INTERCONNECT

Interconnection Between
Short- and Long-Distance Transport Networks

DELIVERABLE D5.2

META-MODELS FOR THE ANALYSIS OF INTERCONNECTIVITY

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INTERCONNECT Project Office

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EXECUTIVE SUMMARY

The topic of interconnectivity has particular relevance at the European level because the Trans-European Networks' role as integrated international networks is compromised by poor interconnectivity and because the next generation of European transport policies will have to be sensitive to the differences between short, medium and long-term transport markets and the market advantages of each transport mode.

In 2006 the mid term review of the EC transport White Paper introduced the concept of co-modality to define a new approach for all transport modes by enforcing a "use of different modes on their own and in combination" in the aim to obtain "an optimal and sustainable utilisation of resources". In 2011, the new transport White Paper claims that better modal choices in transport will necessarily result from greater integration of different modal networks, requiring airports, ports, railways, and other public transport systems to be increasingly linked to facilitate multimodal travel, including the target of all core network airports being connected to the rail network, preferably on high-speed by 2050.

The objective of INTERCONNECT task T5.2 is to use new modelling tools to test to what extent the generalisation of specific solutions to interconnectivity is able to produce significant impacts at European level.

To undertake this analysis, new modelling tools have been developed in the framework of the INTERCONNECT project.

➢ First, a new module (IC Module) has been implemented in C++ to be able to assign TRANS-TOOLS trip matrices onto a single multi-modal transport network which specifically includes interconnections. This integrated modal split and assignment module allows testing the impacts of different interconnection costs.

➢ Secondly, a meta-model has been programmed to produce interconnectivity indicators from results of the IC Module and to carry out sensitivity analyses with the purpose of tracking the most promising scenarios to be later fully modelled with the IC Module.

Task 5.2 has two separate deliverables. *D5.2 Meta-models for the analysis of interconnectivity* builds on the results obtained in task 5.2 to test the impact of improving interconnections. The implementation of the IC Module on modal split and traffic assignment is being reported in deliverable *D5.3 Modelling Module for Interconnectivity*. Although reported separately, both activities were developed simultaneously.

This report presents a set of conclusions split into three major categories: conclusions on the geography of interconnections (how travel behaviour takes place in Europe today in relation to the use of uni-modal and multi-modal chains, and subsequently, on the relevance of interconnectivity in the transport system); conclusions on the impact of improving interconnections (changes in modal split, traffic volumes, trip lengths, CO_2 emissions and transport costs due to the improvement of interconnections); and conclusions relating to the general interest of improving interconnections from a policy point of view.

1   INTRODUCTION

1.1   OBJECTIVES OF TASK 5.2

The goal of task 5.2 was the integration of disperse knowledge that has been gathered through case studies in a systematic way - quantitative whenever feasible - to assess the impact of improving key local and modal interconnections at European level.

The interconnections between local and regional networks are having increasing importance as European transport networks become more integrated. The time (and therefore also the cost) needed to change from one mode to another, from long-distance to short-distance services, is not well integrated in large-scale models. The state-of-the-practice forecast models are based on conventional modular structures, from trip generation, distribution, modal split to network assignment with two major draw-backs:

➢ The separation between mode choice for both passengers and freight and traffic assignment means that hardly intermodal chains can be included and analysed in the model.

➢ Furthermore, interconnections between local and regional networks are also neglected.

To overcome the weaknesses of state-of-the-practice forecast models at continental level in relation to the integration of interconnections into their modal choice and assignment modules, two successive approaches has been proposed:

First, a new module on modal split and assignment has been programmed to analyse how interconnection facilities and services may change user's generalised costs effectively. As a module, it is linked to trip generation and distribution external modules, and also to assignment modules for specific transport modes, especially road. If used in the context of TRANS-TOOLS, or any other state-of-the-practice model, the cost matrices can then be used as input for a specialised modal assignment module. The IC Module also works as stand-alone software. The core routines in the module/model have been programmed in C++ and are open source. This has been documented and is made public. The approach has been based on programming it independently from commercial software and GIS platforms to increase its efficiency working with more detailed networks, and apply expert-system rules to reduce the number of calculations required.

Second, a meta-model approach was proposed (Microsoft EXCEL linked to a GIS with EU multimodal graphs in the easier configuration) to measure network impacts of local and modal key interconnections. The formulation applied is based on using as input data generalised costs obtained from TRANS-TOOLS for the different modes and refining these costs based on the knowledge gathered from INTERCONNECT case studies. The meta-model indicates what could be the impact on the relative modal shares, if adjusted costs (including interconnectivity issues) were considered. The meta-model is then a tool to be used in parallel to a large forecast model to check and refine forecasts by a more explicit consideration of the interconnectivity aspects.

These modelling tools have been tested against the results of the case studies considered in INTERCONNECT and TRANS-TOOLS, and adjusted to assure a satisfactory calibration.

As a conclusion, the task T5.2 has obtained:

➢ A meta-model (Microsoft Access and Excel linked to a GIS with EU multimodal graphs in the easier configuration) able to measure network impacts of local and modal key interconnections (object of D5.2);

➢ A new integrated modal split and traffic assignment module linked to state-of-the practice generation and distribution modules used on European-scale forecast models (object of D5.3);

➢ A test of the impacts of interconnectivity improvements in European Transport Networks.

The object of this deliverable is to report the results of the task T5.2 modelling exercises, to provide insights on the impact of improving interconnections at EU level. At the same time, the report briefly presents the meta-model utilities been developed, and refers to D5.3 *Modelling Module for Interconnectivity* for detailed information on the modelling task itself, in particular the IC Module.

1.2 THE META-MODEL APPROACH

The analysis of case studies developed D4.1 provided relevant insights based on the investigation of the impacts of interconnection improvements in different long-distance transport terminals across Europe. In order to test to what extent the generalisation of interconnectivity improvements in European transport networks may result in significant overall impacts, new modelling tools have been developed in the framework of the task 5.2. First, a new module (IC Module) has been implemented in C++ to be able to assign TRANS-TOOLS passenger trip matrices onto a multi-modal transport network, which specifically includes interconnections across transport modes and scales, from local to European. This integrated modal split and assignment module allows testing the impacts on traffic and modal shares of different interconnection costs, per trip purposes.

The IC Module, like other large modelling tools, generates very large amounts of outputs, and data processing is complex and time-consuming. To facilitate the task of evaluating the impacts of interconnectivity improvements, in task 5.2 a meta-model has been programmed which reads results of the IC Module and returns pre-defined sets of indicators on interconnectivity. This meta-model is programmed as a set of VBASIC macros built over Microsoft Access and linked to Microsoft EXCEL and a GIS platform. These macros are integrated together in a common user-interface (just an ACCESS formulary) providing an easy-to-work environment for the transport analyst.

The interconnectivity indicators defined in task 5.2 and computed by the meta-model are 16 in total, grouped in three families: *modal share* indicators, *interconnection rate* indicators and *travel cost and interconnection cost* indicators. Indicators are computed for NUTS3, NUTS0 and globally for Europe. They are determined in relation to itineraries between different NUTS3, reflecting the geographic notion of travel opportunities; they are also calculated in relation to trips in Europe; and they are finally measured in relation to trip-kilometres. Indicators can be calculated for all trips and for specific travel purposes: business trips, private trips, commuter trips and holiday trips. They can also be calculated for different trip length ranges.

As the time to run an IC Module simulation and to process its results used to be around 12 hours, the meta-model has been enhanced to carry out sensitivity analyses to investigate potential impacts of interconnections using a proxy formulation, with the purpose of tracking the most promising scenarios to be later fully modelled with the IC Module. These meta-model utilities are based on using data on aggregated transport generalised costs obtained from TRANS-TOOLS, refining it based on the knowledge gathered from INTERCONNECT case studies, and performing a proxy analysis of the sensitivity of the system with respect to new transport costs. This meta-model inherits the approach of the TRANSvisions meta-model elaborated for the DGTREN in 2009, in the framework of the EC *Communication on the Future of Transport*[1]. The utilities for sensitivity analyses are built on a Microsoft Excel spreadsheet, since they work with European aggregates.

1.3 OVERVIEW OF INTERCONNECT TASK 5.2 "TEST WITH EU MODEL"

Figure 1-1 provides a glimpse into the inner logic of the modelling process in INTERCONNECT task T5.2. The flow of the work is as follows:

➢ TRANS-TOOLS is used as a reference and a base for inputs onto the IC Module.

➢ The IC Module:

- takes the road, rail and air uni-modal graphs of TRANS-TOOLS to build the INTERCONNECT multi-modal graph (as a super-network);
- takes the modal OD matrices of TRANS-TOOLS segmented by trip purpose, and rearranges them to be assigned onto the multi-modal graph;
- uses TRANS-TOOLS to validate the results by adjusting of interconnection and multi-modal internal parameters in an iterative process.

➢ The meta-model

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[1] The TRANSvisions reports can be consulted at http://ec.europa.eu/transport/strategies/2009_future_of_transport_en.htm, whereas a fully dedicated web site to the project can be reached at http://www.mcrit.com/transvisions/)

- reads data from the IC Module and processes it to produce a bounded set of indicators on modal split, interconnectivity and transport cost;

- does sensitivity analyses of modal split variations, global transport volume variations and CO_2 emission variations in the European transport system, to target the most promising scenarios to be simulated again with the IC Module.
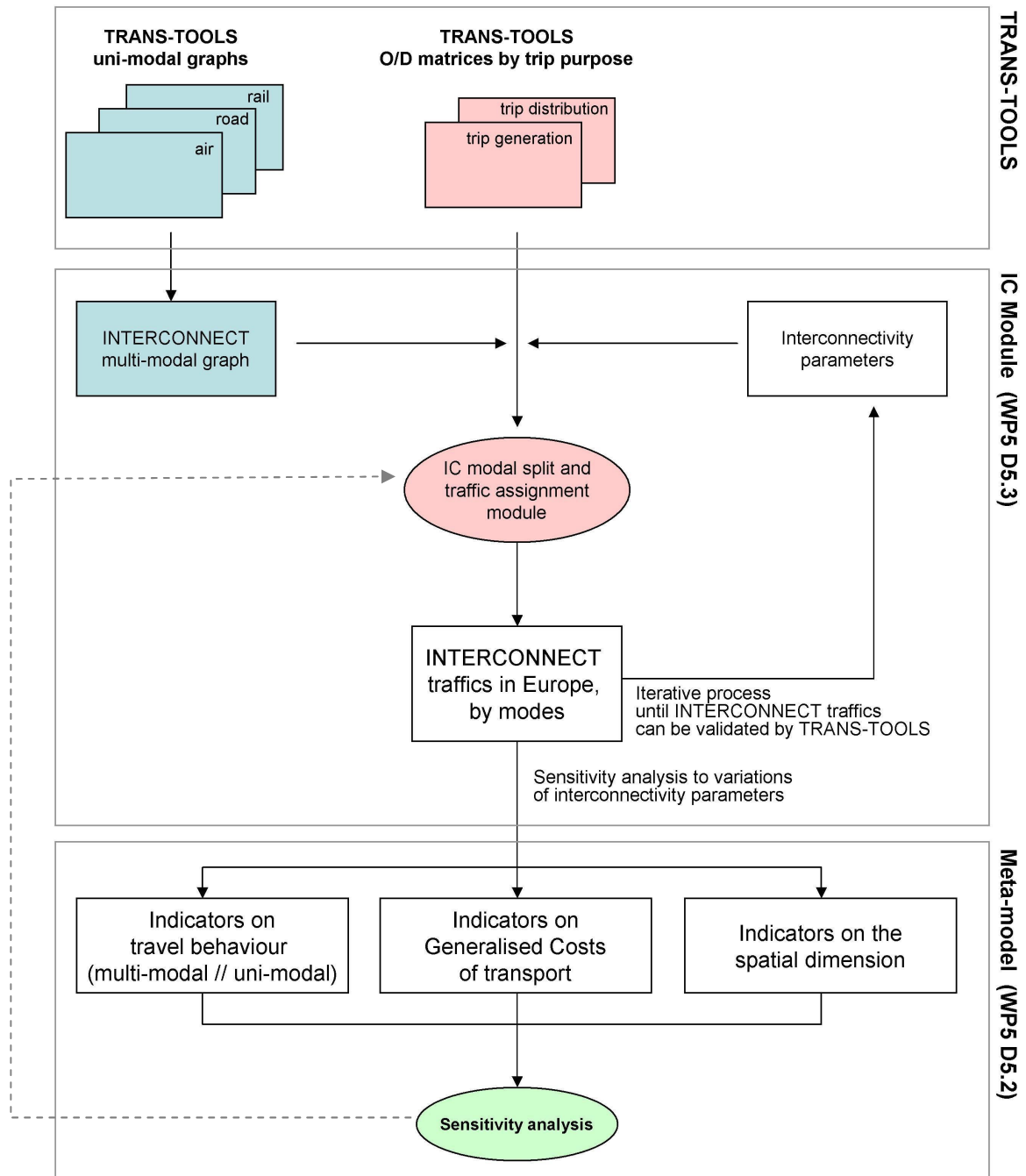

Figure 1-1   WP5 task T5.2 overview

1.4   BACKGROUND REFERENCES TO META-MODELLING

1.4.1 The Concept of Meta-Modelling

"Meta" is a Greek word meaning "beyond" or "after". Therefore, meta-models have to be understood as "models beyond models", or in other words, "models based on models", a term used in system

engineering to describe a process where a simple model reproduces a far more complex one. The meta-model requires less computer resources and can be run intensively under controlled parameters to reveal what affects the system performance.

Meta-models make the task for the analyst easier. They are easy-to-use interactive computer applications with the main purpose of bridging the gap between experts producing qualitative assessments and sophisticated quantitative models. Meta-models can be implemented in spreadsheet applications or access macros, take information from models, complement them whenever needed, and are interactive to confront expert's qualitative intuitions.

In INTERCONNECT, the meta-model processes indicators from IC Module's outputs and carries out sensitivity analyses.

In the following, the EXPEDITE meta-model (developed by RAND Europe, in the 5th EU FP) and TRANSVISIONS and PASHMINA meta-models (developed by MCRIT for the European Commission) are briefly introduced, as reference. In these cases, meta-models involved sophisticated statistical work as well as a conceptual analysis. The purpose always was to be able to substitute a large model by just a number of equations that produced similar enough results under given thresholds.

1.4.2 EXPEDITE Meta-Model

In the EXPEDITE[2] project, carried out for the European Commission, a meta-model approach was developed and applied in forecasting and policy simulation. This model, called the EXPEDITE meta-model, integrated outcomes of five national passenger transport models and four national freight models and results of the SCENES and NEAC models.

The objective of the EXPEDITE meta-model was to overcome the problem of important time and resource consuming computation requirements of EU-wide transport models. Being the focus of the European models usually on the long-distance transport, they may include several sub-modules on short-distance travel, economics or environment. In the case of the SCENES model, the model included a transport module to determine transport within analysis zones – submodel of distance band choice. Running the SCENES model with its 250 zones in Europe and multi-modal networks is cumbersome and time-consuming.

The increase of model requirements and modelling times implies an increasing deficit on modelling manoeuvrability and capacity of reaction. Only relatively bounded sets of scenarios can be implemented, and the modelling activity remains bounded in hypothesis range. Moreover, the SCENES model can only provide a limited number of segmentations of the population and policy sensitivities, especially for short distance transport (more than 90% of all passenger travel in European countries is on trips below 30 kilometres).

The EXPEDITE meta-model objectives were therefore set on:

➢ A fast and easy to use model, so that it could be easily run for multiple different policies;

➢ The model included many different segments of the population, so that differences in behaviour could be incorporated, as well as differences in how policy measures affected different population segments;

➢ The model focused on representing short distance transport.

The meta-model, however, was not intended to replace detailed network-based models – it could not produce assignments to the networks - but to offer the possibility of a quick scan for the effects of a large number of policy measures. More detailed studies for promising measures and for the assessment of specific infrastructure projects should then be done using the network models.

This meta-model was used to generate forecasts for both passenger and freight transport for Europe for a number of future years up to 2020. EXPEDITE chose the SCENES Reference Scenario for 2020 forecasts. For the intermediate years, for which EXPEDITE needed to produce forecasts (2005, 2010,

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[2] The EXPEDITE project was carried out for the European Commission, Directorate-General for Energy and Transport (DGTREN) by a consortium of consultants and institutes, coordinated by RAND Europe, as part of the 5th Framework Programme (http://www.rand.org/pubs/monograph_reports/2005/MR1673.pdf).

2015), the SCENES project could only provide some aggregate information. For these years, EXPEDITE developed its own Reference Scenario using information from SCENES and other European projects.

The meta-model for passenger transport was used to simulate the amount of tours and passenger kilometres in 2020 for each of the policy measures considered. The meta-model approach allowed concluding that over the period 1995-2020 the number of round-trips from home in the travel range under 160 kilometres would grow by 5%, while passenger-kilometres would increase by 10%. It also concluded that long distance travel (over 160 km) would increase much faster than short distance transport (by car, train and especially by air).
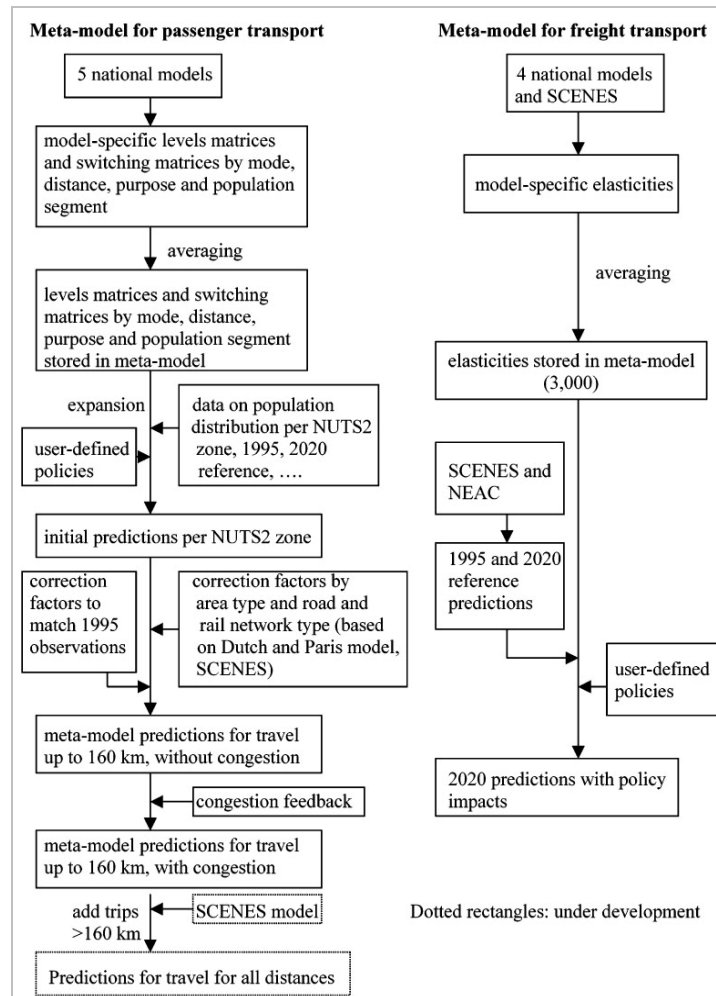
(Source: RAND Europe from EXPEDITE, 2002)
Figure 1-2 EXPEDITE meta-model structure

1.4.3 TRANSvisions Meta-Model

TRANSvisions[3] project (EC DGTren, 2009) adopted a methodological approach based on developing meta-models as a complementary tool to TRANS-TOOLS transport network. The purpose of the TRANSvisions meta-model exercise basically was to validate consistency of qualitative scenarios developed for the study and to provide quantitative forecast characterisation of these scenarios in the long term (2030-2050). Quantitative scenarios in TRANSvisions took into consideration diverse socioeconomic variables, transport variables, energy variables and environmental variables.

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[3] The TRANSvisions project was carried out for the European Commission, Directorate-General for Energy and Transport (DGTREN) by a consortium of consultants and institutes, coordinated by Tetraplan (DK) and integrated by Mcrit (ES), ISIS (IT) and Leed University (UK) in 2008 and 2009 (http://www.mcrit.com/transvisions/).

TRANSvisions scenarios primary outputs were CO_2 emissions resulting from transport in 2050, and these were mostly determined with the TRANSvisions meta-model.

