers boarding and alighting within each zone. Comprehensive data is available from the Office of Rail Regulation on the total number of trips made to and from every railway station in Britain, based on automatically collected ticket sales data (DeltaRail, 2012). 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. ArcGIS was used to allocate all stations to the relevant ITRC zones, and the number of trips recorded at all stations within each zone was then summed to give the total number of passengers per zone in 2010/11 for use as the base demand dataset in the model. This data is mapped in Figure 2. There was no corresponding capacity measure for this demand data, as there is no absolute maximum number of passengers who can be accommodated at particular stations. However, capacity enhancements can be represented by adding additional stations to particular zones. In such cases it is necessary to make an initial forecast of the base demand level at these new stations using the University of Southampton’s trip end rail demand model (Blainey, 2010), to allow the average number of trips per station in the zone where the new station is constructed to be adjusted accordingly.

3.2 Model Form

Like the interzonal model the intrazonal model has a simple elasticity-based form, which predicts the average number of passengers boarding and alighting per station in each ITRC model zone, based on changes in the level of population and GVA in that zone and in the average cost of rail travel and of car fuel. Average generalised journey time (GJT) was also included as a combined proxy for speed (or journey time), train frequency and crowding. Base levels were set to 1 for all flows, allowing proportional changes in GJT (or its component parts) over time to be modelled. This is an aggregate GJT measure, and should not be manipulated in an attempt to model the effect of introducing a new station or service which alters the ‘GJT mix’ within a zone. The model predictions can be multiplied by the number of stations in each zone in each year to give a forecast of the total number of rail trip ends in individual zones. The level of delays was not included as an explanatory variable for this model, as no base data were available, and the lack of a capacity constraint meant that there was no feedback mechanism to predict changes in delays as a result of changes in traffic. The form of the model is given by Equation (4).

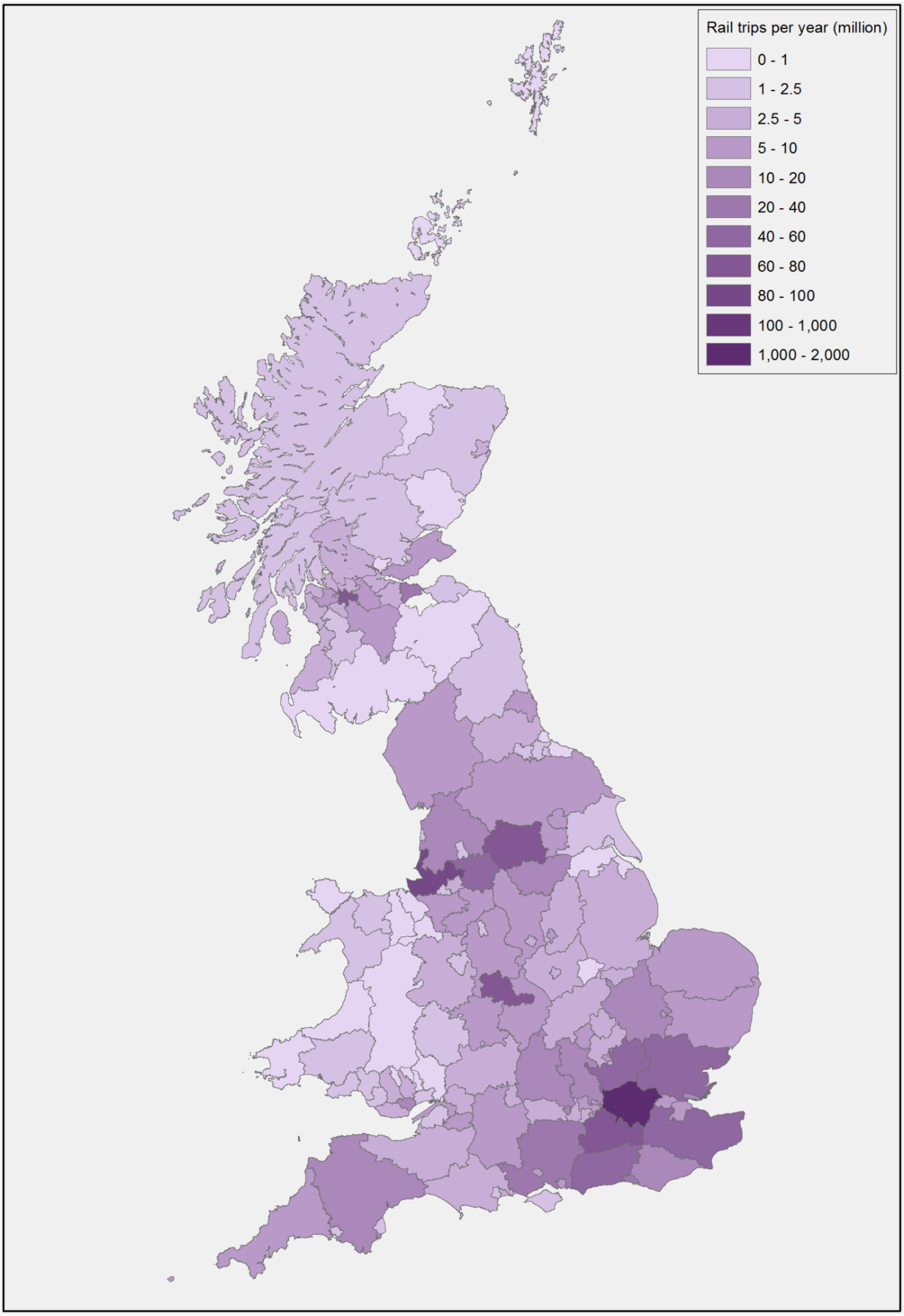

Figure 2: Annual Rail Trip Ends In ITRC Zones

$$\left(\frac{T_{it+1}}{T_{it}}\right) = \left(\frac{P_{it+1}}{P_{it}}\right)^{\eta_p} \left(\frac{I_{it+1}}{I_{it}}\right)^{\eta_I} \left(\frac{C_{t+1}}{C_t}\right)^{\eta_c} \left(\frac{F_{t+1}}{F_t}\right)^{\eta_f} \left(\frac{GJT_{it+1}}{GJT_{it}}\right)^{\eta_{gjt}} \qquad (4)$$