TRANSvisions defined three reference scenarios for the period 2005-2030, based on TRANS-TOOLS, and later extrapolated these scenarios onto 4 additional explorative scenarios for the period 2030-2050. The latest version of the TRANS-TOOLS transport forecast model (November 2008) was applied to explore the most likely evolution of transport demand for the three reference 2030 mid-term scenarios. Explorative scenarios were modelled with the TRANSvisions meta-model based on TRANS-TOOLS results and later validated against other available forecasts.

The TRANSvisions meta-model's main goal was to produce traffic forecasts for 2050 and explore different CO_2 emission scenarios. The use of meta-models was best suited for these long-term 2050 forecasts due to being based on aggregated total volumes of traffic in Europe, while producing more concise and simple indicators than TRANS-TOOLS' which were also less exposed to the multiple uncertainties of transport market evolution in the long-term. Being calibrated with TRANS-TOOLS forecasts at 2030 horizon, the meta-model was then legitimated to produce figures for the very long-term overcoming such uncertainties (e.g. transport network physiognomy in Europe by 2050).

Operatively, the TRANSvisions meta-model was an approximation of TRANS-TOOLS for the 2005-2030 period, and an extension of it for the 2030-2050 period. The meta-model produced traffic and CO_2 emissions for the 2050 scenario, and was able to trace back the path pursued since 2005 combining trends and policies. The Meta-model complemented TRANS-TOOLS with information not included in its current version but valuable and needed for long-term assessment. The meta-model required less computer resources and could be run intensively under controlled parameters to reveal what elements had effects on the performance of the system. It is in this way that the meta-model became better suited for backcasting exercises. The meta-models can also be understood as a strategic policy pre-test interface for TRANS-TOOLS.

The three main reference scenarios for the TRANSvisions meta-model based on TRANS-TOOLS were a Baseline, a High Growth scenario and Low Growth scenario, while the four extreme - but plausible - exploratory scenarios towards a post-carbon society were defined as Induced mobility, Constrained mobility, Decoupled mobility, and Reduced mobility. The exploratory scenarios complemented the reference scenarios for the 2005-2030 period, representing each one of them a plausible alternative path to a 50% direct CO_2 reduction in 2050 - more difficult was to achieve the 10% reduction target for 2020.

The internal structure of the TRANSvisions meta-model can be traced in Figure 1-3. Basically, demographic and economIC Modules were able to produce per capita wealth figures, which combined altogether with personal travel budgets and transport generalised costs, modelled total volume of travel in Europe in passenger-km for a stated time. The modal split module allowed disaggregating total travel into the road, rail and air travel volume figures, and considering technological and behavioural changes in society concluded on CO_2 emission figures.
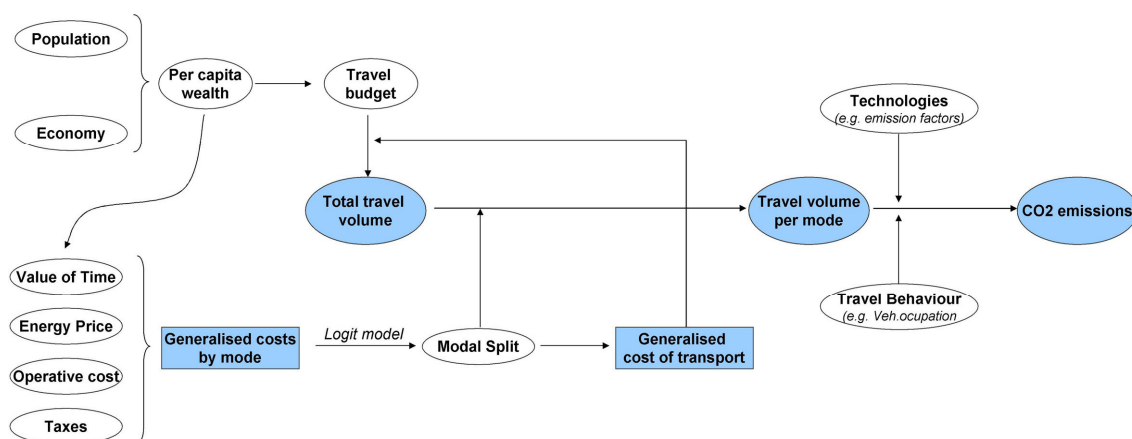
(Source: TRANSvisions 2009)

Figure 1-3   TRANSvisions meta-model structure

The modal split module is based on a multinomial discrete choice logit model with three modes considered: road, rail and air. The choice is performed in relation to each of the different transport modes' normalised generalised cost, which is dependant on users' value of time (in terms of their level of wealth), energy prices, operative costs and taxation schemes. Costs and logit β constant were calibrated with 2005 values and 2030 TRANS-TOOLS forecasts. Modal split determines total travel generalised costs which are at the base of total travel generation, and therefore of single mode travel volumes and resulting CO_2 emissions.

$$P_i = \frac{\exp(\beta \cdot V_i)}{\sum_j \exp(\beta \cdot V_j)}$$

$$P_i = \frac{\exp\left(-\beta \cdot \dfrac{GC_i}{min(GC_s|_{s=1}^3)}\right)}{\sum_j \exp\left(-\beta \cdot \dfrac{GCj}{min(GC_s|_{s=1}^3)}\right)}$$

with P_i the probability of chosing the i travel mode (road, rail or air),

GC_k the generalised cost of mode k

β the Gumbel deviation parameter, calibrated from TRANS - TOOLS, set to value of 5.0.

TRANSvisions meta-model was therefore calibrated with TRANS-TOOLS results for 2005, 2020 and 2030 for three scenarios (Baseline, High Growth and Low Growth) and validated against other forecast studies for 2020 and 2050. In order to calibrate meta-models with TRANS-TOOLS, the qualitative narrative of the exploratory scenarios was translated into the TRANS-TOOLS main transport variables in two scenarios: The Decoupled scenario into the "high growth" scenario and the Reduced into a "low growth" scenario. The 2005-2030 baseline was extended to the 2030-2050 period. The other two exploratory scenarios (Induced and Constrained, distant from mainstream tendencies modelled by TRANS-TOOLS) were validated by comparison with the others.

The variables calibrated were the absolute values of traffic by mode for passengers and transport provided by TRANS-TOOLS in 2005 and 2030, and validated for 2020, assuming the same values in relation to socioeconomic variables.) For 2020 and 2050 the Baseline scenario was also validated against other available forecasts. Elasticity of transport to GDP for different type of trips, such as total trips within the EU-27 made by residents and tourists and visitors, EU-27 residents travelling within the EU-27 and abroad, etc., were validated against different sources, and finally the CO_2 emissions in 2005 was validated against the DG TREN statistical pocketbook values. The main difficulty of the exercise was to compare values corresponding to slightly different indicators that measure the same concept.

1.4.4 Pashmina Meta-Model

The PASHMINA[4] project objective is to model global scenarios based on changes of paradigm in the long-term time perspective (2030—2050) derived from new behavioural trends in Earth societies, especially considering the challenges of energy provision, climate change and land-use equilibrium. The project involves a large number of parties and several different models and sub-models studying different dimensions of the problem, like the evolution of cities, of rural and natural environments, or the evolution of transport.

In order to provide a common framework for modelling in the different tools, a PASHMINA meta-model approach was chosen to generate bounded sets of indicators which are to be used by different partners as inputs for other larger models. The PASHMINA meta-model, under development, is to have enhanced capabilities to take into account the interaction between the economy and the

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[4] The PASHMINA project (2010-2012) is an ongoing project commissioned by the EC in the framework of the 7FP, carried out by a consortium of consultants and institutes coordinated by ISIS (IT) and integrated by Mcrit (ES), WIFO (AU), Charles University in Prague (CZ), CSIC (ES), Enerdata (FR), FEEM (IT), IfW (DE), IIASA (AU), Smash (FR) and Aarhus University (DK). (http://www.pashmina-project.eu/).

environment, paradigm shifts in the energy-transport-environment nexus and the land-use and territorial functions. The PASHMINA meta-model provides coherent indicators for most relevant variables to illustrate qualitative scenarios and storylines, for 6 world macro-regions in the world, and for the world itself. Major trends are considered in the fields of demography, society, economy, transport, energy, environment and governance is being.
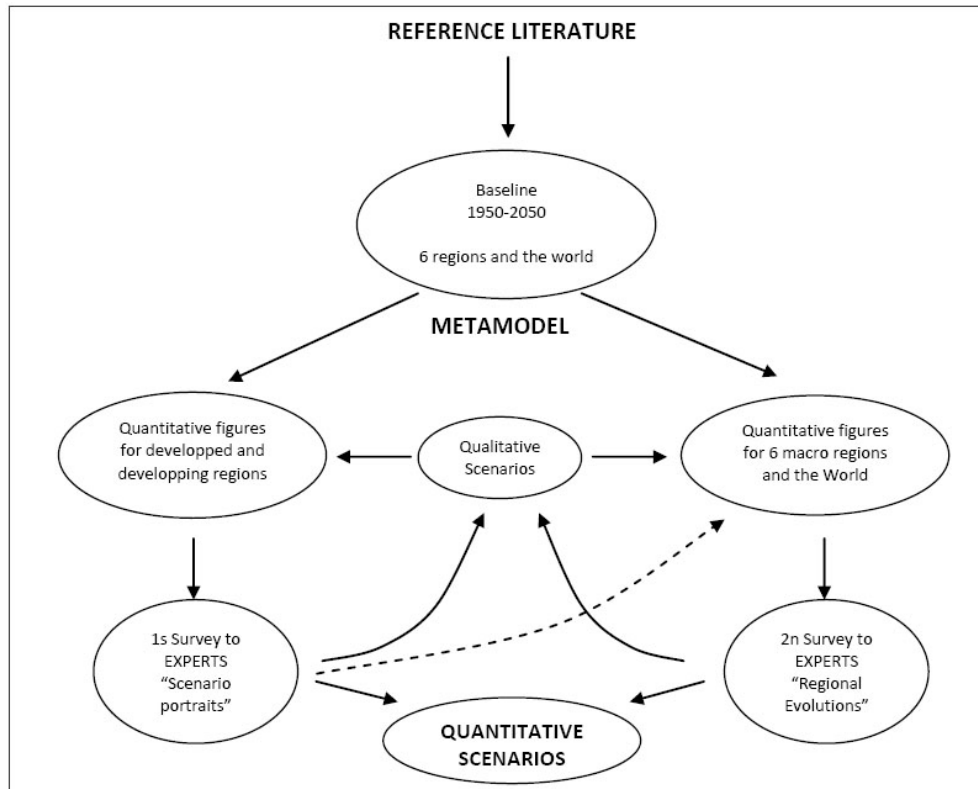
(Source: PASHMINA 2010)
Figure 1-4 PASHMINA meta-model structure

2   INDICATORS TO ANALYSE INTERCONNECTIVITY

2.1   GENERAL INTERCONNECTIVITY INDICATORS

INTERCONNECT work package WP2 reviewed state-of-the-art modelling tools and indicators for the analysis of interconnectivity.   A full description of these problems can be found in depth in the report for INTERCONNECT Milestone M2.4 *Availability and utility of analytical techniques*, but this report is not in the public domain, and therefore the most relevant aspects are included here.

An important issue when dealing with modelling tools is the definition of appropriate indicators to quantify the effect of the modelled solution. Of course a necessary requirement for the indicators used for modelling purposes is that model output should allow computing the indicators themselves. This circumstance often limits the possibility to compute indicators that are suggested in the literature since the amount or the level of details of model output is not sufficient. In general, current literature does not provide numerous definitions of indicators especially tailored to measure passenger interconnectivity.

One of the rare examples found in the current literature is the *interconnectivity ratio* indicator described by S. Krygsman et al (2004). This indicator stems from the consideration that access and egress stages (together with wait and transfer times) are the weakest part of a multimodal chain and their contribution to the total travel disutility is often substantial.

In fact the time and distance disutility associated with interconnections makes uni-modal trips more attractive. Not surprisingly, much attention is paid to policies that aim at improving the quality of access and egress components of trips. Policy and planning measures can be devised to minimise the influence of these weak links in multi-modal public transport chains.

However, even if the time spent in the access and egress part of multi-modal trips can provide information about the interconnected trip, it is not exhaustive to depict the quality of the whole multi-modal trip. If short access and egress stages are in general representative of a good quality interconnection, longer stages do not necessarily mean worse quality; in fact, for long-distance journeys that comprise a long-distance main mode (as for example train or plane), longer access and egress time (to the station or to the airport) can be acceptable when compared to the total travel time.

Therefore to properly measure the "quality" of multi-modal trips the interconnectivity ratio, defined as the ratio between access and egress time to total trip travel time can be used. Given that the INTERCONNECT project analyses long-distance travel, the interconnectivity quality needs to incorporate waiting and transfer times since the service frequency of the long-haul mode is an important element in passenger interconnections. Therefore the computation of average waiting and transfer times in access and egress modes could provide a representative index.

Further indicators to measure interconnectivity can be derived from current literature on graph theory and network analysis. These branches define some indicators that measure the centrality of a vertex within a graph. The term "centrality" means the relative importance of a vertex within the graph (for example, how important a person is within a social network, or, in the theory of space syntax, how important a room is within a building or how well-used a road is within an urban road network). In particular, there are three measures of centrality that are widely used in network analysis, one 'local' measure and two 'global' measures:

➢ Local measures evaluate the degree of connection and prominence of a graph element to its immediate environment in the graph. A very local measure is the degree centrality of a node that denotes the number of connections and local opportunities associated to that node.

➢ Global measures (closeness centrality and betweenness centrality) evaluate the role played by a given node in a graph, in terms of accessibility. The more central a node is, the more important its contribution to the structure of the whole graph should be.

These measures could be reanalysed and adapted to measure the level of interconnectivity within a transport network.

In graph theory, the simplest of centrality measures is *degree centrality*, also called simply *degree*. The degree of a vertex in a network is the number of edges/vertex directly connected to it out of the totality of nodes within the network. In order to adapt this indicator with the purpose of measuring the level of interconnectivity, the degree centrality of a node could be computed as the percentage of other nodes that can be reached with a transfer-free trip and it can be extended and applied separately to one-transfer trips, two-transfer trips, and so on.

This indicator has a two-sided message: on the one hand, the results show that a lower degree centrality index network is less transfer dependent, offering more direct links between different nodes and routes. On the other hand, a higher degree centrality network can show that the network has been optimised to a greater extent in order to resemble a more hierarchical, hub-and-spokes type system where, as an example, buses act as feeders to rail at dedicated interchanges, and as orbital connectors (J. Scheurer et al 2007). The indicator could be used to assess the level of interconnectivity within a uni-modal network or between multi-modal networks.

In graph theory *closeness centrality* of a vertex is defined by the inverse of the average distance, or impediment, between the node in question and all other nodes in the network. It should be noted that the travel time could also be used as a proxy measure for distance and that this metric index can be adapted to public transport networks by using an impediment measure, such as travel time divided by frequency. In this case no adaptation to fit the indicator for the application to transport network is needed. A high closeness centrality value indicates that a given node can reach other nodes on relatively short/fast paths.

Another indicator defined in graph theory is *betweenness centrality*, which is based on the idea that a node is more central when it is traversed by a larger number of the shortest paths connecting all pairs of nodes in the network. The betweenness centrality of a node evaluates the ratio of shortest routes on which the node lies (Bonacich 1987). A high betweenness centrality value indicates that the node lies on a significant number of other shortest paths. This index is very important for public transport networks, since it can capture the relative importance of transfer nodes within the system, and assist in evaluating and modelling route and interchange capacity (J. Scheurer et al 2007).

Another indicator to measure the level of connectivity within a network (derived from a street connectivity indicator developed for an urban design-based context analysis of local areas in ISTP et al 2007) proposed by J. Scheurer et al 2007 is defined as *nodal connectivity index*. This indicator allocates a value to each point on the network that is equivalent to the number of connections into adjacent nodes (nearest neighbours), minus two. Thus a four-way intersection has a value of two, an intermediate point along a street has a value of zero, and a dead-end (cul-de-sac) has a negative value of one.

Finally, in context of the cohesion policy of the European Commission outlined as well in the "White Paper" the *accessibility of a region* across the Member States of the European Union indicates the travel time needed by an inhabitant to reach all other regions of the European Union using a specific transport mode (respectively the fastest mode) whereby the travel time is weighted by the regions' population. Alternatively, the determination of the rank of a region an accessibility indicator can be computed considering the accessibility by a specific mode (respectively the fastest) compared to the European average. These indicators are officially used at European level to identify cohesion problems, and allowing to show how differences on accessibility resulting from the effects of a cost reduction on transport.

For the purpose of the analysis to be carried out in INTERCONNECT Task 5.2, the *interconnectivity ratio* appears more suitable than any of the indicators derived from graph theory. The main problem is that Task 5.2 will analyse interconnectivity from a trips perspective; that is considering the concatenations of links used in the network, and how costs of interconnectivity may affect route choices. Therefore, approaches from the node perspective (investigating connectivity characteristics of nodes) remain less suitable. The accessibility index appears an interesting indicator, and its approach has been considered in the building of the INTERCONNECT spatially distributed indicators.

2.2 DEFINITION OF INTERCONNECT INDICATORS

The following list shows concepts used in the definition of indicators.

➢ **Itineraries** (transport chains) are defined as shortest paths from one NUTS3 to another. For each NUTS3 pair, there are four shortest paths in cost, one for each trip purpose (business, private, commuter, holiday). In TRANS-TOOLS, there are 1,441 NUTS3 considered (including all EU-27 and other zones in neighbouring countries). The total number of itineraries is therefore $(1,441^2 \cdot 4)$ = 8.3 million.

➢ **Trips** are the number of people travelling from one NUTS3 to another.

➢ **Trip-kilometres** are the number of trips between two NUTS3 multiplied by the distance which separated them.

➢ **Uni-modal itineraries** are those itineraries where only roads are used, and those where roads are used in combination with air or rail but represent less than 15% of the total length of the itinerary. *Road*, *rail* and *air* uni-modal itineraries are considered.

➢ **Multi-modal itineraries** are all those itineraries that are not uni-modal. *Road-rail*, *road-air*, *rail-air* and *road-rail-air* multi-modal itineraries are considered.

➢ **City connectors** are links of the graph joining transport networks to cities.

➢ **Network connectors** are links of the graph joining different transport networks.

➢ **Shift** is defined in an itinerary as a change from one mode to another

➢ **Break or change** is defined in an itinerary as a change from one transport network onto another, which can be *shift* or a change within a single mode (e.g. change of airplanes, or change from a long-distance rail network to a regional rail network).

➢ **Steps** are the part of an itinerary between two successive breaks

All indicators can be calculated for the following criteria:

➢ Indicators are initially calculated from each NUTS3 to all others and shown in maps through a GIS interface, but can be aggregated to obtain results in a NUTS0 basis, or even more, to provide synthetic indicators for the whole European transport system.

➢ Indicators can be calculated for all trip purposes together or separately for each trip purpose.

➢ Indicators can be calculated for different ranges of length of the itineraries: less than 300 kilometres, 300 to 1000 kilometres, 1000 to 2000 kilometres, and more than 2000 kilometres.

➢ Indicators can be calculated based on length, trips or trip-kilometres.

➢ Indicators can be calculated based on length or cost.

Next, the list of 15 indicators used in INTERCONNECT is presented:

1. Percentage of uni-modal itineraries with respect to total itineraries.

2. Percentage of multi-modal itineraries with respect to total itineraries.

3. Percentage road uni-modal itineraries with respect to total uni-modal itineraries.

4. Percentage rail uni-modal itineraries with respect to total uni-modal itineraries.

5. Percentage air uni-modal itineraries with respect to total uni-modal itineraries.

6. Percentage road-rail multi-modal itineraries with respect to total uni-modal itineraries.

7. Percentage road-air multi-modal itineraries with respect to total uni-modal itineraries.

8. Percentage rail-air multi-modal itineraries with respect to total uni-modal itineraries.

9. Percentage road-rail-air multi-modal itineraries with respect to total uni-modal itineraries.

10. Multi-modality rate, defined as the number of different modes used in an itinerary. It has a value between 1 and 3.

11. Inter-modality rate, defined as the number of shifts between different modes in an itinerary. These are changes between road-rail, road-air and rail-air.

12. Interconnectivity rate, defined as the number of shifts between different modes or between different services in the same mode (e.g. air-air / long-distance rail-regional rail).

13. Diversity rate, defined as the total length of road, rail and air used in an itinerary aggregated according to an entropy formulation. It reflects the diversity of modes used, has a minimum value of 0 when only one mode is used, and a maximum value of 1 when all modes are used in the same proportion (33%; 33%; 33%).

14. Travel cost, defined as the cost in euros of an itinerary. Travel costs on the network depend on the length of the itinerary, the modes used, the geographic location of the links used and the value of time of users in the origin NUTS3. These parameters are dependant on GDP of each NUTS3[5]. (Travel costs are averaged for each NUTS3 for itineraries, trips or trip-kilometres).

15. Percentage of travel cost spent in interconnections (city connectors and network connectors) with respect to total travel cost.

2.3 MATHEMATICAL FORMULATION OF INTERCONNECT INDICATORS

For each NUTS3 to NUTS3 and for each trip purpose (business, private, commuter, holiday) the IC Module returns the length the shortest path itinerary (based on cost), the number of trips that use this itinerary, the cost of the itinerary, and the sequence of links used.

To compute indicators on a NUTS3 level, NUTS0 level, or a European wide level, the meta-model averages the results of the indicators calculated at itinerary level.

For the main indicators, the mathematical formulation is the following:

Indicator 1. Percentage of uni-modal itineraries with respect to total itineraries:

Based on length

$$\% \text{ Uni - modal } NUTS3_j = \frac{\sum_i \text{length\_uni - modal\_transport\_chains}_{ij}}{\sum_i \text{length\_all\_transport\_chains}_{ij}}$$

Based on trips

$$\%\text{Uni - modal } NUTS3_j = \frac{\dfrac{\sum_i \text{length\_uni - modal\_transport\_chains}_{ij} \cdot trips_{ij}}{\sum_i trips_{ij}}}{\dfrac{\sum_i \text{length\_all\_transport\_chains}_{ij} \cdot trips_{ij}}{\sum_i trips_{ij}}}$$

Based on trip-kilometres

$$\%\text{Uni - modal } NUTS3_j = \frac{\dfrac{\sum_i \text{length\_uni - modal\_transport\_chains}_{ij} \cdot trips_{ij} \cdot length_{ij}}{\sum_i trips_{ij} \cdot length_{ij}}}{\dfrac{\sum_i \text{length\_all\_transport\_chains}_{ij} \cdot trips_{ij} \cdot length_{ij}}{\sum_i trips_{ij} \cdot length_{ij}}}$$

Indicator 2. Percentage of multi-modal itineraries with respect to total itineraries: it is computed as the supplementary to uni-modal transport chains (1-% of uni-modal).

For indicators 3 to 9, the mathematical formulation is always as the example for indicator 3. A similar approach is used, substituting the *length_uni-modal_transport_chain* variable by the *length of the mode* being analysed, and using as a denominator the lengths of uni-modal or multi-modal trips.

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[5] For full report on the cost functions considered in the IC Module, consult D5.3 *Modelling Module for Interconnectivity*

Indicator 3. Percentage road uni-modal itineraries with respect to total uni-modal itineraries:

Based on length

$$\% \text{ road } NUTS3_j = \frac{\sum_i \text{length\_road\_transport\_chains}_{ij}}{\sum_i \text{length\_uni - modal\_transport\_chains}_{ij}}$$

Based on trips

$$\% \text{ road } NUTS3_j = \frac{\dfrac{\sum_i \text{length\_road\_transport\_chains}_{ij} \cdot trips_{ij}}{\sum_i trips_{ij}}}{\dfrac{\sum_i \text{length\_uni - modal\_transport\_chains}_{ij} \cdot trips_{ij}}{\sum_i trips_{ij}}}$$

Based on trip-kilometres

$$\% \text{ road } NUTS3_j = \frac{\dfrac{\sum_i \text{length\_road\_transport\_chains}_{ij} \cdot trips_{ij} \cdot length_{ij}}{\sum_i trips_{ij} \cdot length_{ij}}}{\dfrac{\sum_i \text{length\_uni - modal\_transport\_chains}_{ij} \cdot trips_{ij} \cdot length_{ij}}{\sum_i trips_{ij} \cdot length_{ij}}}$$

For indicators 10 to 15, the formulations are the following:

Indicator 10. The *multi-modality rate* indicator counts the number of different modes used in a given itinerary. For each NUTS3, the meta-model calculates the average of the *multi-modality rates* with all other NUTS3, or what is the same, the total number of modes used in all itineraries from a NUTS3 to all others, divided by the number of NUTS3.

Based on length

$$\text{Multi - modality rate } NUTS3_j = \frac{\sum_i NumMODES_{ij}}{n^\circ NUTS3}$$

Based on trips

$$\text{Multi - modality rate } NUTS3_j = \frac{\sum_i NumMODES_{ij} \cdot trips_{ij}}{\sum_i trips_{ij}}$$

Based on trip-kilometres

$$\text{Multi - modality rate } NUTS3_j = \frac{\sum_i NumMODES_{ij} \cdot trips_{ij} \cdot length_{ij}}{\sum_i trips_{ij} \cdot length_{ij}}$$

Indicator 11. The *inter-modality rate* indicator is defined as the number of shifts between modes an itinerary. For each NUTS3, the meta-model calculates the average of the *inter-modality rates* with all other NUTS3, or what is the same, the total number of shifts between modes in all itineraries from a NUTS3 to all others, divided by the number of NUTS3.

Based on length

$$\text{Inter - modality rate } NUTS3_j = \frac{\sum_i MODALchanges_{ij}}{n^\circ NUTS3}$$

Based on trips

$$\text{Inter - modality rate } NUTS3_j = \frac{\sum_i MODALchanges_{ij} \cdot trips_{ij}}{\sum_i trips_{ij}}$$

Based on trip-kilometres

$$\text{Inter - modality rate } NUTS3_j = \frac{\sum_i MODALchanges_{ij} \cdot trips_{ij} \cdot length_{ij}}{\sum_i trips_{ij} \cdot length_{ij}}$$

Indicator 12. *Interconnectivity rate* indicator is defined as the total number of shifts in an itinerary between modes and services. For each NUTS3, the meta-model calculates the average of the *interconnectivity rates* with all other NUTS3, or what is the same, the total number of shifts in all itineraries from a NUTS3 to all others, divided by the number of NUTS3.

Based on length

$$\text{Interconnectivity}_j = \frac{\sum_i shifts_{ij}}{n^\circ NUTS3}$$

Based on trips

$$\text{Interconnectivity}_j = \frac{\sum_i breaks_{ij} \cdot trips_{ij}}{\sum_i trips_{ij}}$$

Based on trip·kilometres

$$\text{Interconnectivity}_j = \frac{\sum_i breaks_{ij} \cdot trips_{ij} \cdot length_{ij}}{\sum_i trips_{ij} \cdot length_{ij}}$$

Indicator 13. The *diversity rate indicator* is an alternative way of studying the multi-modality by means of an entropy formulation. In this case the meta-model adds the length of each trip in each mode as follows:

$$\text{Diversity rate } NUTS3_j = -\sum_k \sum_i \%length_{ijk} \cdot \ln\left(\%length_{ijk}\right)$$

Where k is the three possible transport modes (road, rail, air) and $\%length_{ijk}$ is the proportion distance of mode k used to get from $NUTS3_i$ to $NUTS3_j$ over total length of the trip. The entropy formulation takes values from 0 to 3, where 0 indicates minimum mode variety (all trips from $NUTS3_i$ are done with just one mode) and 3 indicates maximum variety, with an equal length share of the three modes.

Indicator 14. The cost of transport can be calculated at European level as the aggregation of all costs (travel and time) for all itineraries between NUTS3 and multiplied by the number of trips.

$$TotalCost = \sum_i \sum_j cost_{ij} \cdot trips_{ij}$$

At NUTS3 level, it is calculated as the aggregation of all costs between a NUTS3 and all others averaging them again in three different ways, by itineraries, trips and trip-kilometres.

Based on length

$$\text{Cost}_j = \frac{\sum_i \text{cost}_{ij}}{n^o\, NUTS\,3}$$

Based on trips

$$\text{Cost}_j = \frac{\sum_i \text{cost}_{ij} \cdot trips_{ij}}{\sum_i trips_{ij}}$$

Based on trip-kilometres

$$\text{Cost}_j = \frac{\sum_i \text{cost}_{ij} \cdot trips_{ij} \cdot length_{ij}}{\sum_i trips_{ij} \cdot length_{ij}}$$

Indicator 15. The percentage of travel cost spent in interconnections. It is calculated as the aggregation of all costs spent in interconnections (City connectors and Network connectors) divided by the total cost of travel in Europe).

$$\%\text{Cost\_interconnections} = \frac{\sum_j \sum_i \text{cost\_connector\_links}_{ij}}{TotalCost}$$

Where *i* refers to each single link used in the trips of purpose *j*, and connector_links refer to interconnections.

3 INTERCONNECT META-MODEL DESIGN

3.1 CALCULATION OF INDICATORS

The meta-model is a tool intended to read outputs of the IC Module (up to 16GB databases with 440 million registers), to process contained data and produce a set of comprehensive indicators. The meta-model requires around 6 hours for processing the output of the IC Module.

Key indicators characterise travel behaviour in Europe in terms of multi-modal travel and uni-modal travel and the use of different characteristic transport chains as shown in the previous section.

They will also provide a spatial dimension of the indicators presented on GIS support. The meta-model provides synthetic results for the whole Europe, and at NUTS0 and NUTS3 levels.

The figure below provides an image of the functionality of the INTERCONNECT meta-model indicator processor.

Figure 3-1 INTERCONNECT meta-model indicator processor structure

The INTERCONNECT meta-model indicator processor is composed of a set of VBASIC macros built over Microsoft Access to process and evaluate interconnectivity indicators from data obtained as

output of the IC Module. These macros are gathered together in a common interface (MSAccess formulary) allowing an easy use of all tools in a easy-to-work-with environment. This set of macros allows reading IC Module outputs to the process of OD matrices assignation onto the IC multimodal graph and returning comprehensive indicators to analyse impacts of interconnectivity upgrading in the European transport system.

The meta-model is built on three MSAccess databases and four text files. All these files are linked together and are controlled by a control panel in the database. The separation in several databases responds to the capacity constraints of MSAccess, which is limited to 2GB per file. In doing so, databases can be automatically compacted every time a calculation is performed, preventing files from excessively growing given that the temporary tables which are needed increase the size of the databases to near the limit.

There are about 5,600 lines of code written in Visual Basic to perform all calculations, leading to a total of 187 tables including the intermediate ones needed for calculation.
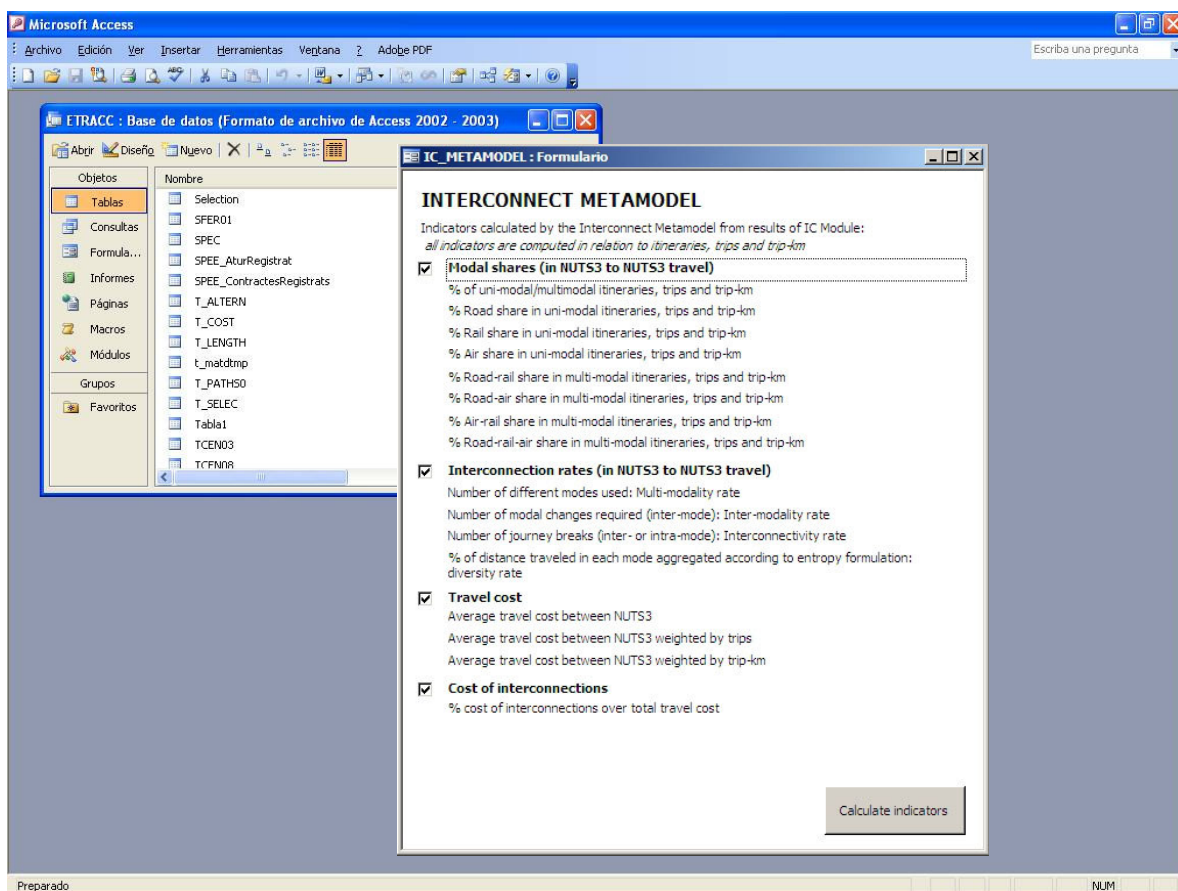

Figure 3-2   Meta-model indicator processor control panel

The meta-model gathers results from IC Module traffic assignations, specifically it analyses tables with traffic per link, costs per origin-destination and complementary text files that contain the complete paths of each origin-destination pair. The first table allows computing indicators on their three different variants of *itineraries, trips* and *trip-kilometres*. The second table allows accounting for costs of travel between different origins and destinations. The text files allow keeping track of the interconnectivity patterns, by means of analysing each different transport chain and processing the corresponding sequences of modes and interconnections used.
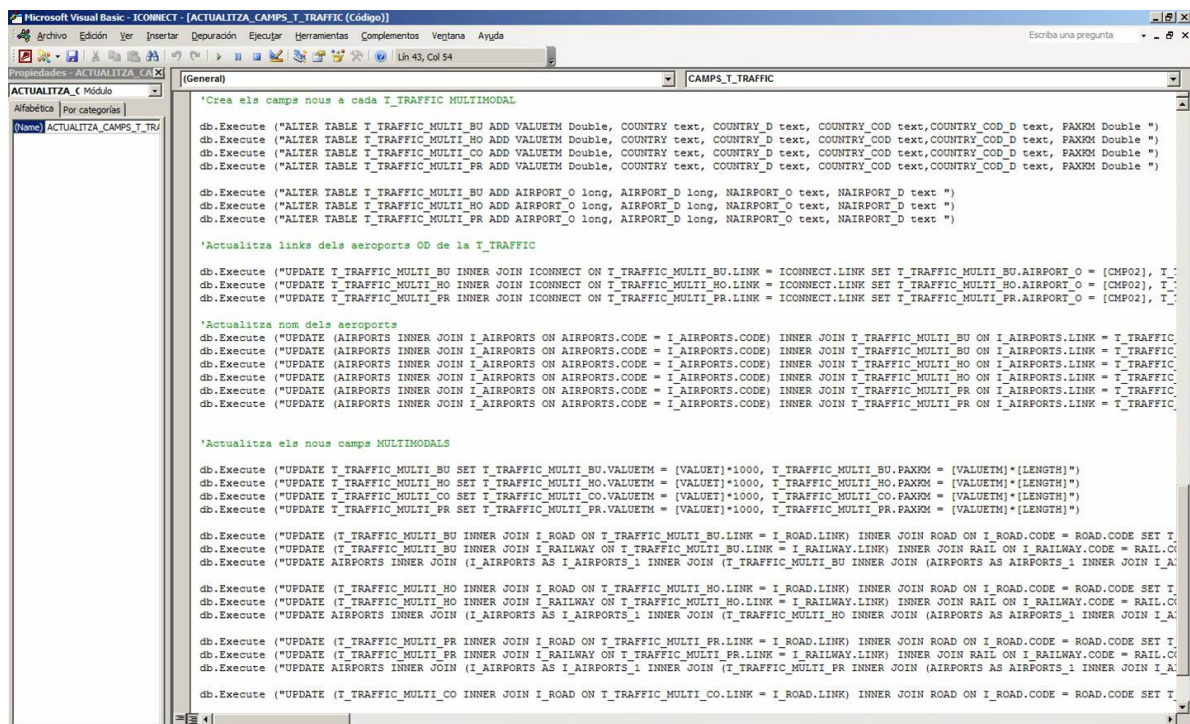
The first step consists of converting the raw data text file (corresponding to the outputs of the IC Module) N_COSTB_XX.txt (where XX can be BU, HO, PR or CO, standing for Business, Holiday,

Private and Commuter) to a new text file, INTERCONNECTIVITY_XX.txt. This conversion transforms the data from a link by link table to a per link type basis, preparing it for indicator processing.

The first set of indicators to be calculated are the interconnection rate indicators: multi-modality, diversity, inter-modality, interconnectivity. The sequence is undertaken in the following order: *interconnectivity rate*, defined as the number of journey breaks in a trip; *inter-modality rate* indicator counting the number of times a trip changes transport mode (connections inter-mode), which is simply the preceding removing the short/long intra-mode interchanges; and the *multi-modality rate* indicator, which is based on the *inter-modality rate* and consists of only counting the number of different modes used in a given trip. The *diversity rate indicator* is an alternative way of studying the multi-modality by means of an entropy formulation.

The previously calculated tables serve as basis for obtaining the next set of indicators: the modal share indicators. For each possible transport chain defined the meta-model identifies it in each origin-destination trip, and computes the total length of each one of these trips. Then an aggregation is carried out by origin at NUTS3 level and at country level. Each of these aggregations is also summarised adding all origins together and obtaining a synthetic indicator whose resulting value is the sum of the whole transport system. The indicators are calculated from the second text files N_COST2_XX.txt where the IC Module has previously computed the total length of each type of link used for each origin-destination pair.

The next set of computed indicators is the cost of trips, obtained from the origin-destination cost tables of the IC Module. The Module computes the total travel cost between each origin-destination pair using the data of costs in each of the links in the graph and the value of time of the user, and then adds it for all the links used in this O-D pair. The meta-model aggregates cost results between O-D pairs for each origin at NUTS3 level, averaging them again in three different ways, by itineraries, trips and trip-kilometres. To determine the cost of interconnections, using the traffic per link tables from the IC Module the meta-model computes the cost of travelling in each link and estimates the time cost by using the average value of time of each type of user (retrieving unitary costs, speeds and lengths from the IC graph).

Figure 3-3   Example of VBASIC macros integrated in the INTERCONNECT meta-model

3.2 SCENARIO SIMULATOR

The process of running the IC Module to simulate a specific transport scenario takes almost 10 hours. This implies that a limited number of scenarios can be simulated within a reasonable working time. Therefore, scenarios need to be well defined before being computed.

To assist the analyst in defining scenarios, the meta-model was enhanced to carry out simplified simulations. The aim of the meta-model is to provide a proxy to calculate modal changes induced by interconnectivity cost variations at EU aggregate level. It is based on using data on aggregated transport generalised costs obtained from TRANS-TOOLS and performing a proxy analysis of the sensitivity of the system with respect to new transport costs, using previous runs of the IC Module as reference to interpolate other alternatives.

More specifically, the aim of the meta-model is:

➢ Change costs of interconnection (local or long-distance terminals);

➢ Obtain impacts on modal split (road, rail, air);

➢ Obtain CO_2 emissions based on general emission factors per mode.