Where:
T_{ist} is the average number of rail trips per railway station in zone *i* in year *t*
GJT_{it} is the average generalised journey time for trips starting or ending in zone *i* in year *t*

The population, GVA and car cost elasticities used in this model were the same as for the interzonal rail model. However, more detailed evidence on spatial variations in fare elasticities is provided by the Passenger Demand Forecasting Handbook (PDFH) (ATOC, 2009), as shown in Table 1.

Area		Ticket type		Journey purpose		
		Seasons	Other	Commuting	Business	Leisure
London Travelcard	Anytime	-0.45		-0.85	-0.50	-1.20
	Off-peak	-0.45		-0.65	-0.40	-0.90
Within South East		-0.9	-1.0	-0.9	-0.6	-1.1
PTE		-0.6	-0.85	-0.6	-0.5	-0.9
Non PTE < 20 miles		-0.7	-1.0	-0.7	-0.6	-1.05
Non-London > 20 miles		-0.9	-1.0	-0.9	-0.6	-1.10

Table 1 – Fare Elasticities From Passenger Demand Forecasting Handbook

This shows that there are, for example, clear differences between the fare elasticities in London and in the former PTE (Passenger Transport Executive) areas around other large conurbations. The PDFH also provides data (taken from the National Travel Survey) on the proportion of passengers within each area who fall into the categories identified in Table 1. These proportions were used to estimate average fare elasticities for each of the area types shown in Table 1, giving values of -0.550 for the London Travelcard area, -0.940 for the South-East area, -0.675 for PTE areas and -0.915 for other non-London areas. The ITRC zones were then allocated to these areas, with the ‘South-East’ (for which definitions vary) assumed to comprise the area covered by the former South East Standard Statistical Region excluding Greater London. Similar methods were used to calculate GJT elasticities for these area types, giving values of -0.732 for the London Travelcard area, -0.966 for the South-East area, -0.775 for PTE areas and -0.737 for other non-London areas. Elasticity zone codes were incorporated into the model input files to ensure that the correct elasticity was used in each case.

4) IMPLEMENTATION

4.1 Model Implementation

Both sub-models were coded in Visual Basic (VB) scripts using Microsoft Visual Studio 2010, with the scripts for all elements of the ITRC transport model then compiled into a simple Windows-based application, which is illustrated in Figure 3. The rail sub-models read input data from a set of csv files, containing information on base levels of demand and of the various explanatory values, on the changing values of these explanatory variables over time, on changes to infrastructure (for example the construction of additional stations), and on model elasticity values (which can also vary over time if required for a particular scenario). Model forecasts are written to similar csv output files, allowing easy input to a spreadsheet or GIS for further analysis or visualisation.

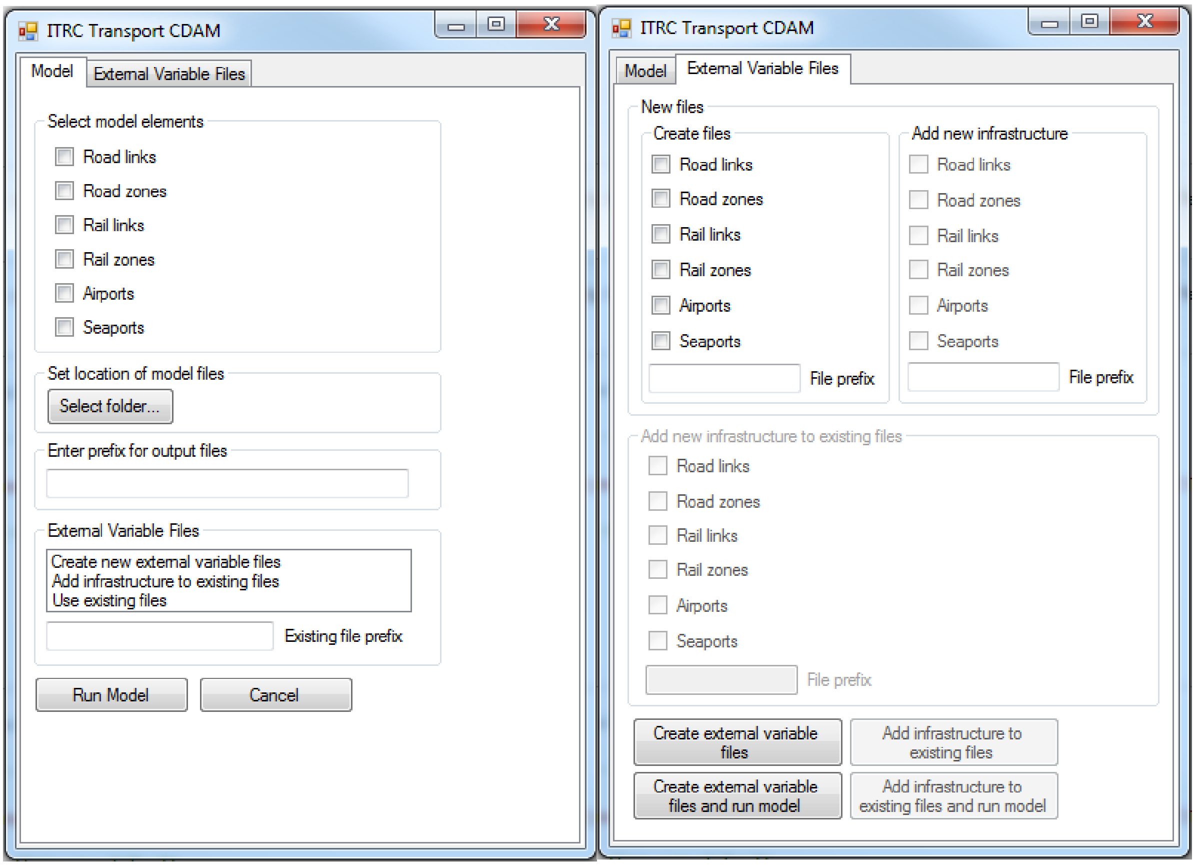

Figure 3: Windows-based Implementation of ITRC Transport Model

The outputs produced by the model are obviously highly dependent on the input values assigned to the various explanatory variables, and these therefore formed the main means of representing different future scenarios in the model. Ultimately a wide range of different scenarios will be explored using the ITRC Transport Model together with the other sectoral models, with bespoke data on future population, GDP and energy cost levels produced by other ITRC project partners. Initially, however, the model was tested using a small number of possible future conditions, many of which had previously been used in the ITRC Fast Track Analysis (Hall et al., 2012). Population data were taken from extended versions of the principal, low and high growth projections produced by the Office of National Statistics, with the principal estimates suggesting that the population of Great Britain will increase from its current level of 60 million to around 88 million by 2100. These projections are only disaggregated to the level of the constituent countries of Great Britain (England, Scotland and Wales), and therefore it is assumed that population will change at the same rate across each of these countries.

Model input data on estimated future economic growth are based on figures from Pricewaterhouse Coopers (2011) and projections made by Cambridge Econometrics using the MDM-E3 multisectoral dynamic econometric model (Junankar et al., 2007). Three sets of projections were again produced, with the low growth scenario predicting economic growth of 1.6% per annum, the medium growth scenario predicting economic growth of 2.3% per annum, and the high growth scenario predicting economic growth of 3.0% per annum. The recent and continued stagnation of the UK economy does perhaps cast some doubt on such assumptions of sustained economic growth, and this issue will be explored further in later stages of the ITRC project.

Finally, input data on energy prices are based on figures produced by DECC (2010) based on an analysis of the international energy market and other forecasts. Again, three scenarios were used for initial analysis, with the low price scenario based on low global energy demand, the central price scenario reflecting timely investment and moderate demand, and the high price scenario reflecting high demand and producers' market power (Hall et al., 2012). All these scenarios assume that costs will remain largely similar between 2030 and 2100, which may not reflect reality, and this will again be explored further in subsequent stages of the ITRC project. It is also possible (and perhaps likely) that transport fuel prices may increasingly diverge from the oil prices on which these estimates are based as 'alternative' fuels become more important in the transport context.

4.2 ITRC Transport Strategies

The main reason for developing the ITRC sector models was to test the performance and robustness across a range of future conditions (scenarios) of long-term strategies for national infrastructure provision. Future scenarios are generated based on variables exogenous to the analysis, and these are discussed above in Section 4.1. In contrast, future strategies are based on variables endogenous to the particular sectoral models, which for transport might include different levels of infrastructure investment and construction, or different taxation regimes. These are represented in the model by adjusting levels of the model input variables and/or the model elasticities. Seven such strategies have been developed for transport, under the broad headings of 'decline and decay', 'predict and provide', 'cost and constrain', 'adapting the fleet', 'promo-pricing', 'connected grid' and 'smarter choices'. Ultimately these will be considered in combination with associated strategies in other infrastructure sectors, but for the purposes of this paper two transport strategies will be considered in isolation to illustrate their application via (and effect on the results of) the rail submodel.

The first strategy tested here is 'Adapting The Fleet', where rapid technological development allows wide-ranging modernisation of the vehicle fleet by all modes. In the rail sector this would include the widespread and rapid electrification of the rail network, and the adoption of lighter vehicle construction materials allowing faster, longer trains to be operated, capable of carrying more passengers per unit of infrastructure capacity. This would be represented in the interzonal model by a slight increase in the maximum train density permitted on each link over time (to reflect changes to train characteristics, as braking and acceleration rates improve) and by changes to the rail cost variable to account for the impact of electrification.

The rail cost variable would see similar alterations in the intrazonal model, where mean GJT values would also be reduced over time to reflect the operation of faster, longer trains. While in reality these changes would occur in 'steps' at discrete points in time, in this case a smooth change over time in the maximum train density and GJT variables was assumed for simplicity, with the former increasing by 0.025% per year (giving a total increase of 25% over the model time period) and the latter decreasing by 0.02% per year (giving a total reduction of 16.5% over the model time period).