These utilities are built on a Microsoft Excel spreadsheet.
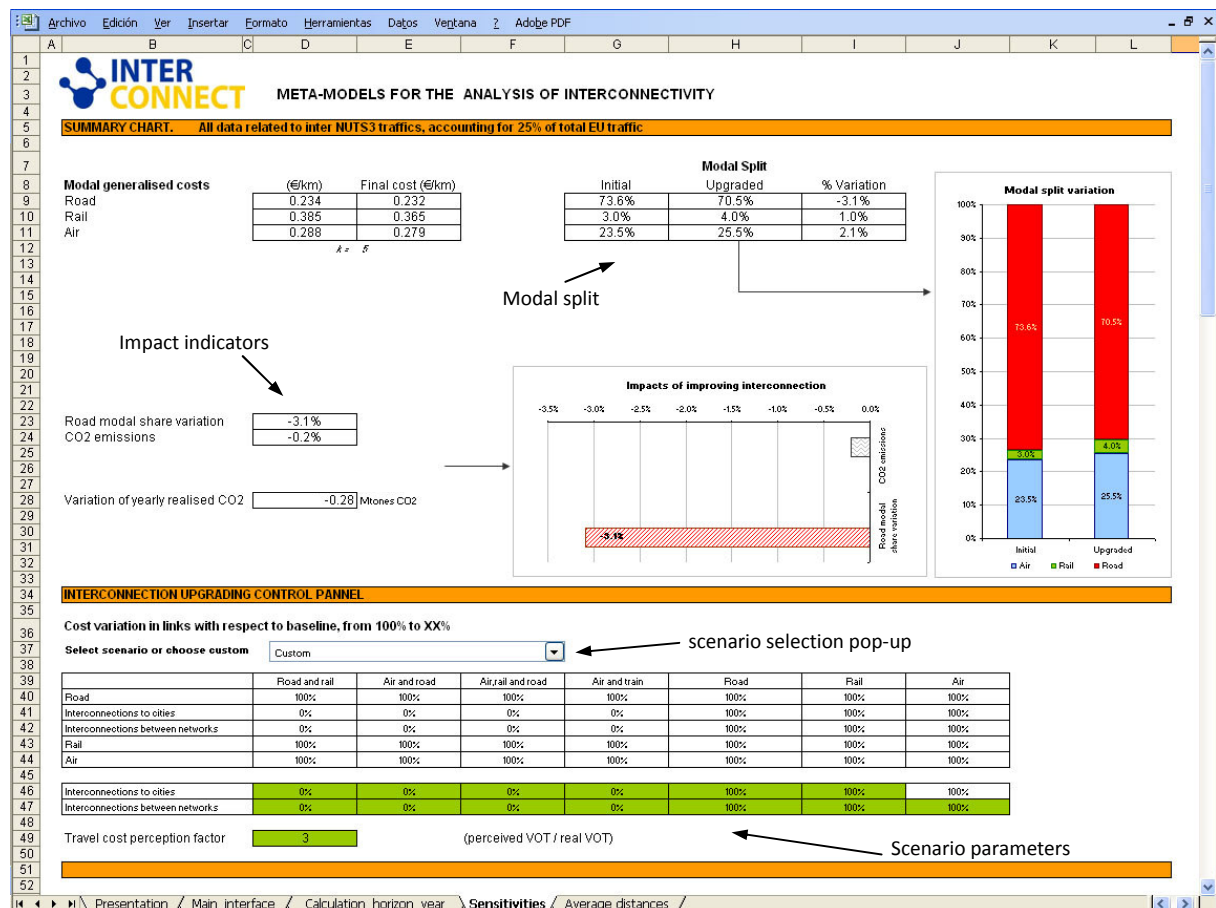
Figure 3-4   Meta-model user interface for sensitivity analysis

The meta-model considers three modes (road, rail and air) and two sorts of interconnection (city connectors linking cities to transport networks, and network connectors linking different transport networks).

All costs are given in a fixed price per kilometre, representing an important simplification of the IC Module (where costs depend on the link, the NUTS3 where it is located, the NUTS3 origin of the trip, and the trip purpose).

Distribution of traffic among different modes is considered in the meta-model through a LOGIT formulation relative to travel prices on road, rail and air. The approach of the meta-model is to incorporate the costs of interconnections into the cost functions of the different transport modes, so that changes on these costs result in variations of the road, rail and air costs that are introduced in the meta-model LOGIT formulation to estimate modal split changes. The shift of trip-kilometres from one mode to another will result also in CO_2 emission changes, assuming general ratios of CO_2 emissions per mode.

The formulation is as follows:

$$P_i = \frac{\exp(\beta \cdot V_i)}{\sum_j \exp(\beta \cdot V_j)}$$

$$P_i = \frac{\exp\left(-\beta \cdot \dfrac{GC_i}{min(GC_s\big|_{s=1}^{3})}\right)}{\sum_j \exp\left(-\beta \cdot \dfrac{GCj}{min(GC_s\big|_{s=1}^{3})}\right)}$$

with P_i the probability of chosing the i travel mode (road, rail or air),

GC_k the generalised cost of mode k

β the Gumbel deviation parameter, calibrated from TRANS-TOOLS, set to value of 5.0.

The hypothesis used in the meta-model to aggregate the network detailed information of the IC Module are explained next:

➢ Centroids representing NUTS3 are always connected to the closest road, and are connected to the closest rail station, if the station is not located further than 15 kilometres.

➢ Airports are reached only from rail networks or road networks. Airports are only connected to rail, if the closest rail station is not located further than 10 kilometres.

➢ Therefore, local connectors (city connectors) are only related to road and rail, and local connectors to airports (from airport to city) are included in the trips. Trips accessing airports from cities by train are all included in air-rail trips or air-rail-road trips.

Table 3-1 shows the contribution of each mode in rows to the total cost of each of the different transport chains in columns. The table has to be read as follows: for a trip of the chain Air&Rail&Road the trip costs are a combination of 20.2% of road costs, plus 5.2% of rail costs, plus 68.2% of air costs, plus 1.0% of local connectors and 5.4% of network interchange costs between long-distance terminals.

Trips are defined as uni-modal when only roads are used (road uni-modal) or when roads are used for less than 15% of the total trip length (rail uni-modal and air uni-modal chains). For this reason, road uni-modal chains have 0% contribution of the air and the rail modes, but air and rail uni-modal chains have contributions by the road mode, as shown in Table 3-1.

Table 3-1   Weight of road, rail, air modes and interconnections in total cost of different transport chains

	Road & rail	Air & road	Air, rail & road	Air & rail	Road	Rail	Air

Road	52.5%	21.4%	20.2%	3.1%	91.0%	4.1%	3.3%
Rail	38.1%	0.0%	5.2%	3.2%	0.0%	87.2%	0.0%
Air	0.0%	69.6%	68.2%	87.7%	0.0%	0.0%	86.5%
Local connections	3.9%	1.3%	1.0%	0.8%	8.7%	3.8%	1.5%
Long-distance connections	5.5%	7.7%	5.4%	5.2%	0.3%	5.0%	8.6%
Total cost	100%	100%	100%	100%	100%	100%	100%

To incorporate the costs of interconnections in the different mode's cost functions (road, rail and air), the approach is to transfer, for each transport chain, the costs of local and network long-distance interconnections towards the modes present in the transport chain. The total cost of the interconnections is then distributed among the different modes according to the weight of each mode in the transport chain, in length (kilometres). Figure 3-5 illustrates this approach:

Air&Rail transport chain

Network interconnection

Air

Rail

The cost of interconnection is transferred to the modes involved in the transport chain, proportionally to each mode's weight in the total length of the transport chain.
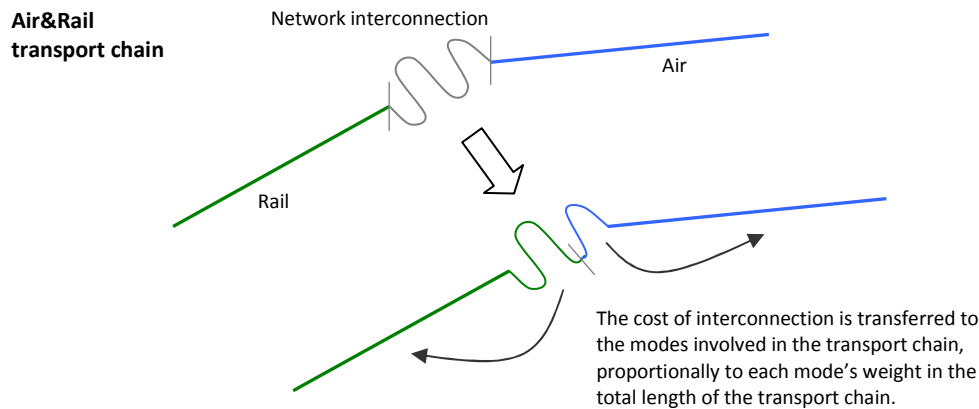
Figure 3-5   Scheme of incorporation of interconnections in mode costs

Mathematically:

$$ModeCost_{i,j}^{*} = ModeCost_{i,j} + Cost_{CityConnector_j} \cdot \frac{ModeLength_{i,j}}{Length_j} + Cost_{NetworkConnector_j} \cdot \frac{ModeLength_{i,j}}{Length_j}$$

Where
i is each one of the transport modes (road, rail, air) and j is a specific transport chain in study (road uni-modal, rail uni-modal, air uni-modal, road-rail multi-modal, road-air multi-modal, rail-air multi-modal, road-rail-air multi-modal);
ModeCost*$_{i,j}$ is the cost of the mode i in the transport chain j incorporating costs of interconnection;
ModeCost$_{i,j}$ is the cost of the mode i in the transport chain j without costs of interconnection;
Cost$_{CityConnector}$ is the cost of the connectors between cities and transport networks;
Cost$_{NetworkConnector}$ is the cost of the connectors between networks;
ModeLength$_{i,j}$ is the length of the mode i in the transport chain j;
Length$_j$ is the length of the transport chain j;

To determine average lengths of each transport chain, modal share indicators for trip-kilometres resulting from the IC Module simulations for the baseline provide an image of how trips take place in Europe today. Lengths are calculated dividing the total volume of trip-kilometres of each mode (road, rail and air) and type of connector (local, to access the long-distance networks, and between long-distance networks) by the total number of trips associated to the chain, as follows.

$$average\_length_{i,j} = \frac{trip \cdot kilometres_{i,j}}{trips_j}$$

Where

*i is each one of the transport modes (road, rail, air) and interconnections (to cities, between networks),
and j is a specific transport chain in study (road uni-modal, rail uni-modal, air uni-modal, road-rail
multi-modal, road-air multi-modal, rail-air multi-modal, road-rail-air multi-modal);*

Average_length_{i,j} *is the average length of the mode i in the transport chain j;*

Trip·kilometres_{i,j} is the amount of trip·kilometres travelled with the i mode in the transport chain j;

Trips_j is the amount of trips travelled in the transport chain j;

Figure 3-6 summarises information on mode average lengths for each different transport chains.
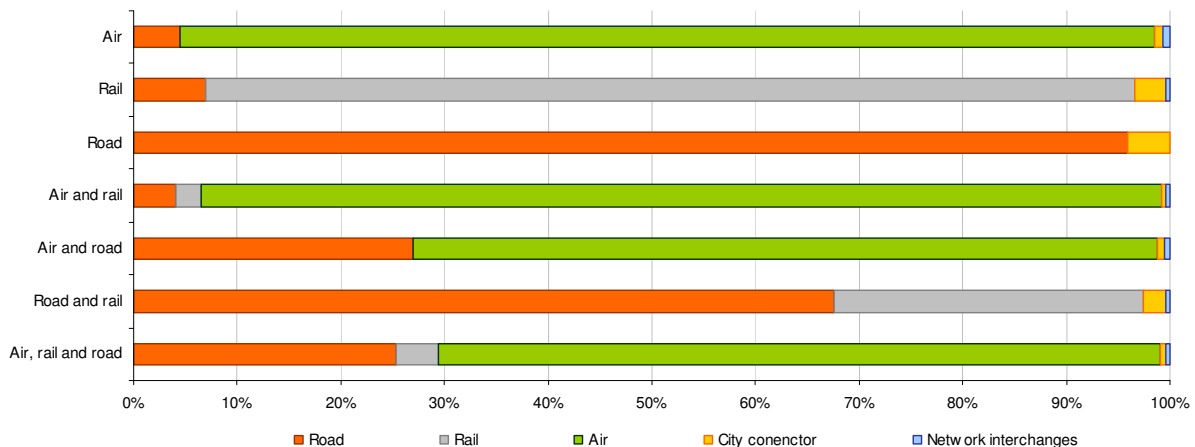
Figure 3-6   Allocation of passenger-kilometres in different modes and types of connector

The figure is to be read as follows:

➢ In road uni-modal chains, 95.9% of passenger-kilometres are travelled by car, and 4.1% are travelled on connectors to cities.

➢ In air-road multi-modal chains, 27.0% of passenger-kilometres are travelled by road, 71.7% by air, 0.7% on city connectors and 0.5% on network connectors.

➢ In road-rail-air multi-modal chains, 25.4% of passenger-kilometres are travelled by road, 4.0% by rail, 69.7% by air, 0.6% on city connectors and 0.4% on network connectors.

4 TEST WITH EU MODEL: MAIN RESULTS

4.1 ASSUMPTIONS

➢ All results correspond to simulations with the IC Module, elaborated for INTERCONNECT task 5.2.

➢ Origin / Destination matrices are TRANS-TOOLS' for 4 trip purposes: business, private, commuter and holiday.

➢ Multi-modal graph is built from TRANS-TOOLS' uni-modal graphs.

➢ Average values of time are based on TRANS-TOOLS, enhanced to consider the effect of GDP disparities on travellers' value of time depending on their NUTS3 of origin.

➢ Travel cost values are based on TRANS-TOOLS, enhanced to consider the effect of GDP disparities in different areas of Europe (links in richest NUTS3 are more expensive to travel).

➢ Increased value of time by travellers when waiting or transferring are only considered indirectly through connector reduced speeds.

➢ No additional transfer time is considered in connections between long-distance rail networks (TEN-T) and regional or short-distance networks.

➢ Airports are accessed only from road and rail networks, and not from cities. Time to access cities from airports is included in trips rather than in connectors (local interconnections).

➢ All itineraries are computed with an all-or-nothing routine based on shortest cost travel paths.

4.2 INTERCONNECTIVITY IN THE EUROPEAN TRANSPORT SYSTEM

Long-distance travel at EU level

INTERCONNECT deals with long-distance trips in Europe. Long-distance trips are here considered as trips inter NUTS3, so any trips taking place within NUTS3 regions are not being considered in this approach. It is therefore important to begin by bounding the horizon of work in the global framework of the whole European transport system.

Inter NUTS3 trips account only for 8.8% of total trips in Europe, and for 29.0% of trip-kilometres.
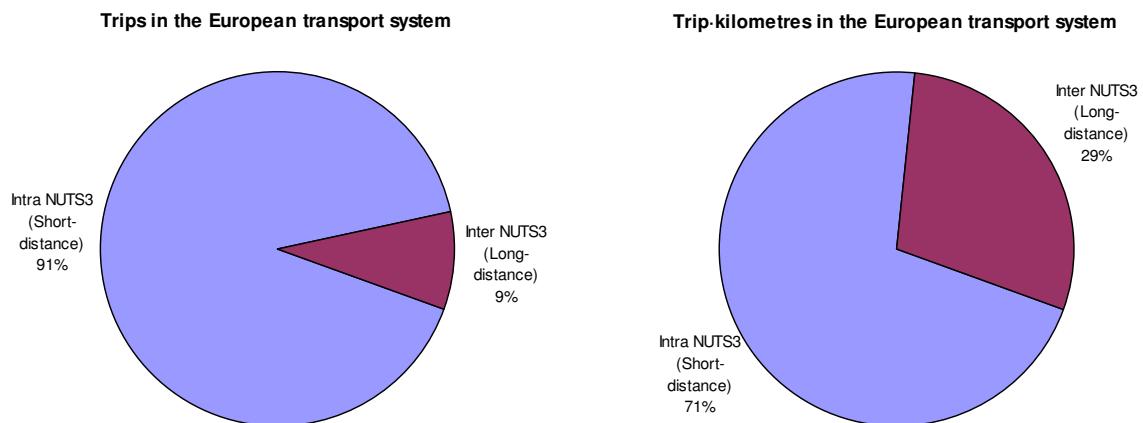
(source: INTERCONNECT, based on TRANS-TOOLS 2005 databases)

Figure 4-1   Inter NUTS3 relations as a share of total relations, in trips and trip-kilometres

By trip purposes, trips with most relevance are business and private, but in terms of trip-kilometres, holiday trips have an important weight due to their longest nature.
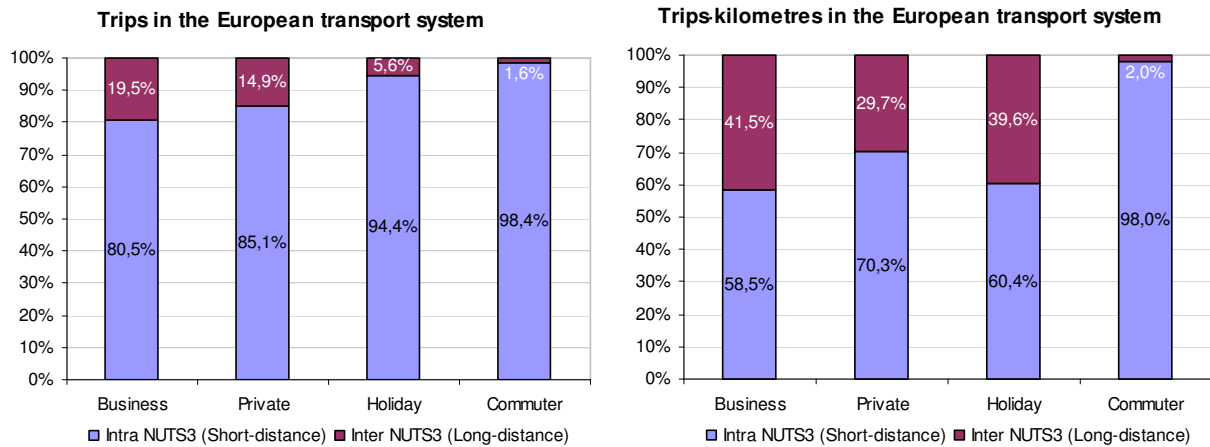
Figure 4-2   Inter NUTS3 relations as a share of total relations by trip purposes

Shortest path itineraries in Europe (EU27) involve almost equal shares of uni-modal and multi-modal itineraries. For uni-modal itineraries, road weights as much as 75% of all trips, while for multi-modal itineraries, the use of different transport combinations is more balanced, although air-road chains are dominant. (Reminder: Itineraries are defined as uni-modal when only roads are used (road uni-modal) or when roads are used for less than 15% of the total trip length (rail uni-modal and air uni-modal chains)).
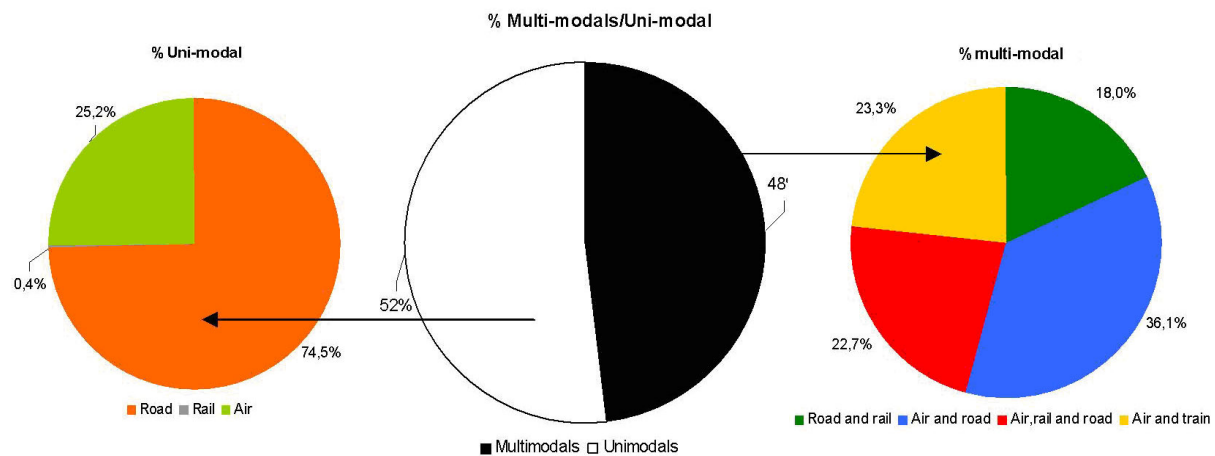
Figure 4-3   Modal share of kilometres travelled in itineraries between NUTS3 (distance)