While in reality the progress of rail electrification would be highly spatially variable, it was assumed here that an additional 2.5% of the trains operating in each zone or link would be converted to electric traction in each year (and that the proportion of trips made on electric trains would vary in direct proportion to this). The proportion of trips using each power source was then used together with estimated changes in fuel prices (from DECC, 2010) to proportionally adjust the rail cost variable for each year. It was assumed that changes in cost were solely driven by changes in fuel prices, with other costs remaining constant relative to inflation (which is unlikely to be the case in practice, as it ignores factors such as government-imposed above inflation fare increases). Fuel and electric traction charges were estimated to form 8.77% of total TOC costs in research carried out as part of the Rail Value for Money study (Booz and Co, 2010, p.18). This 8.77% of costs was therefore increased in line with changes in fuel prices, with the assumption that fuel efficiency does not change over time. As the proportion of electric and diesel trains operated is predicted to change over time as a result of electrification, it was necessary to set base line figures for the fuel costs of electric and diesel trains. The absolute value of these figures is not crucial, providing that they are correct relative to each other, as the model uses proportional changes over time to make forecasts rather than absolute values. According to the Network Rail Electrification Route Utilisation Strategy, electric fuel costs per vehicle mile are 45.7% lower than diesel fuel costs (£0.26 compared to £0.47) (Network Rail, 2009, p.31). This document also suggests that maintenance and lease costs are lower for electric traction than for diesel traction, with electric train maintenance per vehicle mile 33% lower for electric trains (£0.40 compared to £0.60) and lease costs per vehicle per annum 18.2% lower for electric trains (£90,000 compared to £110,000). Combined, these two cost elements make up 26.62% of total costs (Booz and Co, 2010). In 2010 there were 12,186 passenger vehicles operating on the UK network (Network Rail, 2011) and 1.47 billion vehicle miles were operated (Booz and Co, 2010, p.15), meaning that on average each vehicle operated 120,630 miles per year. This gives an average maintenance cost per vehicle of £48,252 for electric vehicles, and £72,378 for diesel vehicles, giving a combined total annual operating cost of £138,252 for electric vehicles, and £182,378 for diesel vehicles. In other words, electric trains are 24.2% cheaper to maintain and lease than diesel trains. These figures can then be used to give base level estimates of the maintenance and lease costs for all trains in each zone (based on the base level proportions of electric and diesel traction), and the resulting figures can then in turn be used to adjust these base costs over time as increased electrification changes the proportion of electric and diesel trains operating. The remaining 64.61% of costs were assumed to remain constant over time, and it is also assumed that the maintenance and leasing costs per vehicle for diesel and electric traction remain constant over time.

The second strategy considered here is 'Connected Grid', where the maximum possible use would be made of ICT to enhance the operation of transport systems, with a high and increasing level of embedded technology. For rail transport this might include the network-wide implementation of flexible pathing and moving block signalling, allowing more trains to be operated per unit of infrastructure. Developments in ICT would also lead to a progressive reduction in overall traffic volumes, as the increased use of video-conferencing, 3D printing, ultra-high-speed internet connections and hologram-based communications reduce the need for travel. For the interzonal model this would lead to an increase in maximum train density over time (by 0.03% per year, giving a total increase of 30% over the model time period), and a reduction in the population (by 0.005 per year) and GVA (by 0.0025 per year) elasticities over time. These elasticity reductions were also used in the intrazonal model. Electrification was assumed to proceed at a slower rate than in 'Adapting the Fleet', with an additional 1% of trains operating on each zone or link converted to electric traction in each year. The effect of this change was incorporated in the cost variable of both models in the same way as for the 'Adapting the Fleet' strategy. As before, only fuel costs were allowed to vary proportionally over time, with other costs held constant.

5) RESULTS

One of the major challenges facing ITRC is the sheer number of potential future overall scenarios generated by even a small number of possible future sets of conditions in each aspect of the work. Even the three sets of population, economic and energy cost projections considered here combine to give 27 possible future scenarios with each transport strategy, and the results from such a large number of model runs could quickly become overwhelming. This paper will therefore only consider three underlying scenarios with each strategy, and these can be summarised as follows:

- Scenario 1: High population growth, high economic growth, high energy prices
- Scenario 2: Central population growth, central economic growth, central energy prices
- Scenario 3: Low population growth, low economic growth, low energy prices.

The models were run for each of the two transport strategies under each of the three scenarios. The results from the interzonal model for the 'Adapting the Fleet' strategy are shown in Figure 4, and the results from the intrazonal model in Figure 5. Equivalent results for the 'Connected Grid' strategy are shown from the interzonal model in Figure 6, and from the intrazonal model in Figure 7.

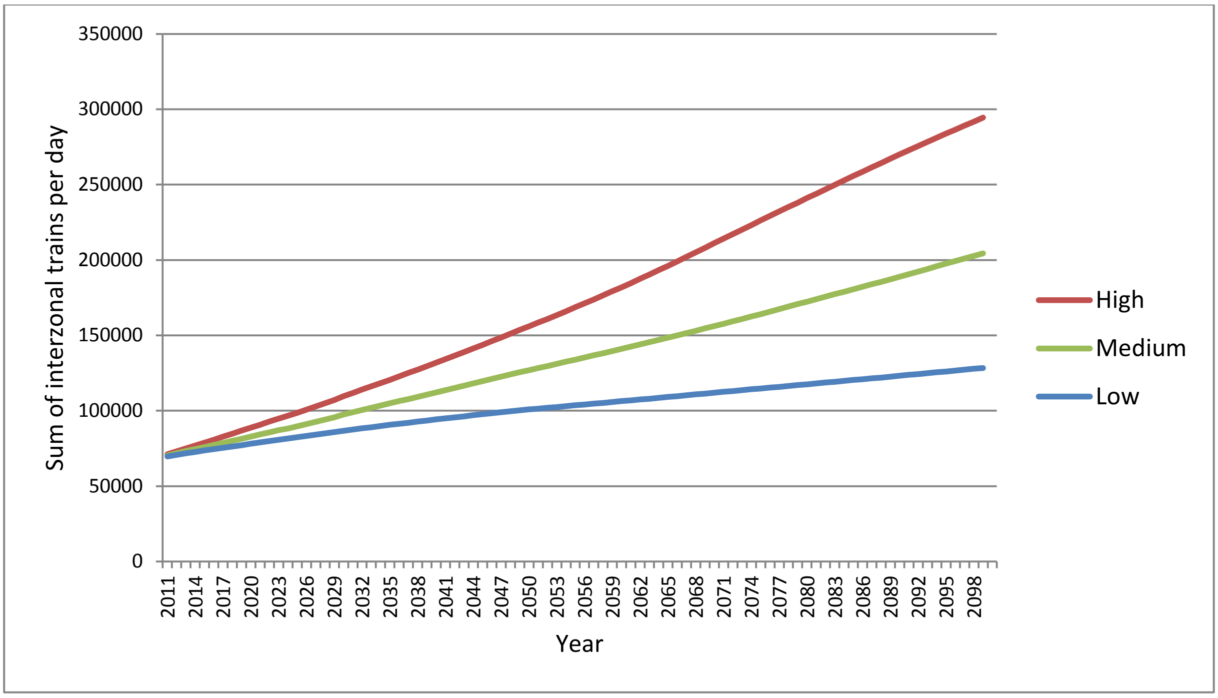

Figure 4: Sum Of Interzonal Trains Per Weekday Predicted By Interzonal Rail Model Using 'Adapting The Fleet' Strategy

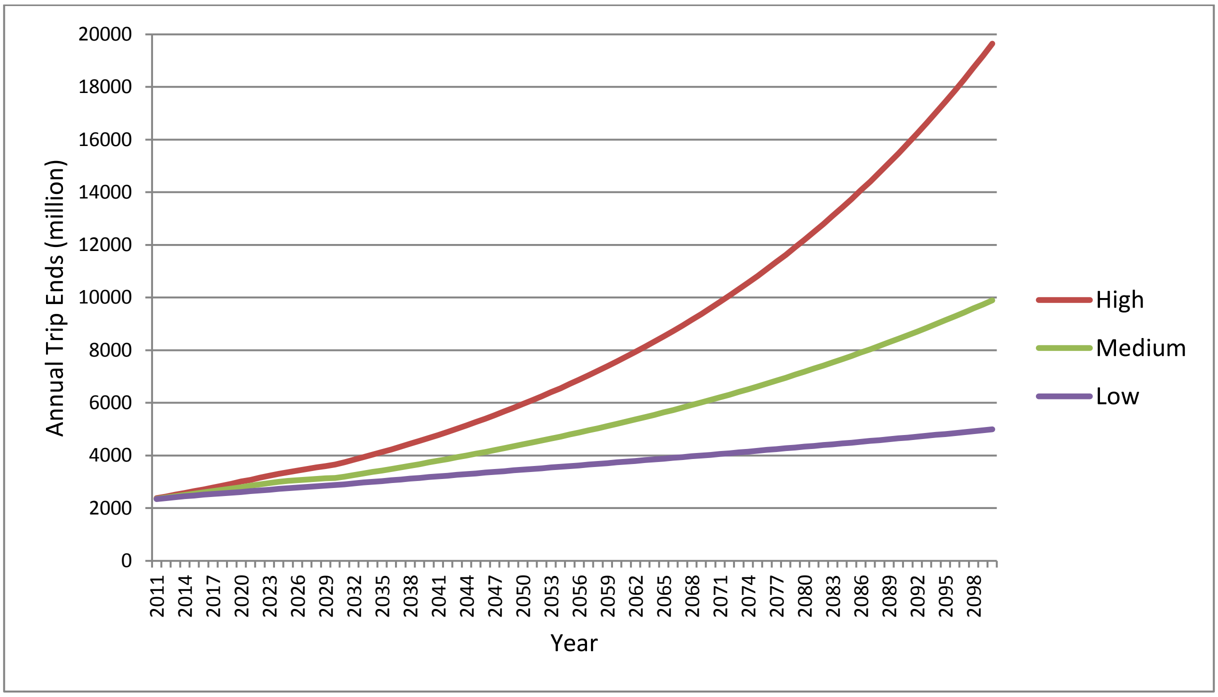

Figure 5: Total GB Rail Trips Predicted By Intrazonal Rail Model Using 'Adapting The Fleet' Strategy

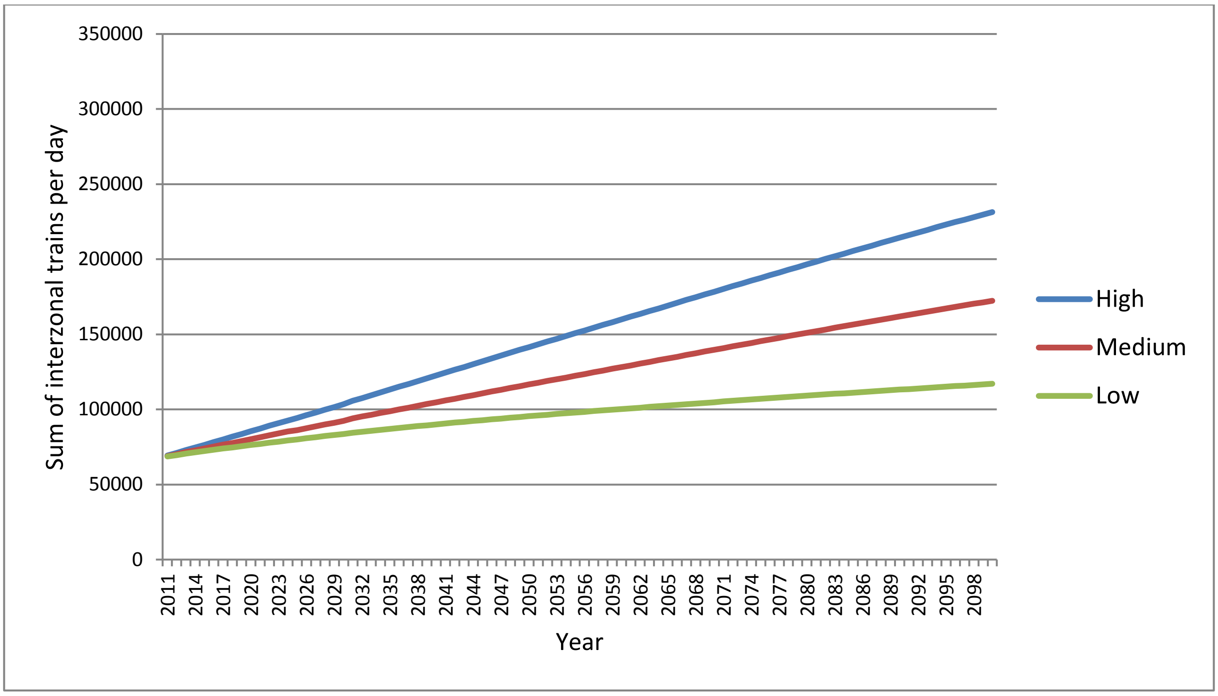

Figure 6: Sum Of Interzonal Trains Per Weekday Predicted By Interzonal Rail Model Using 'Connected Grid' Strategy