In terms of trips, 7% long-distance trips on the continent are multi-modal. For uni-modal trips the road mode represent almost all trips (97.6%), while multi-modal trips involving road and rail dominate with more than 75% of the total number of trips.
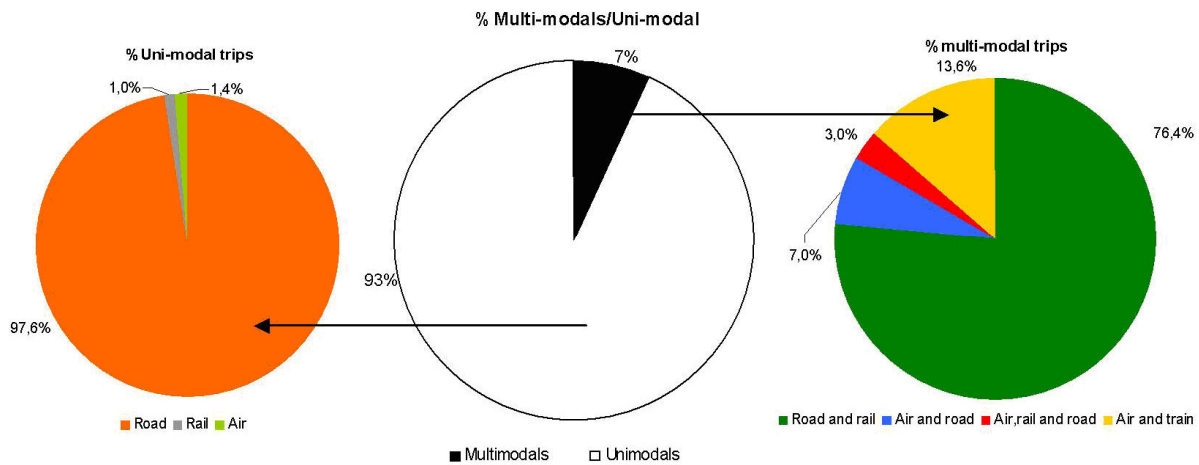
Figure 4-4   Modal share of kilometres travelled in trips between NUTS3 (trips)

In terms of trip-kilometres, multi-modal trips in Europe represent roughly 20% of Europe's trip-kilometres. This increased value with respect to their share in trips indicates that multi-modal trips tend to be much longer than uni-modal trips. For uni-modal trips, the air mode represents 12.9% of total trip-kilometres (for only 1.4% of the trips). Rail shares remain low, at 1.5% for uni-modal trips. For multi-modal trips, road-rail trips and rail-air trips are dominant with approximately equal shares.
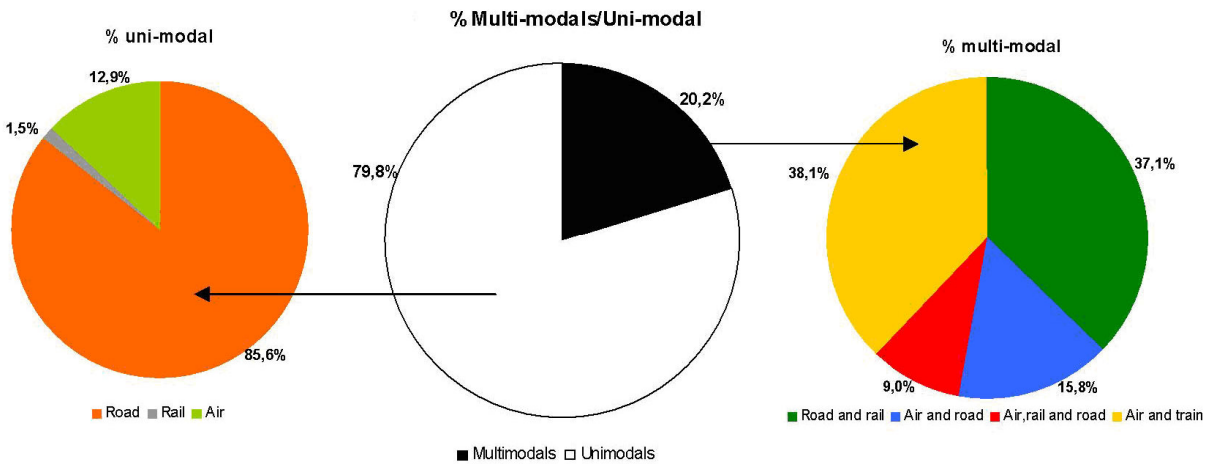
Figure 4-5   Modal share of trip-kilometres travelled in trips between NUTS3 (trip-kilometres)

Multi-modality rate: number of modes used in the shortest-cost chains between NUTS3

The multi-modality rate indicator is defined as the number of modes used in a trip. Applied to NUTS3 level, the indicator averages the number of modes used to travel from that NUTS3 to each of the other NUTS3 for all trip purposes.

The multi-modality rate indicator is computed for itineraries, weighted by the number of trips between every NUTS3 (gives more relevance those inter NUTS3 relations where the number of trips is larger), or weighted by trips and trip distance (gives more relevance those inter NUTS3 relations where the number of trips is larger and the magnitude of these trips is longer).

All three parts of the figure are displayed with the same scale. The minimum value is 1, the maximum value 3, and black indicates the highest and light red the lowest multi-modality rate.

Figure 4-6 shows that peripheral regions tend to have higher multi-modality rate levels than central areas (itinerary analysis, upper-left in the figure). This means that for peripheral regions, more modes are required on average to travel to all other regions, while central regions tend to have more relations where trips can be undertaken with few modes.

However, the analysis of the indicator weighted by trips (upper-right in the figure) reveals a far more important uniformity all over the continent, indicating that most complex routes – those including a larger number of modes used -- correspond to relations where there are low volumes of trips.

The indicator weighted by trip-kilometres (bottom in the figure) reveals that some peripheral areas in Scandinavia and in southern Europe require using more modes for their longest trips.

Figure 4-6   Multi-modality rate for each NUTS3 based on itineraries, trips and trip-kilometres

Inter-modality rate: number of modal shifts in the shortest-cost chains between NUTS3

The inter-modality rate indicator is defined as the number of modal shifts in a trip, that is the number of changes between modes. Applied to NUTS3 level, the indicator averages the number of modal changes used to travel from that NUTS3 to each of the other NUTS3.

The inter-modality rate indicator is computed here for itineraries (basic formulation), weighted by the number of trips between every NUTS3 (gives more relevance those inter NUTS3 relations where the number of trips is larger), or weighted by trips and trip distance (gives more relevance those inter NUTS3 relations where the number of trips is larger and the magnitude of these trips is longer).

The *inter-modality rate* indicator in Figure 4-7 shows a very similar behaviour to the previous one, where peripheral regions require more modal changes to reach all other regions in Europe. Regions with poorest travel conditions are especially islands, and peripheral regions in peripheral countries, like the Mediterranean arch in the Iberian Peninsula.

Again, upper-right figure and bottom figure show that when weighting each relation with its trips or trip-kilometres, the image becomes more uniform, reflecting that relations requiring more connections have low volumes of trips associated.   An exception seems to be regions close to big mega-cities (e.g. Paris surroundings) which have important long-distance mobility flows requiring more connections.
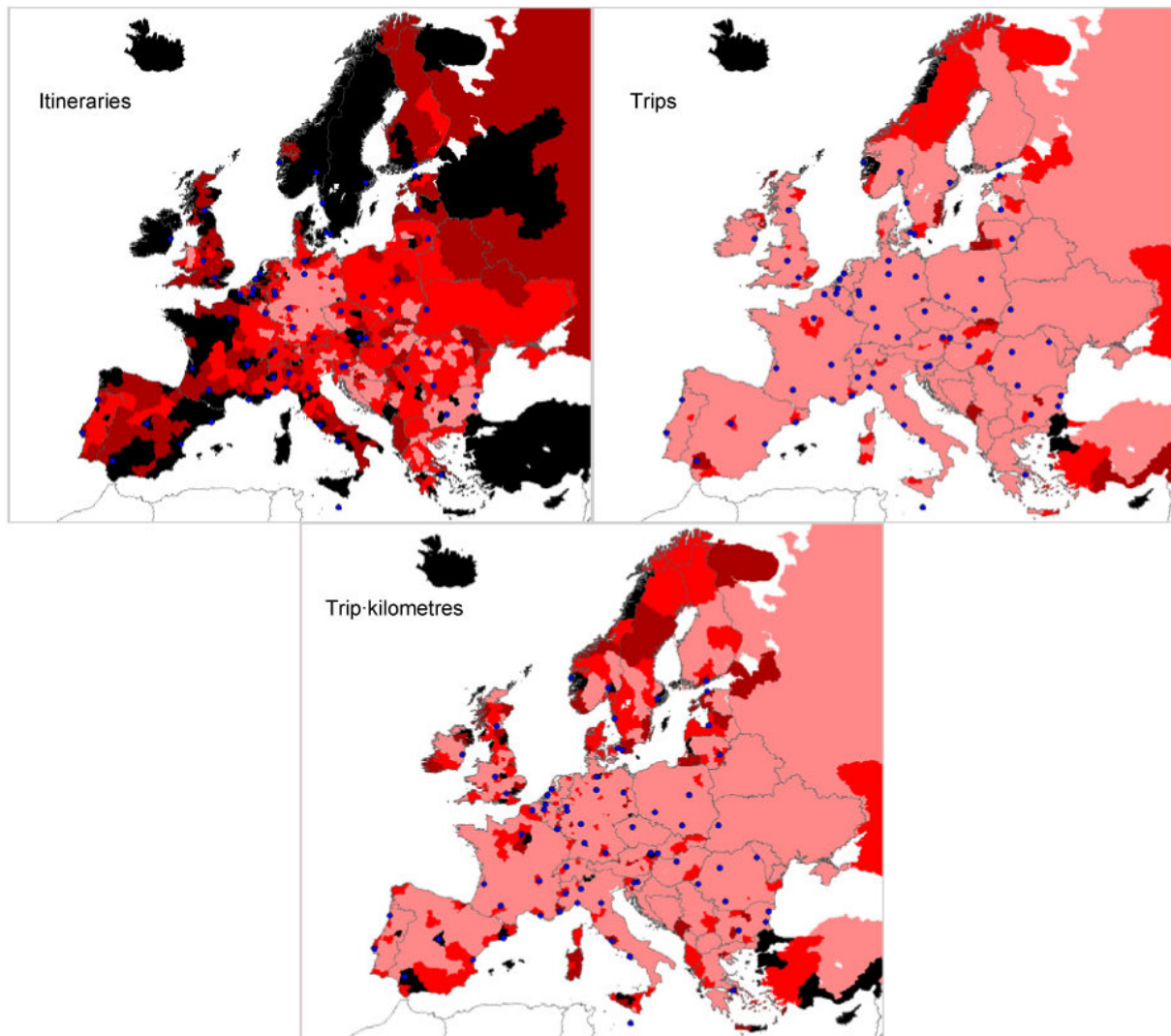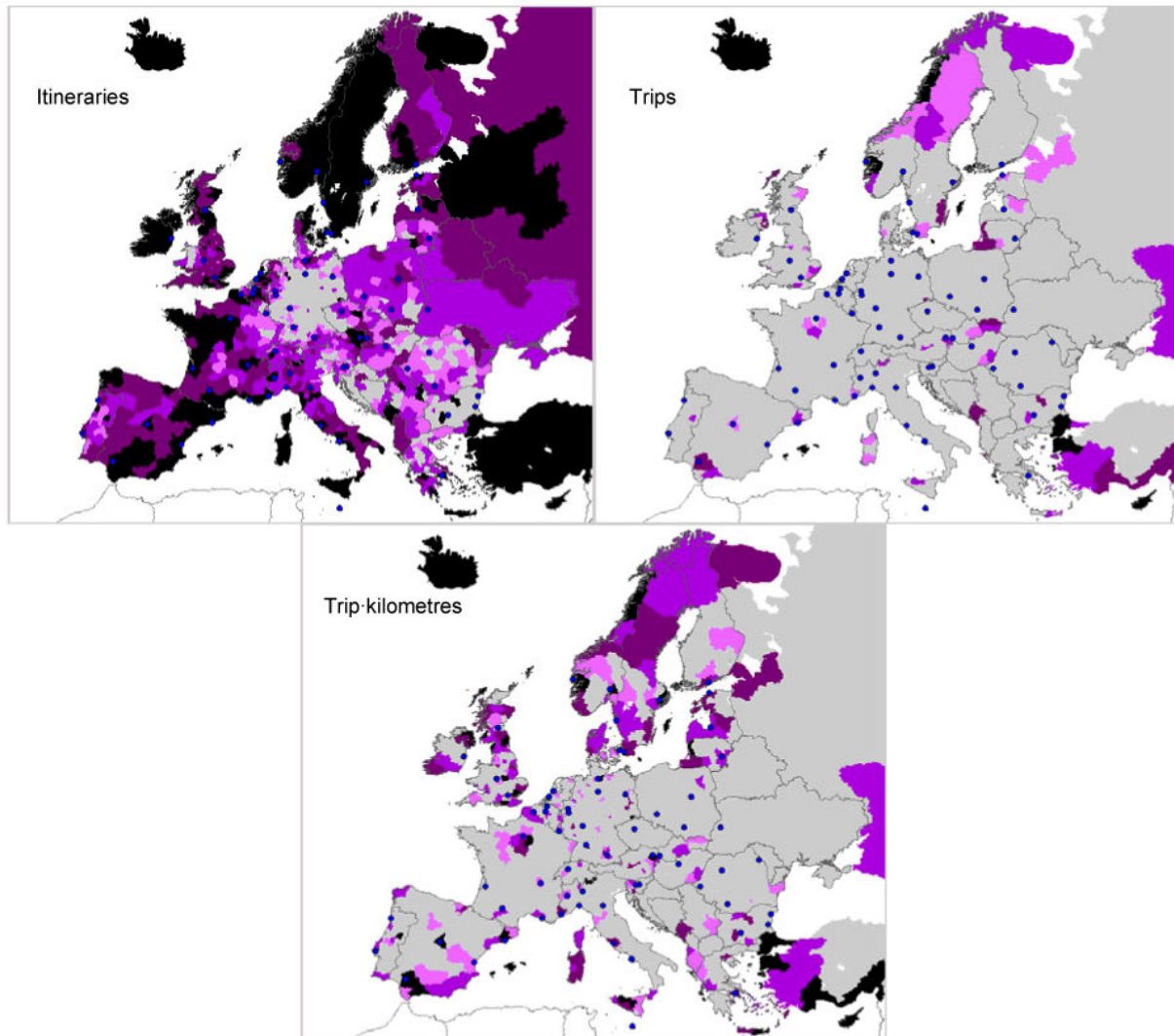
Figure 4-7   Inter-modality rate for each NUTS3 based on itineraries, trips and trip-kilometres

Interconnectivity rate: number of breaks in the shortest-cost chains between NUTS3

The Interconnectivity rate indicator is defined as the number of steps or changes in a trip, that is the number of changes inter or intra modes. This concept includes changes between different modes, and also between different networks of the same mode, e.g. successive plane trips or going from regional rail to long-distance rail (associated the latter to the TEN-T core networks).

Applied to NUTS3 level, the interconnectivity indicator averages the number of steps required to travel from that NUTS3 to each of the other NUTS3. A higher value of the indicator indicates a higher number of interconnections required in trips to other NUTS3.

The interconnectivity rate indicator is computed here for itineraries (basic formulation), weighted by the number of trips between every NUTS3 (gives more relevance those inter NUTS3 relations where the number of trips is larger), or weighted by trips and trip distance (gives more relevance those inter NUTS3 relations where the number of trips is larger and the magnitude of these trips is longer).

The *interconnectivity rate* indicator in Figure 4-8 shows again that regions which require more connections intra mode or inter mode are mostly located on the periphery. The main difference here is introduced in the fact that this indicator considers air-air connections as an additional break in the transport chains.

Variations with respect to previous indicators reflect the need of using more than one air connection to long-distance travel in Europe from more distant regions. This is reflected in a less uniform landscape in the bottom figure (yellow areas) than in previous analysis.
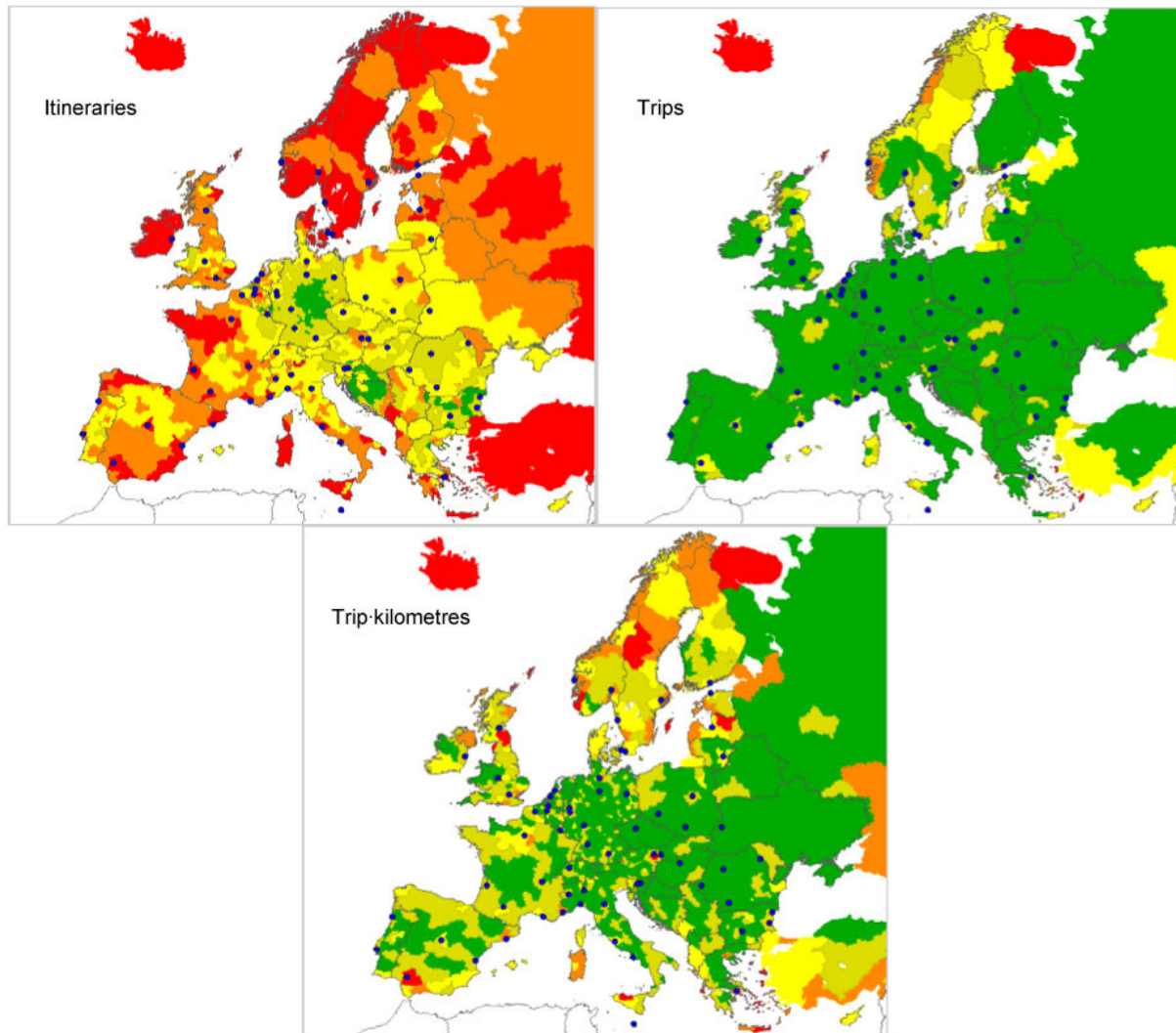
Figure 4-8   Interconnectivity rate for each NUTS3 based on itineraries, trips and trip-kilometres

Diversity rate: diversity of modes used in the shortest-cost chains between NUTS3

The diversity rate indicator measures the diversity of modes being used in travelling from each NUTS3 to all others, measured according to an entropy formulation.

The indicator has a minimum value of 0 and a maximum value of 1. These two situations, respectively, reflect an ideal situation were a single mode is being used for all trips to access all other NUTS3, while a maximal value of entropy reflects maximal diversity, that is an equal share of rail, road and air modes used to travel to other NUTS3.

The diversity rate is computed based on total and mode's partial length of the trip, and does not take into account the composition of the trip, i.e. the number or order of modal chain steps. The indicator is computed on partial lengths of the trip, but trips are determined according to a shortest-path algorithm based on travel cost.