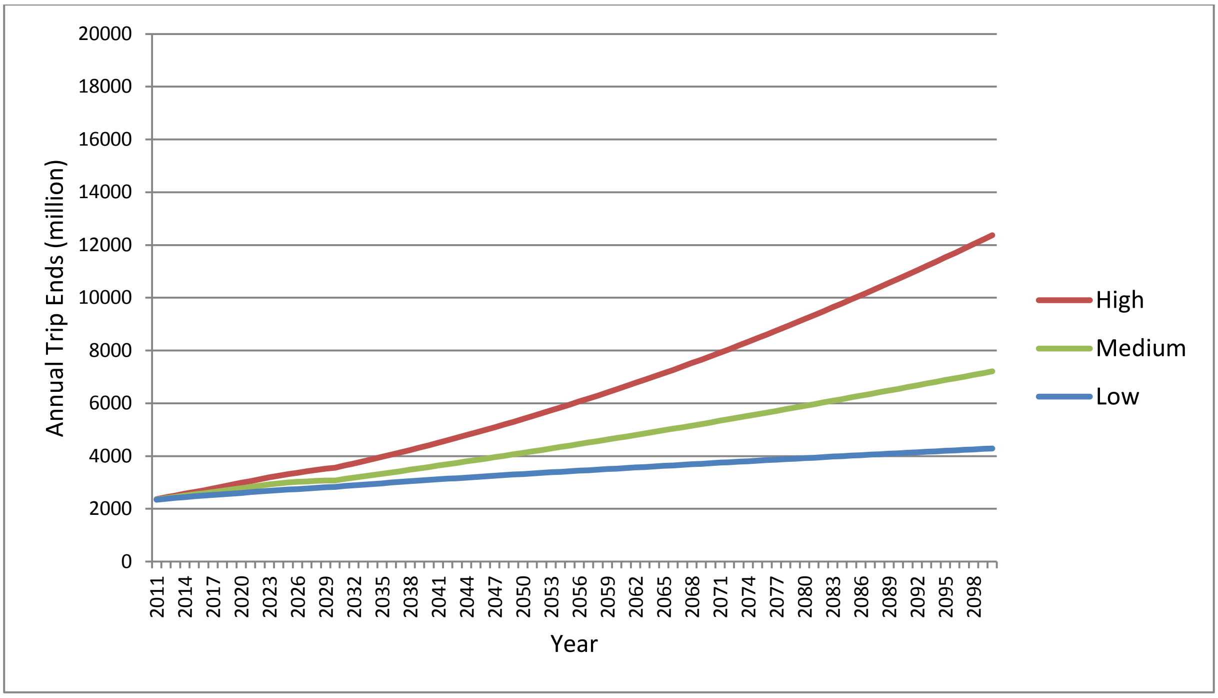

Figure 7: Total GB Rail Trips Predicted By Intrazonal Rail Model Using 'Connected Grid' Strategy

These figures show some clear differences between the patterns of rail usage predicted by the two models. The inclusion of a capacity constraint in the interzonal model in the form of the maximum train density variable appears to be acting to suppress growth in interzonal trains over time, so that the growth pattern is much closer to a straight line than the exponential growth in passenger numbers predicted by the intrazonal model with the high growth scenarios. The results from the two models are not necessarily incompatible, as it is possible that such unconstrained growth in passenger numbers could be accommodated even with a constraint on the number of trains operated through an increase in train occupation rates. However, crowding would be expected to act as an increasingly significant deterrent to travel as train occupation rates became progressively higher.

Figures 4 to 7 also show that there are clear differences between the forecasts generated using the different transport strategies. In general much high levels of train operation and passenger traffic are predicted under the ‘Adapting the Fleet’ strategy than under the ‘Connected Grid’ strategy. This is not unexpected, given the reductions in the population and GVA elasticities under the latter strategy combined with forecasts of sustained growth in both these variables under all three demographic and economic scenarios. While maximum capacity utilisation levels grew at a slightly higher rate under the ‘Connected Grid’ strategy, this would only lead to additional train operation if the underlying factors determining demand generated demand for such trains. The faster rate of network electrification (and consequent cost reduction) and the progressive reductions in GJT under the ‘Adapting the Fleet’ strategy will also have contributed to the higher levels of growth predicted with this strategy.