The diversity figures in Figure 4-9, computed for business trips only, portray that very long distance trips (> 1000 kilometres) tend to be more varied terms of the modes used to do them, that is, they tend to have more similar shares of each mode approaching to 1 third per mode. For trips from 300 kilometres to 1000 kilometres, the diversity values are recognisably lower, showing that some modes

become preferential. It is also worth noting that western countries tend to have more varied transport systems than central Europe.
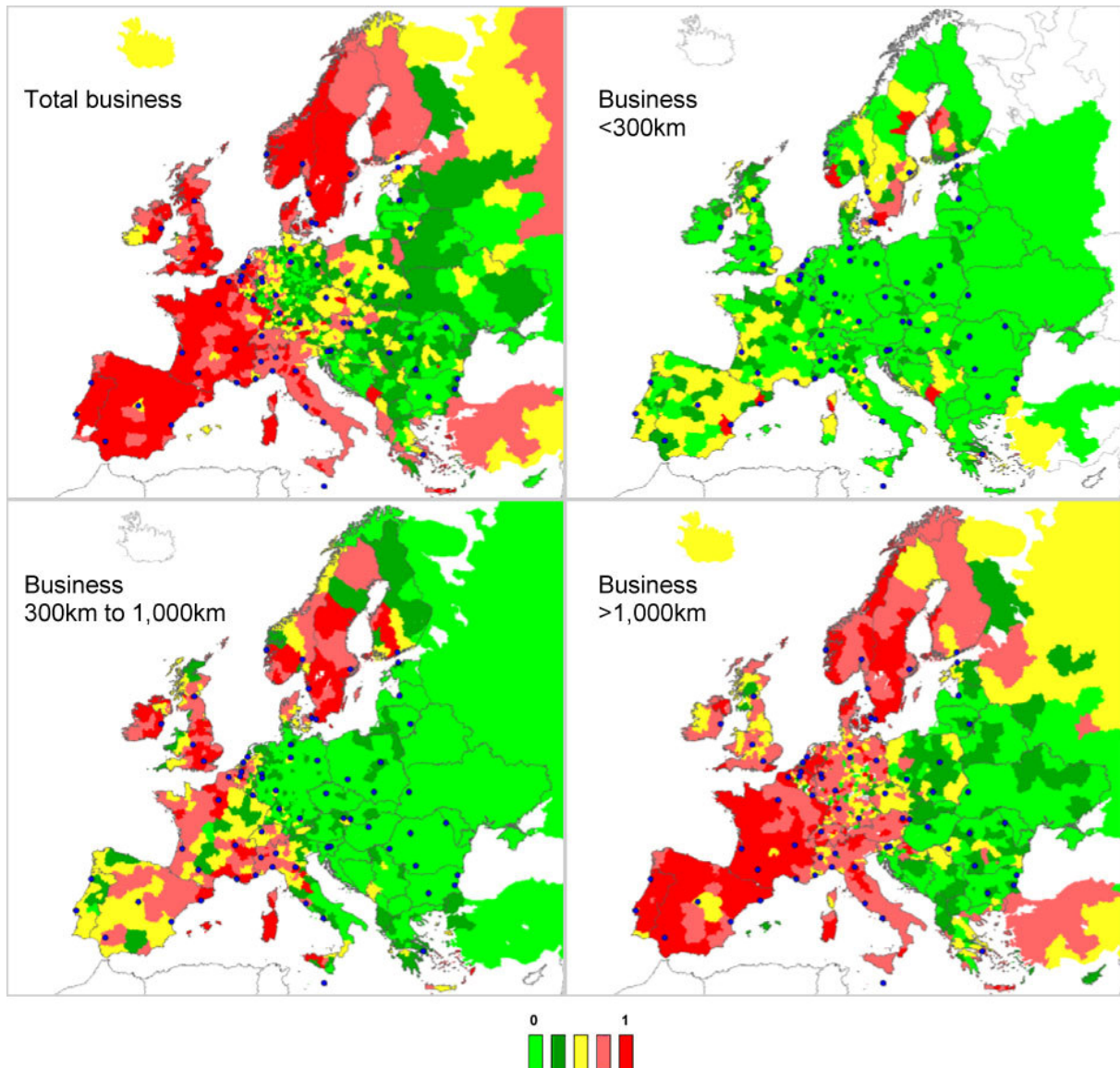
Figure 4-9   Diversity rate in Europe for business trips

Changes in the travel costs

Figure 4-10 shows, as was to be expected, that costs of travelling are higher for peripheral regions than for central European regions. However, costs appear much higher for northernmost regions than for southernmost ones, reflecting a relative different behaviour between different peripheries.

In relation to trip purposes, business and holidays sections reflect much uniform cost patterns than private and commuter purposes.

The maps also reflect that eastern countries tend to have cheaper average travel costs. This can be an effect of lower values of time considered there, as the value of time in the IC Module is dependant on GDP per capita in the NUTS3 of origin. Also there might be fewer long-distance trips.

One would expect that in the progressive integration of eastern countries - generating more long-distance east west trips - and economic convergence - rising wealth per capital levels - would tend to increase travel costs in the eastern regions of the continent.
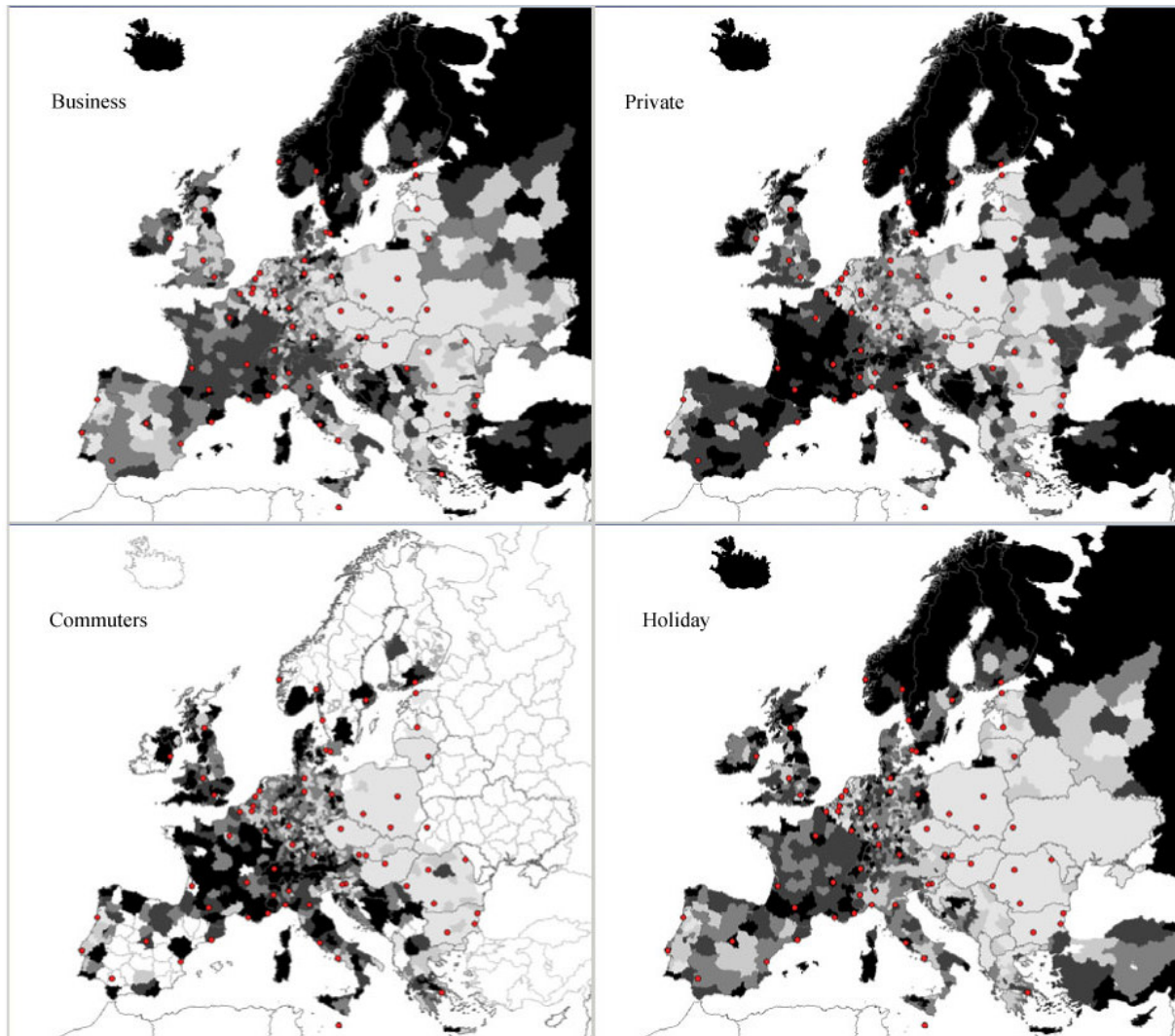
Figure 4-10   Average travel cost to travel from one NUTS3 to all others

4.3   IMPACTS OF REDUCING INTERCONNECTIVITY COSTS

Three scenarios have been calculated to analyse the impact of connection costs.

➢ Scenario A lowers the cost of all interconnections to half of today's.

➢ Scenario B lowers the cost of all interconnections to zero.

➢ Scenario C lowers the costs of access and egress to rail terminals to zero (city-rail, road-rail, air-rail). Scenario C is built as a pro-rail scenario.

4.3.1 Impact on Travel Costs

Reducing the interconnection costs allows the user to select cheaper routes that lead to lower global functioning costs. This effect is most important in scenarios where all costs of interconnection are lowered, while in the pro-rail scenario, global costs remain almost unchanged. In Figure 4-11 the aggregated cost for each scenario is shown, summing up all travel costs in the trip matrices by purpose.

(relative variations in relation to the baseline are indicated for each scenario)
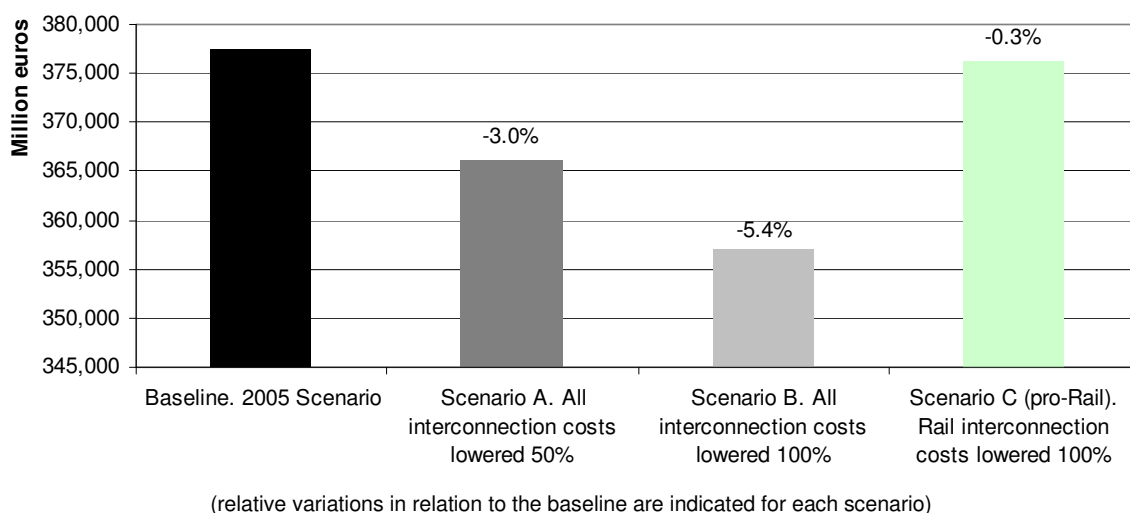
Figure 4-11   Transport cost of different scenarios with alternative hypotheses on interconnection improvements

The analysis by different trip purposes indicates that the better-off users are holiday travellers and commuters, followed by private travellers (visiting relatives or friends), and finally by business travellers. More specifically, for the scenarios with all interconnection costs decreased by 50% and 100% respectively, holiday travellers and commuters have travel costs reduced by 4.3% and 7.2%, and 3.5% and 7.1% respectively, while private travellers have 2.6% and 5.1% decreases and business travellers 1.2% and 2.1%. In the scenario with reduced costs of access and egress to rail mode the global cost reductions are small when compared to the other scenarios, given that rail has a low modal share; however the trips using rail highly benefited from this reduction and some trips will now use rail because of the lower cost.

Commuter trips (between different NUTS3 zones) represent a small share of total trips in Europe, therefore the impact of such important reductions are relatively small. On the other hand, holiday and private trips represent important shares of total travel, meaning that the reductions in their travel cost have a measurable impact on the global cost of the transport system, even when considering that they represent a "cheaper" traveller set than business.

Business travellers are less affected by the improvement of interconnections. This may be a consequence of the fact that having greater value of time, these kind of travellers tend to use more expensive travel modes that involve fewer interconnections. Therefore, the impact is more limited.
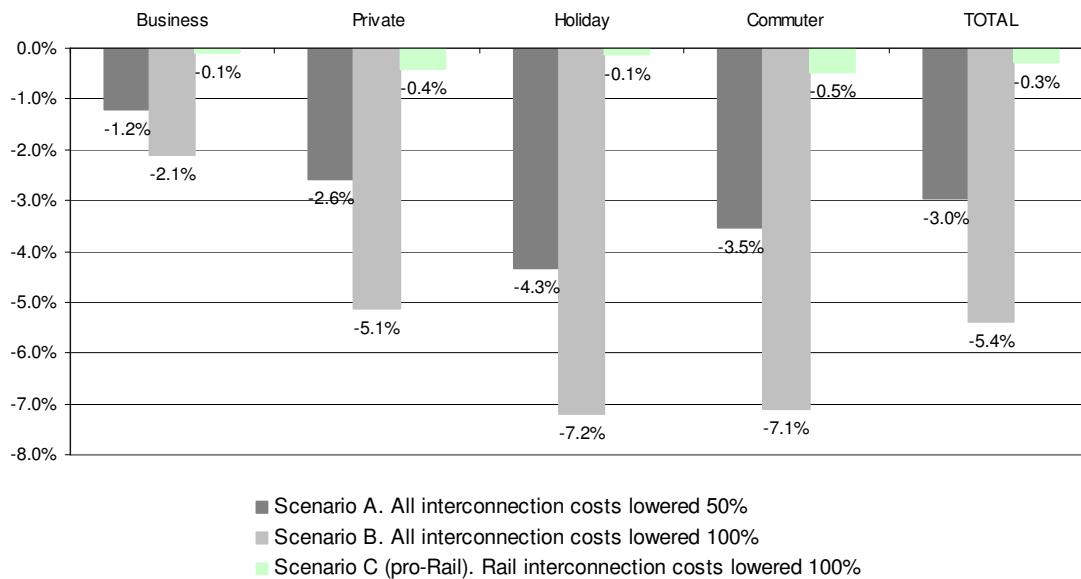
Figure 4-12 Transport cost variations by trip purposes (grouped by trip purposes)
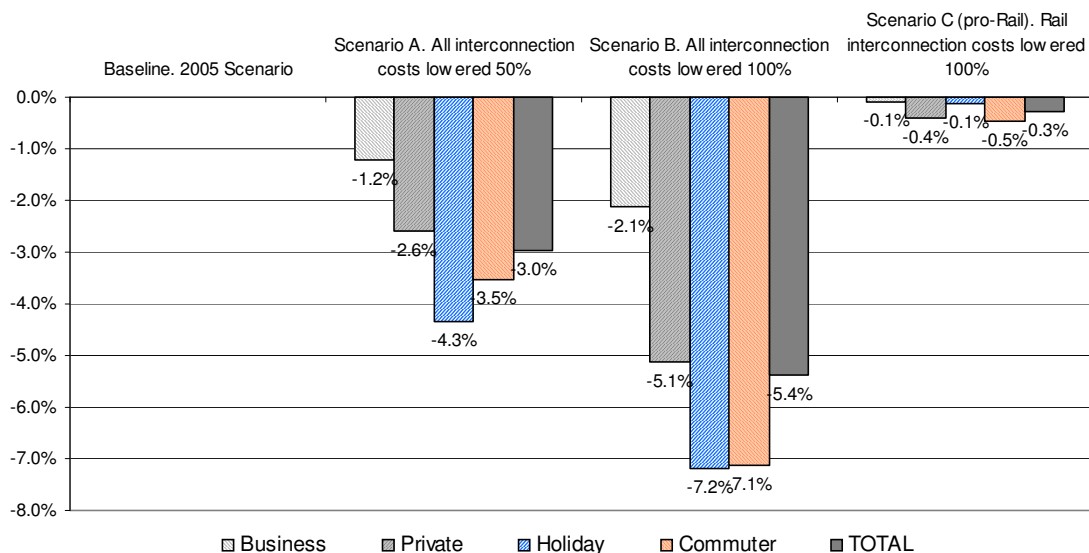
Figure 4-13 Transport cost variations by trip purposes (grouped by scenarios)

4.3.2 Impact on Modal Split

Figure 4-14 and Figure 4-15 show the resulting modal split in the three scenarios. It can be seen that reducing the interconnection costs uniformly in all interconnections (scenarios A and B) has important impacts on the modal split, with air mode increasing steadily at the expense of road and rail. In the case of reducing connection costs to rail mode (scenario C), the rail mode wins a small share from the air mode. A homogeneous reduction of all costs of interconnection plays in favour of the air mode, increasing its modal share from 23.6% in the baseline to 31.2% in Scenario B (without interconnection costs) to the detriment of the road and rail modes, both of them decreasing their modal share.   A pro-rail scenario works in the opposite direction, raising the level of rail from 3.0% to 3.3%, in this case to the detriment of the air mode, which loses 0.2% of modal share and reducing the level of road by a small 0.07%.
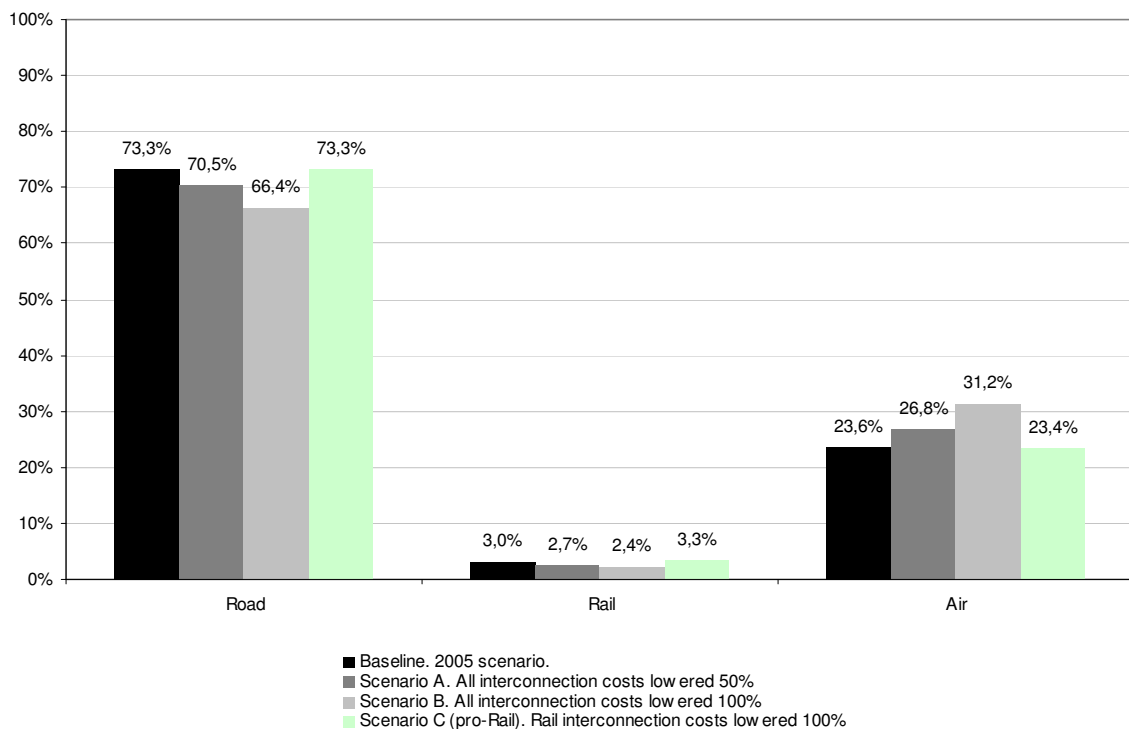
Figure 4-14   Improving interconnections: impact on modal split (in trip-kilometres) (I)
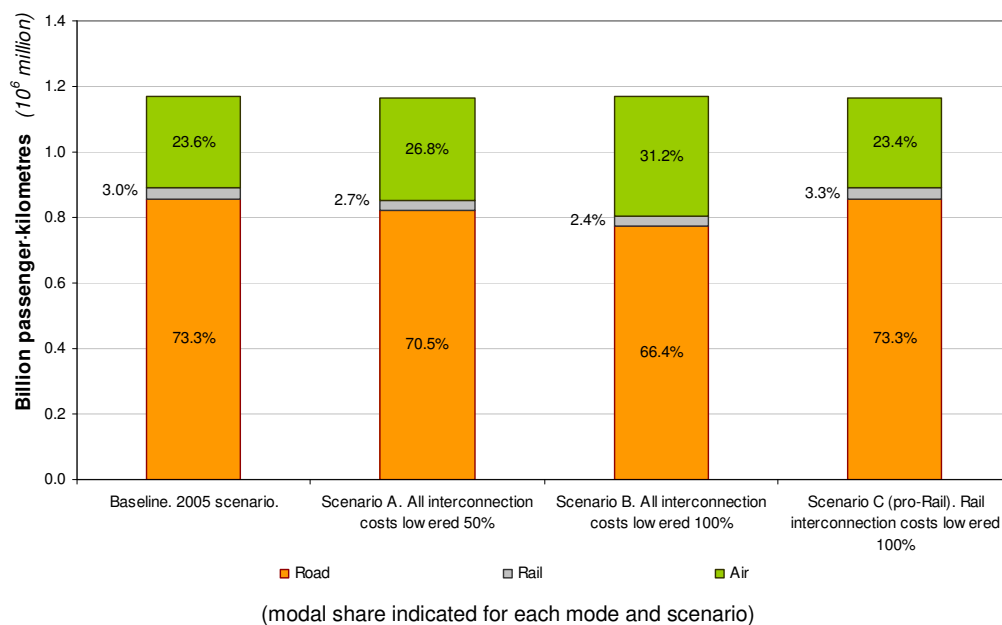
(modal share indicated for each mode and scenario)
Figure 4-15   Improving interconnections: impact on modal split (in trip-kilometres) (II)

When analysing the share of the different transport chains (in terms of trip-kilometres), the share of multi-modal trips increases with respect to the baseline (Figure 4-16 to Figure 4-19. More specifically, scenario A results in a 1% increase in the multi-modal trips, scenario B results in a 2% and scenario C in a 3% increase. This confirms the assumption that making interconnections cheaper results in increasing shares of multimodal travel.

Within the uni-modal trips, scenarios A and B involving uniform cost reductions in all interconnections result in increases of the air uni-modal trips (2% and 4% respectively) and reductions of the road uni-modal trips, while for the pro-rail scenario (scenario C), there is a 1% increase of the rail uni-modal trips, a 1% increase of the road uni-modal trips and a 2% air decrease.

Within the multi-modal trips, for scenarios A and B there is a clear trend towards reduction of the road-rail multi-modal chain, but an increase on all others, in particular on the air-road multi-modal chain but also of the air-rail multi-modal chain. For scenario C, the most significant change is an increase of the tri-modal chains (road-rail-air). The global increase of trips by air mode is a consequence of reducing the higher cost of access/egress to airports, which are more significant than costs of accessing the rail and road networks.

In scenarios A and B the increase of the air modal share (see previous chapter 4.3.1) from 23.6% to 31.2% results in a general increase of the share of most transport chains involving the air mode, basically the air uni-modal chains and the air-road and air-rail multi-modal chains, while for scenario C, the increase of the rail modal share results in the increase of rail uni-modal trips and the tri-modal road-rail-air chains.

Figure 4-16 Baseline: modal share of trip-kilometres travelled in trips between NUTS3
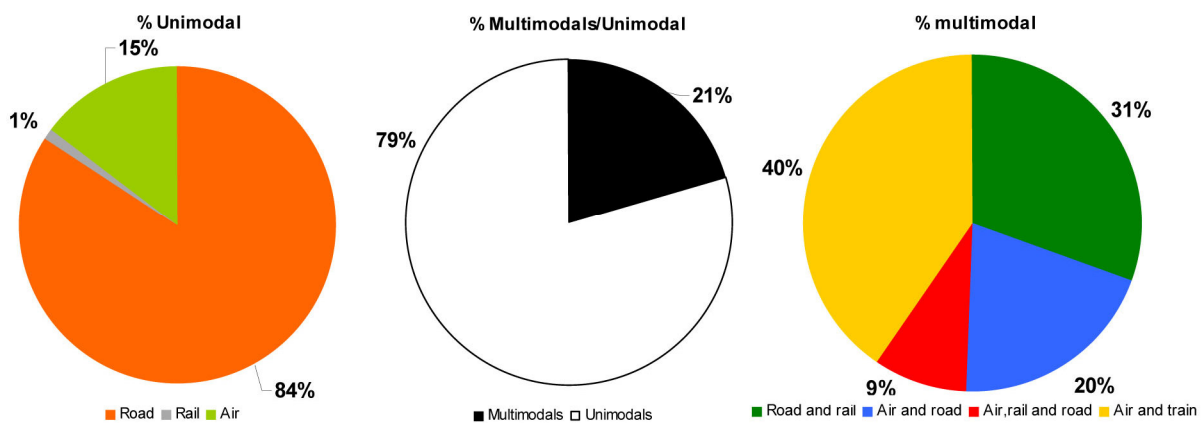
Figure 4-17 Scenario A: modal share of trip-kilometres travelled in trips between NUTS3
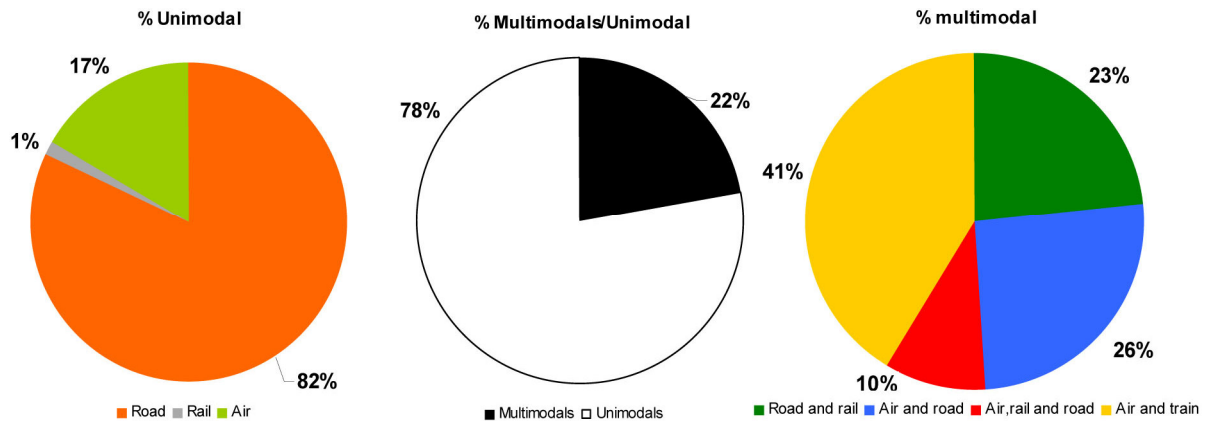
Figure 4-18 Scenario B: modal share of trip-kilometres travelled in trips between NUTS3
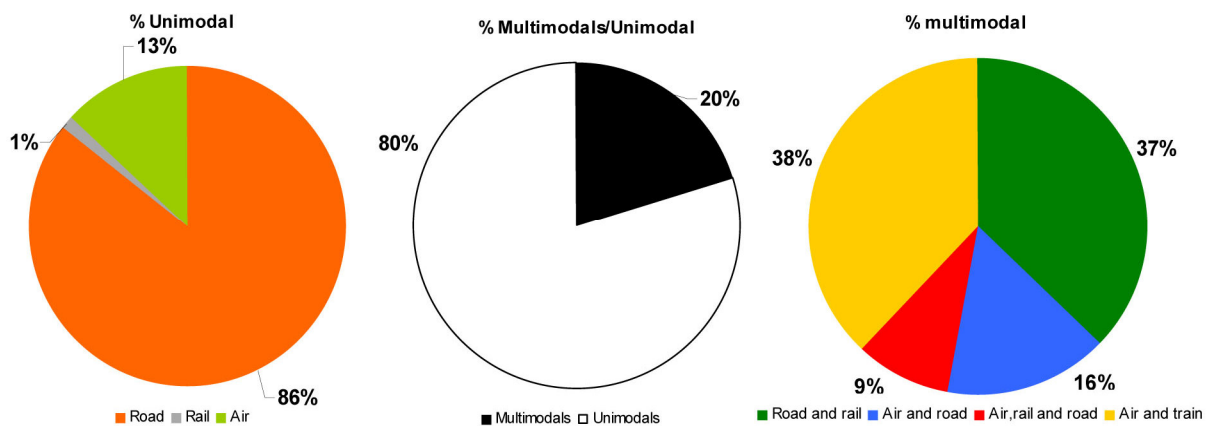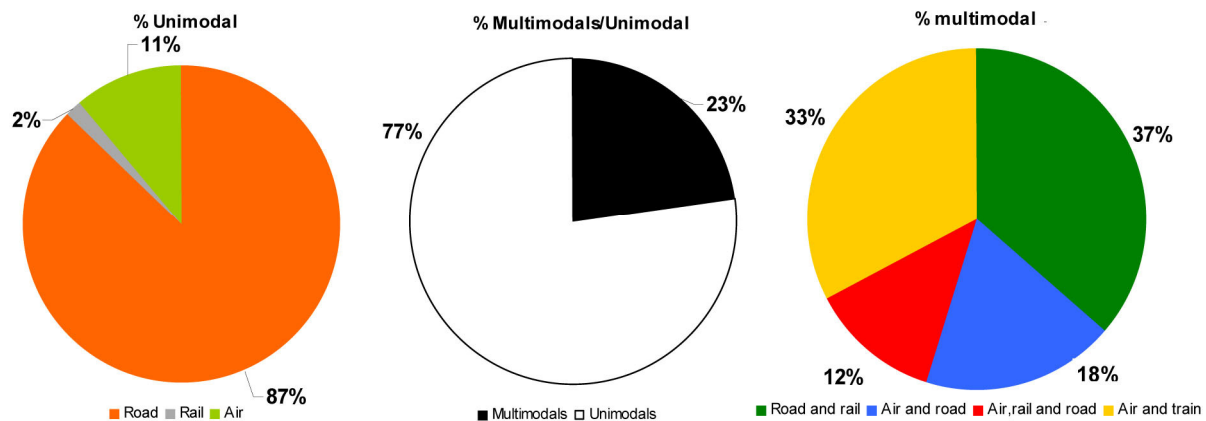

Figure 4-19 Scenario C: modal share of trip-kilometres travelled in trips between NUTS3

Figure 4-20 presents the allocation of each mode's trip-kilometres in the different transport chains. The upper block of the figure corresponds to the air mode, and represents for each scenario in which transport chains are air trip-kilometres being travelled (e.g. for the baseline, air trip-kilometres are mostly being travelled on air uni-modal trips – almost 50% - and on air-train multi-modal trips – around 35%). Inside the bars, the absolute magnitude of the bar is shown with respect to the total EU travelled trip-kilometres (e.g. for the baseline, the air fraction of the air-train transport chain represents 7.1% of the total EU travelled trip-kilometres).

The analysis of this figure leads to conclude the following points:

➢ In the air mode, an uniform decrease of the cost of all interconnections (scenarios A and B) results in a restructuring of the multi-modal chains, increasing the air-road trip-kilometres and the tri-modal trip-kilometres and decreasing the air-train trip-kilometres, but the uni-modal air trip-kilometres maintain their relative share (even if they increase their total weight in the transport system from 9.9% to 12.6%). On the other hand, scenario C results in a decrease of the uni-modal trip-kilometres in favour of all other chains, especially tri-modal road-rail-air chains.

➢ For the rail trip-kilometres, the upgrading of interconnections in all scenarios leads to an increase of the relative weight of the rail uni-modal chains with relation to all others, and a decrease of the road-rail multi-modal chains. Even in scenarios A and B, where the total weight of the rail uni-modal trip-kilometres remains unaltered in 0.7% of the total, the relative share of this transport chain increases in the context of the rail mode, or what is the same, the decrease of trip-

kilometres of rail in these scenarios is a consequence of the decrease of multi-modal chains involving rail.

➢ The road mode is heavily dominated by road uni-modal trips in all scenarios, but shows a relatively important increase of the relative weight of multi-modal transport chains in scenario C. In general, there is a transfer of road-rail trip-kilometres towards road-air trip-kilometres.

(The relative magnitude in relation to total EU trip-kilometres is shown inside the bar)

Figure 4-20   Trip-kilometre allocation in the different transport chains
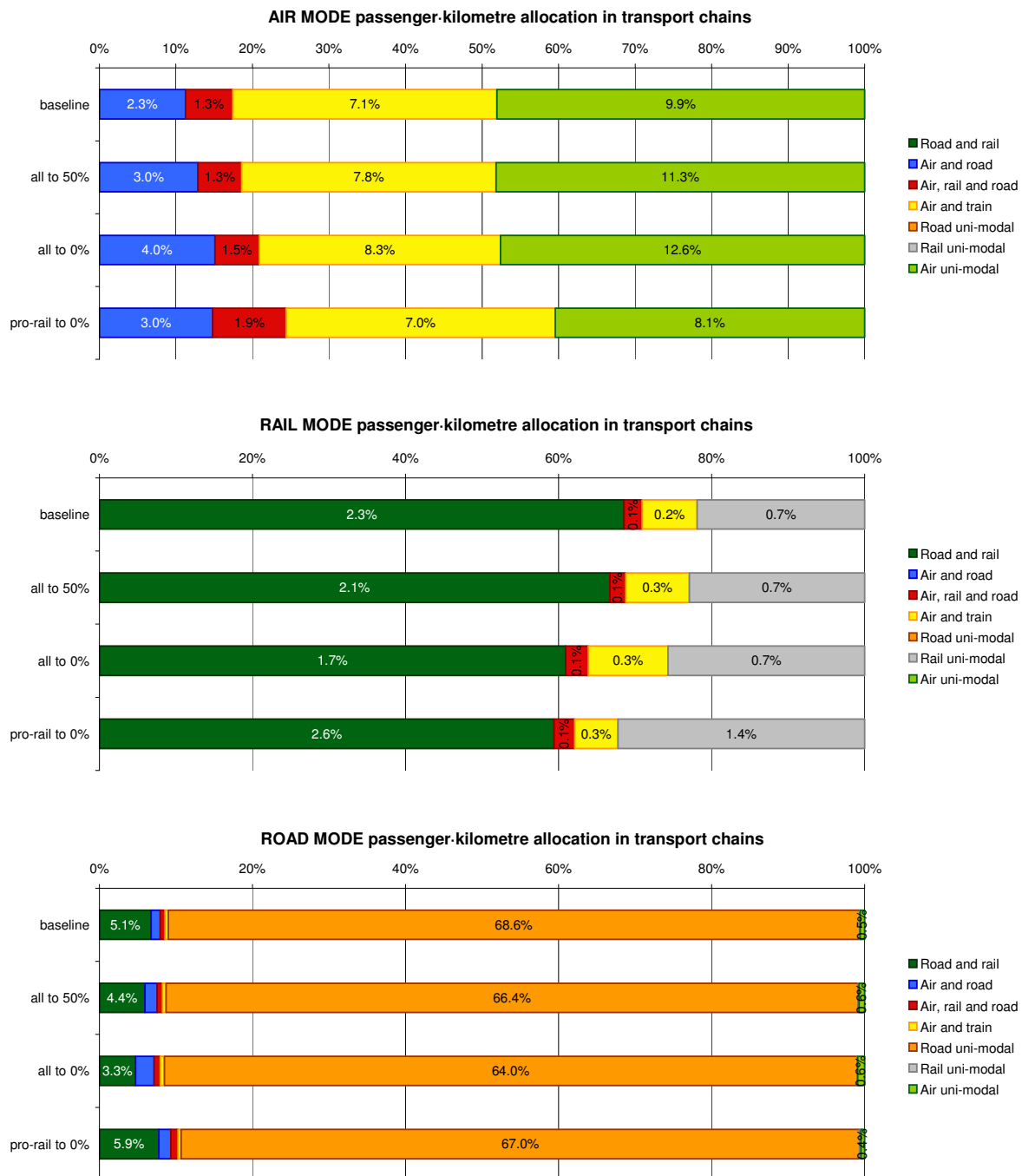
4.3.3 Impact on Traffic

The redistribution of traffic between modes has an important impact on the volume of traffic in the network in the scenarios. The upgrading of interconnections in Europe results in traffic decreases in all cases, implying that fewer kilometres are travelled in the European transport system and that shorter itineraries are therefore being used to do the same trips. The pro-rail scenario is the one that optimises trip lengths to a higher degree, resulting in a 3.2% drop of the volume of trip-kilometres with respect to baseline. Paradoxically, Scenario B results in longer trips than Scenario A (larger volumes of trip-kilometres), implying that when interconnections have no cost, it is cheaper for the system to use longer transport modes at a lower cost per kilometre, while with interconnection costs set to 50%, the trend is rather to use shorter itineraries.

(relative variations in relation to the baseline indicated for each scenario)
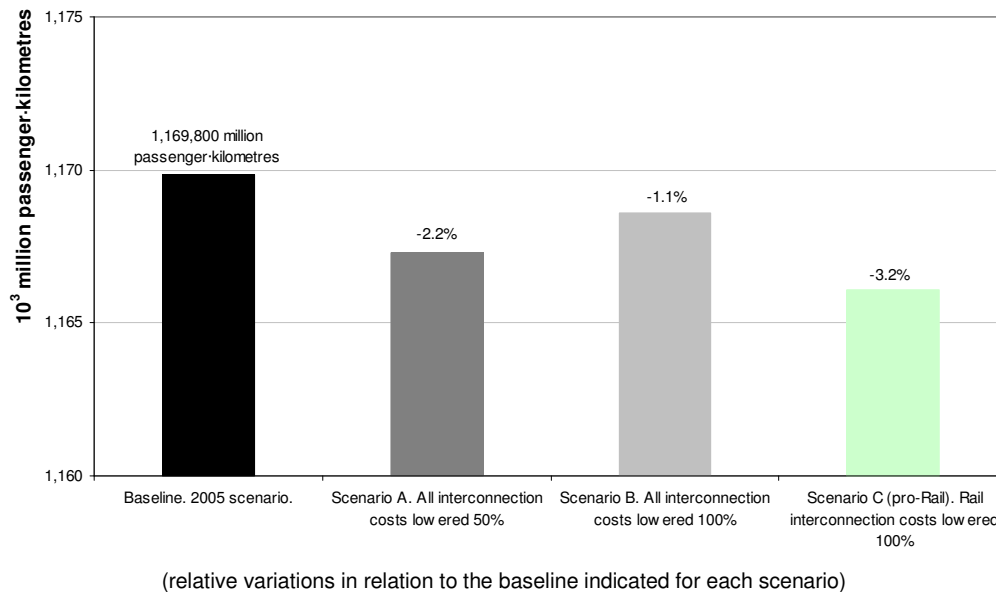
Figure 4-21   Total traffic volume for different scenarios with alternative hypotheses on interconnection improvements, in trip-kilometres

Next an analysis of average trip lengths is presented (Figure 4-22 to Figure 4-24). For each type of trip according to the transport chain, an average length of each mode has been calculated using the trip-kilometres and total trips.

For road and air modes the reduction of costs in scenarios A and B result in a reduction of the average trip length in all transport chains. The reductions of about 10% in length in some cases do not imply a similar reduction in total trip-kilometres, as these figures have to be weighted with the share of each transport chain which changes in a significant way in each scenario.

For instance, the road uni-modal trips are in scenario B 10% shorter than in the Baseline (these trips represent around 70% of total trip-kilometres travelled in Europe), while air uni-modal trips are around 18% shorter in scenario B than in the baseline (representing around 10% of total trip-kilometres). However, as there is a transfer from road uni-modal to air uni-modal trips, and air uni-modal trips are much longer than road uni-modal trips, the total decrease in trip-kilometres for scenario B is inferior than what would be intuitively expected (it could even increase in an extreme situation).

The average rail length does not change much across the different scenarios in each transport chain, as the share of rail is low in all cases and thus fewer trips are involved in these figures.