The effects of the capacity constraint in the interzonal model are illustrated more clearly by Figure 8, which shows the predicted number of interzonal trains under the ‘Adapting the Fleet’ strategy with the high growth scenario for three individual flows, specifically Flow 13 (Bath and North East Somerset – South Gloucestershire), Flow 15 (Bedford – Cambridgeshire), and Flow 37 (Buckinghamshire – Greater London). Rail traffic on Flow 37 grows rapidly until 2041, when the capacity constraint is reached, at which point growth virtually ceases other than a very small annual increase generated by the incremental increase in maximum permitted train density. Rail traffic on Flow 15 grows at a much slower rate, with the result that the capacity constraint is not reached until 2086, whereas traffic on Flow 13 starts an even lower base, and growth continues throughout the study period with the binding capacity constraint never reached (although increasing levels of capacity utilisation will still have led to increased delays, with a consequent suppression of growth). It would of course be possible to assume that additional rail capacity (in the form of extra tracks) would be constructed to overcome the capacity constraint on ‘full’ links, such as Flow 37, and such enhancements could easily be included in the modelling via the capacity enhancements input file. Table 2 shows the number of flows (out of a total of 237) where capacity is predicted to become effectively full by 2100 under the different ITRC strategies and growth scenarios. This shows that in five out of the six possible combinations of future conditions, there are few if any links where capacity is constrained to the extent that no more trains can be accommodated. However, this should not automatically be taken to mean that there will be relatively few capacity problems facing the UK rail network during the remainder of the 21st century. This model uses a universal approximation of maximum line capacity, based on the number of trains which can be accommodated on a ‘standard’ route, but in fact most limiting capacity constraints will occur at ‘non-standard’ locations such as stations and junctions. It is therefore likely that in fact a much larger proportion of interzonal links would be effectively ‘full up’ as far as current capacity is concerned if the number of trains operated grew at the rate predicted by the ITRC models, and therefore that significant and widespread investment in additional capacity would be required if the numbers of trains predicted here were to be able to operate in reality.

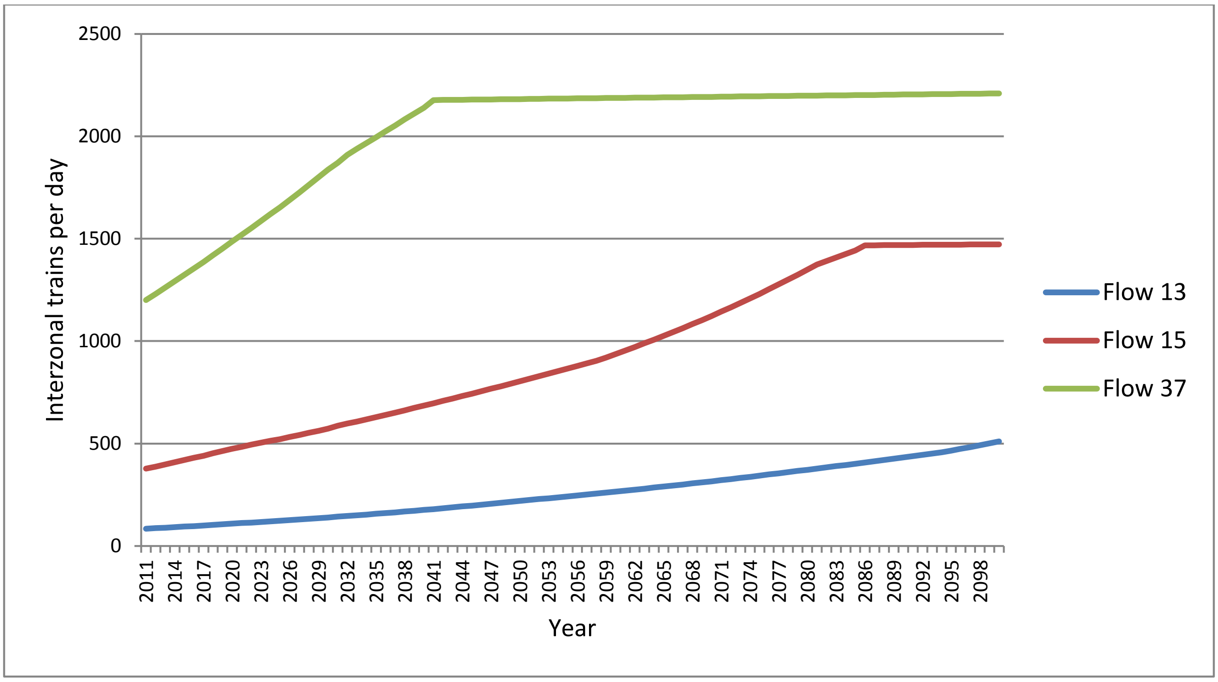

Figure 8: Interzonal Trains Per Day Predicted By Interzonal Rail Model For Three Example Flows Using 'Adapting the Fleet' Strategy With High Growth Scenario

Growth scenario	High	Medium	Low
Adapting the Fleet	75	10	0
Connected Grid	10	4	0

Table 2: Number Of Interzonal Flows Where Rail Capacity Is Fully Utilised By 2100

As discussed in Section 1.3, this research is not the first attempt that has been made to forecast long-term rail sector demand and capacity utilisation. It therefore seemed sensible to compare the forecasts produced by the ITRC model with the most recent forecasts produced by the rail industry and with recent observed trends in rail usage. Figure 9 shows the intrazonal forecasts under both strategies for the period up to 2050 alongside actual rail usage for the period 1997-2010 (obtained from ORR station usage spreadsheets, for example DeltaRail (2012)) and predicted trip ends for 2011-2035 based on forecasts from Network Rail's Strategic Business Plan, with the growth in indexed demand shown in this document used to scale the ORR base level trip ends in 2010 (Network Rail, 2013, p.11). The observed data shows that there has been substantial growth in the number of trips made by rail in Britain in recent years (as has been widely reported elsewhere), and Figure 9 suggests that if this trend were to continue until 2050 it would correspond most closely with the ITRC forecasts based on a high growth scenario using the two strategies investigated here. The Network Rail forecasts also seem to correspond very closely with the high growth scenario results from the ITRC model, which provides some reassurance that the ITRC methodology is producing results which (if not automatically realistic) are at least consistent with those produced by other modelling approaches.

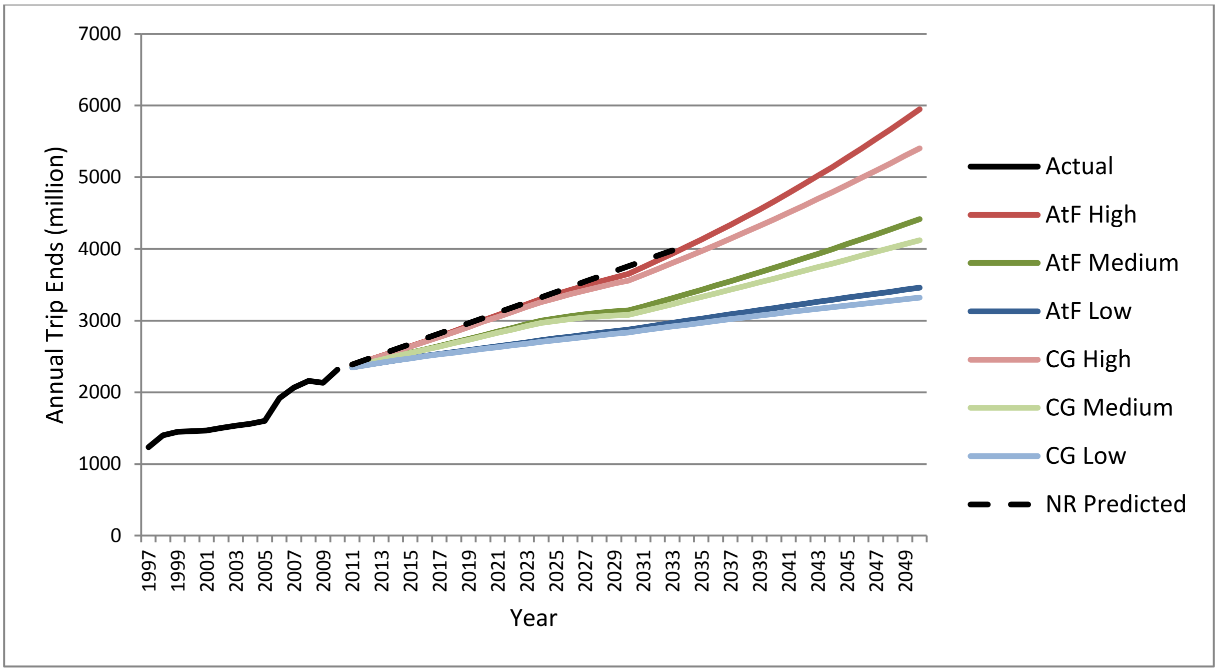

Figure 9: Observed Rail Usage Trends Compared to ITRC and Network Rail Predictions

6) CONCLUSIONS AND FUTURE WORK

The most obvious conclusion to draw from this research is that the forecasts produced by the ITRC rail models suggest that the recent trend of sustained growth is likely to be continued well into the future, at least based on the two transport strategies and three combinations of future trends in population, economic growth and energy prices investigated here. The results also suggest that if the growth that occurs follows the highest range of estimates produced here (which are the most consistent with Network Rail forecasts) then there will be no spare rail capacity on a large number of interzonal links by the end of the 20th century. Given the similarly high levels of growth in passenger numbers predicted by the intrazonal model, this suggests that extensive rail network capacity enhancements will be required over the next nine decades in order to accommodate the demand for rail travel.

However, there is of course no guarantee that the futures on which these demand forecasts have been based will actually occur in reality, as it is possible that in fact future conditions will be very different. The obvious next step with this research is therefore to use the ITRC models to predict rail use under the remaining five transport strategies which were not considered in this paper, and also to test the full matrix of 27 possible combinations of population, economic and fuel cost scenarios. A second set of demographic and economic scenarios which are being produced by other members of the ITRC consortium will become available shortly and will have a much greater level of spatial disaggregation than the country-level scenarios used here. These should generate a much higher level of spatial differentiation in the forecasts of rail use than was given by the model runs described in this paper, and will therefore allow trends in different areas under the various strategies to be compared by making use of GIS-based visualisation techniques. More accurate and strategy/scenario-specific energy cost estimates will also become available from the ITRC energy model during the second quarter of 2014, which should again provide higher levels of forecasting accuracy and spatial specificity when they are fed into the rail models. Once these energy prices are available, the rail models will need to be run alongside the ITRC road models (and will need to take into account the impacts of the transport strategies on road transport), as changes in the energy mix of road transport will affect the level of car fuel costs, which will then in turn impact on the forecasts produced by the rail models via the elasticity of rail demand with respect to car fuel cost.

As well as being influenced by outputs from other elements of the ITRC modelling suite, the forecasts produced by the rail model will also themselves influence the forecasts produced by some of these other models. Probably the most significant way in which this will occur is through the impact of rail's fuel mix and total fuel consumption on the demand for (and also the supply of) different forms of energy. It will therefore be necessary for the rail model to produce energy use estimates alongside the forecasts of passenger and train numbers. There is no reliable way to derive estimated energy use from the passenger trip end forecasts produced by the intrazonal model, because the relationship between passenger numbers and train movements is both highly complex and highly variable over both time and space. Energy consumption figures will therefore have to be derived from the forecast numbers of train movements produced by the interzonal model, and work is currently underway to extend this model so that it is capable of generating such estimates. This is not a straightforward task, as energy consumption is obviously a function of the total number of train kilometres operated across the whole rail network, rather than just the total count of trains crossing interzonal boundaries. The spatial coverage of the model will therefore have to be extended so that it forecasts the number of trains operating on all links of the rail network (again based on timetable data), which will then allow the total train kilometres operated in future years to be estimated. These estimates can then be used together with data on the proportion of services operated by diesel and electric traction on each link and average fuel consumption figures of 12.611 kwh/train km for electric traction and 1.873 litres/train km for diesel traction (Office of Rail Regulation, 2010) to give the total predicted energy use of British rail services for each year in the study period. It would also be desirable in the future to provide more explicit differentiation in model forecasts between the levels of passenger and freight traffic, as while these are distinguished in the base data only an aggregate figure is provided in the model output. However, further research into the relevant elasticities for rail freight traffic will have to be carried out before this modification can be implemented.

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