Baseline. 2005 scenario.
Scenario A. All interconnection costs low ered 50%
Scenario B. All interconnection costs low ered 100%
Scenario C (pro-Rail). Rail interconnection costs low ered 100%

Figure 4-22   Air Mode average trip length (kilometres) in different transport chains

Baseline. 2005 scenario.
Scenario A. All interconnection costs low ered 50%
Scenario B. All interconnection costs low ered 100%
Scenario C (pro-Rail). Rail interconnection costs low ered 100%

Figure 4-23   Rail Mode average trip length (kilometres) in different transport chains

Figure 4-24   Road Mode average trip length (kilometres) in different transport chains

4.3.4 Impact on GHG Emissions

In the previous sections, it has been seen how the uniform upgrading of interconnections in Europe (scenarios A and B) leads to an increase of the air modal share. The redistribution of mobility within all different transport modes leads to reduced costs of the European transport system, and reduced volumes of vehicle-kilometres travelled. However, the effect of this modal change towards the air mode results in an increase of the GHG emissions in these scenarios (Figure 4-25). More specifically, for scenarios A and B, the increase of CO_2 emissions released into the atmosphere is 0.5% and 0.9% respectively (0.64 and 1.91 million tonnes). On the other hand, the pro-rail scenario C reveals a 0.5% (0.76 million tonnes) decrease of the CO_2 emissions as a result of withdrawing trip-kilometres from the air mode onto the road and rail modes.

It is worth noting that the model is focused on reducing costs, not taking into account any environmental consideration, leading in some cases to a rise in CO_2 emissions. However, if external costs such as these CO_2 emissions were internalised and the assignment function of the model took them in consideration, the final picture of transport chains in Europe would look different.

Therefore, interconnection improvement does not need to necessarily result in a more sustainable and environmentally friendly transport system. Interconnection upgrading will result in a transport system with lower transport costs, but as externalities are not being internalised in the analysis, GHG emissions may end up increasing, like in the case of scenarios A and B.

However, considering finally the fact that only 29% of total trip-kilometres in the European transport system are long-distance trips and are actually being modelled in INTERCONNECT, the variation of CO_2 emissions for the global system would be lower, and the relative increases resulting from scenarios A and B would be more limited.

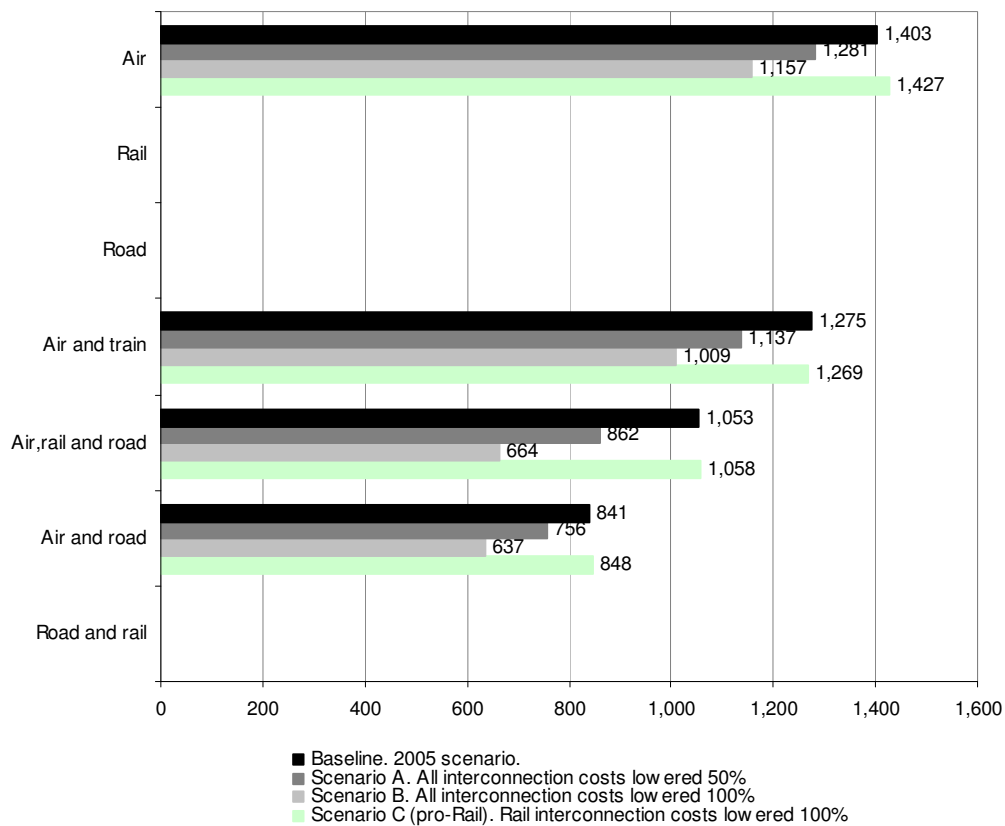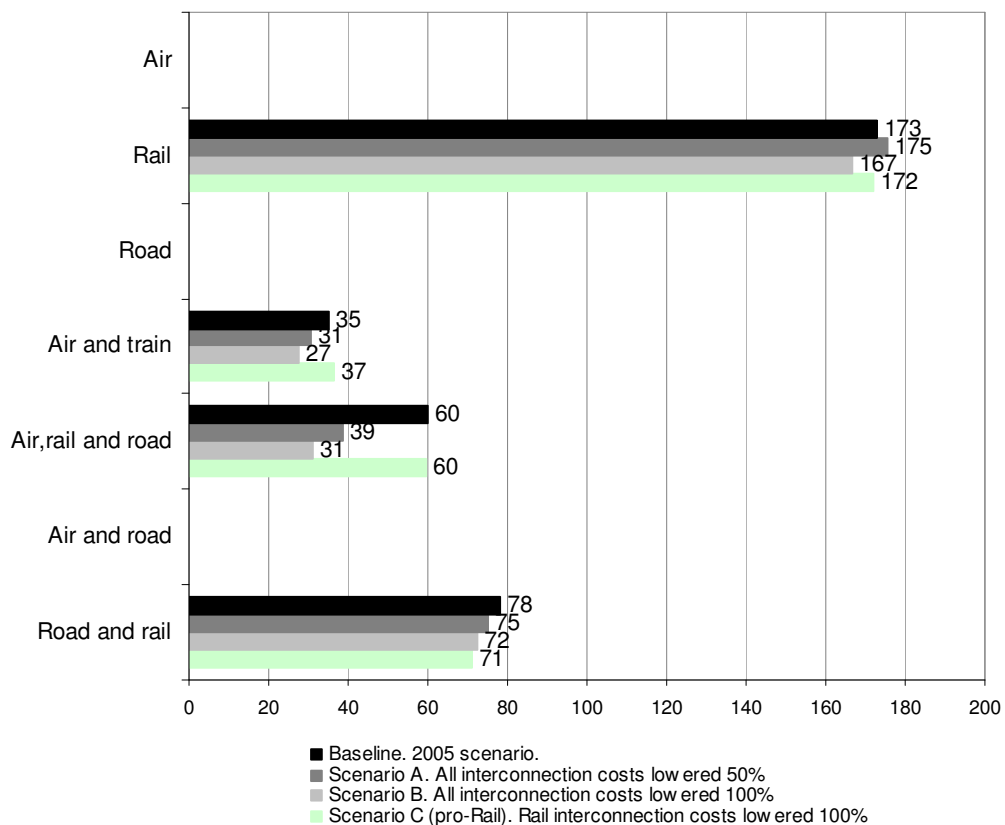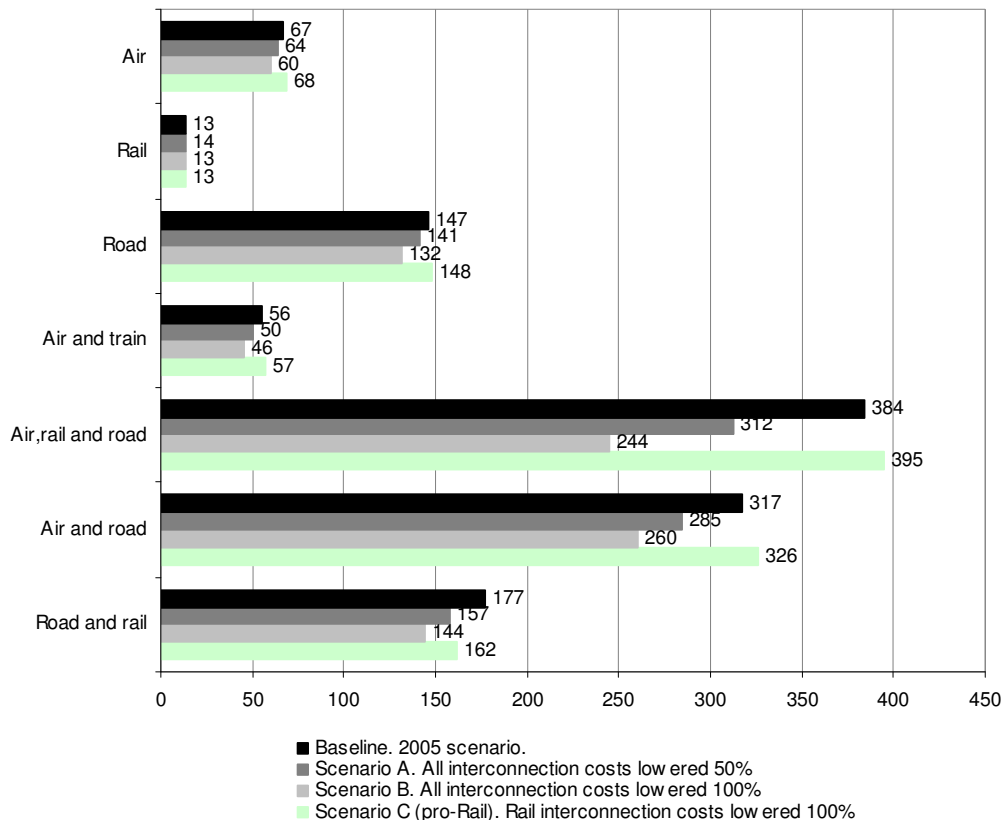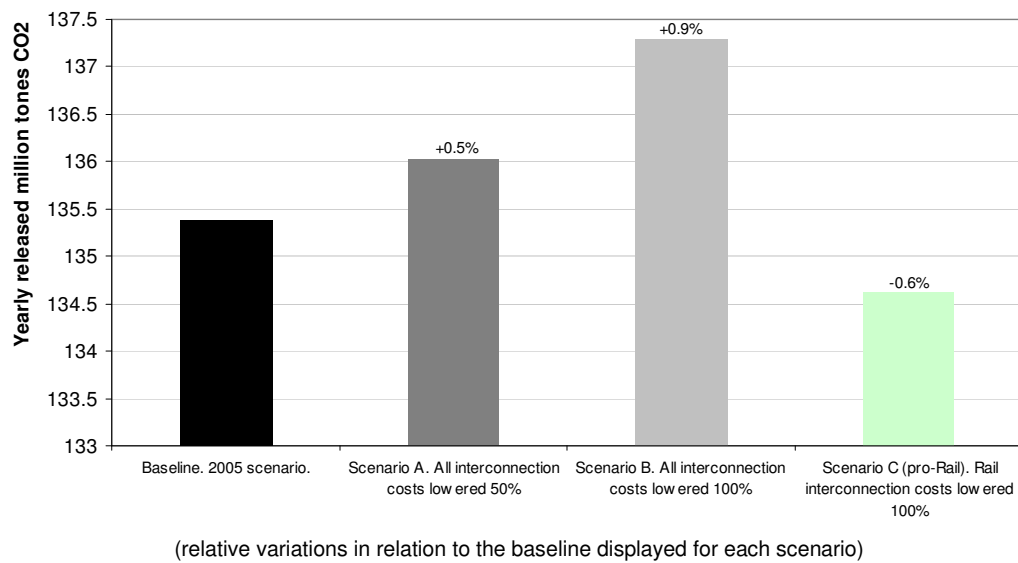(relative variations in relation to the baseline displayed for each scenario)

Figure 4-25 CO_2 emissions for different scenarios with alternative hypothesis on interconnection improvements

5   CONCLUSIONS

The topic of interconnectivity has particular relevance for the European transport policy. The new transport White Paper 2011-2020 claims that better modal choices in transport will necessarily result from greater integration of different modal networks, requiring airports, ports, railways, and other public transport systems to be increasingly linked to facilitate multimodal travel. To optimise network effects, it is important to track those interconnections affecting a highest share of users in the transport system.

INTERCONNECT provides an assessment to these policy-aims, based on a number of selected case-studies and test-beds, as well as by using modelling tools to be able to test the impacts of interconnectivity improvements at European level.

The IC Module developed on INTERCONNECT provides an integrated modal split and traffic assignment procedure on top of TRANS-TOOLS passenger trip matrices 2005 for four trips purposes, and uses TRANS-TOOLS transport networks enhanced to model interconnections between long-distance services and local networks to long-distance terminals. The large volume of outputs produced by the IC Module is processed by meta-model routines developed in order to compute specific assessment indicators as well as to carry on sensitivity analyses.

Next, the main conclusions of the modelling exercise are discussed:

About the geography of interconnections in Europe today

1. Long-distance travel in Europe represents less than 10% of all passenger trips in Europe, nut approximately 30% of all kilometres travelled in Europe, considering long-distance trips as those between different NUTS3 in Europe. According to many forecast studies, these trips (as well as trips from Europe to the rest of the world) are expected to grow in the future much faster than short-distance trips.

2. Out of all long-distance travel in Europe, only 7% of trips use modal combinations involving more than one mode. However, this set of trips represents 20% of the total amount of kilometres travelled in Europe, indicating that multi-modal trips are much longer in magnitude than uni-modal trips. Uni-modal trips are those which use only road, or where road is used with rail or air but represents less than 85% of total trip length. Multi-modal trips are all others.

3. The share of the road mode is dominant in long-distance travel. The modal share of road in long distance travel is of 73% (in trip-kilometres), almost 88% in uni-modal chains and approximately 34% in multi-modal chains.

4. The modal share of the rail mode is very limited in long-distance travel. The modal share of road in long distance travel is 3% (in trip-kilometres), 1% in uni-modal chains and 13% in multi-modal chains. Most trip-kilometres on rail are allocated in multi-modal chains, approximately 70% of total trip-kilometres for rail mode.

5. The modal share of the air mode in long-distance travel is 24% (in trip-kilometres), approximately 11% in uni-modal chains and 53% in multi-modal chains. The air mode is mostly used in air uni-modal chains (46% of air trip-kilometres) and air-rail multi-modal chains (36% of air trip-kilometres). Air-train multi-modal chains include all trips using rail to access an airport, regardless of the length of the rail stretch.

6. Opportunities for uni-modal trips are lower in the periphery than in central areas. Itineraries from the periphery to all other regions in Europe have to cope with a relatively larger amount of interruptions (interconnections inter mode or intra mode) than itineraries originated in core regions. It is not just a geographic question: transport networks are denser and better interconnected in core areas, where there are higher volumes of trips and more frequent services.

7. The most frequented transport relations between NUTS3 cope with a similar number of interruptions all over in Europe. Interconnection rates weighted by trip volumes show similar

values for all NUTS3. The complexity of the itineraries reduces the volumes of trips, independently from being central or peripheral.

About the impact of improving interconnections

8. Upgrading interconnections results in global savings in the whole transport system: with reductions of 50% and 100% in interconnection costs, transport costs may decrease 3.0% and 5.4% respectively, which translates to a € 11,000 million and € 20,000 million saving per year. (Average values of time are based on TRANS-TOOLS and only indirectly consider waiting times as having additional value, while the reduction of comfort related to the interruption of the trip is not considered.)

9. The users that capture more benefits from reducing the costs of interconnection are those with lower values of time, like tourists. Users with highest values of time, like business travellers, tend to use optimal paths from a *time* point of view even if more expensive, and these itineraries are characterised by a lower amount of interconnections.

10. The reduction of costs of interconnections provides reductions in the global volume of trip-kilometres travelled, implying that more efficient routes are globally chosen. With reductions of 50% and 100% in interconnection costs, volumes of traffic decrease 2.2% and 1.1% respectively. This is a total of 2,600 and 13,000 million passenger-kilometres respectively. The average trip length for each transport chain becomes substantially lower, but there is a net transfer from shorter transport chains to longer ones (e.g. from road to air).

11. Interconnections represent 5.4% of the total cost of transport in Europe assuming average values of time based on TRANS-TOOLS. Approximately 20% of this cost corresponds to interconnections between transport networks (rail-air, air-road and road-rail), while 80% corresponds to interconnections of the transport networks at local level. Obviously, long-distance traffic must use local interconnections, but not necessarily intermodal or modal interconnections between transport networks. If waiting times are considered as having higher value in relation to travelling time in the car, then the cost could be also higher as perceived by the traveller.

12. The reduction of costs of interconnection increases the share of multi-modal trips, as expected. But the increase is relatively small: if costs of interconnections are eliminated all together, multi-modal trips' share out of long-distance trips just increases by 2%, reaching 22%.

13. By selectively reducing the cost of interconnections to favour the increase of rail, the multi-modal share increases by 3%, reaching 23%, but rail share increases only marginally, just by 0.3%.

14. The reduction of costs of interconnections mostly increases the share of the air mode. Air may increase up to a 7.6% maximum, if all interconnection costs are eliminated.

15. The reduction of costs of interconnection causes long-distance traffic CO_2 emissions to increase up to 0.9% (1.9 million tones CO_2) in scenarios with simultaneous reductions of costs of all interconnections, and to decrease 0.5% in scenarios favouring rail. In the context of the whole European transport system, CO_2 emission variations would be rather limited due to the fact that long-distance travel represents less than one third of total European traffic.

16. Values mentioned above are minimum values, indirectly based on average TRANS-TOOLS parameters for values of time and transport costs.

Other considerations

The next considerations, mostly qualitative, integrate the conclusions of case studies and test beds.

17. Improving interconnections will provoke changes in the services provided by rail and air operators, leading to a likely redefinition of the role of long-distance terminals in the networks. Some small airports may become more accessible and competitive in relation to larger airports. These changes, not included in the modelling exercise carried out, may result in a larger impact of interconnectivity improvements and larger gains of efficiency.

18. Costs of improving interconnections are often marginal, in relation to the cost of long-distance networks, making the investments cost effective even if the number of users and their time savings are also limited, especially when they do not require infrastructure upgrading.

19. Effective interconnection requires the provision of integrated networks and services and involve close co-operation between a range of authorities and infrastructure and service providers in the public and private sectors, often with contradictory and competing business and political goals. The creation of effective interconnection may sometimes conflict with the priorities of transport infrastructure managers, service providers and infrastructure planners (and market regulators). More than the cost, often the difficulty is legal or commercial.

20. Infrastructure managers, e.g. private airport operators, may have a limited interest in improving interconnections, as an important part of their business comes from the shopping areas within the terminals and the car parking lots, and their business interest is therefore to maximise the time spent by users within terminals while having important private car access shares to the airport. Only when the traveller welfare is obviously reduced or there is a real competition between neighbouring airports, private operators may prefer to improve interconnections onto other transport networks, like in the case of Heathrow Express.

21. Transport service operators, e.g. rail operators and airlines, can be interested in improving interconnectivity as it helps to make their services more attractive for passengers. In this context, many initiatives arise such as the onboard bus ticket sales by Ryanair, the easyBus from easyJet or the many rail-airline operator co-operations such as Airail by Lufthansa and DB or the TGVAir in France. In the case of alliances between different service providers, e.g. in the aviation sector, interconnections between services within companies of the same alliance are promoted, while interconnections with other services are restricted. The planning debate concerning the interconnection between the two terminals in the airport of Barcelona has been deeply influenced by these considerations.

22. Improving local interconnections to long-distance transport networks is likely to be of local and European interest at the same time, and doing so is also likely to have a big impact on transport as approximately 80% of costs of interconnection relate to local interconnections.

23. Interconnections can provide positive market and regulatory impacts beyond the optimisation of travel times and travel convenience for users, since often they require complex public and private partnership agreements and more advanced cooperation strategies among transport operators and infrastructure managers.

24. Infrastructure planners are mostly interested in assuring the efficiency of interconnections which are mostly going to be used by users in their domain of competence. National planners are mostly concerned about national citizens, while regional administrations are more likely to be concerned about local residents and taxpayers. With the increasing scarcity of budgets, local planners are usually not eager to spend funds on facilities that are not intended to serve local users.

25. Upgrading connections between long-distance transport networks (e.g. linking all high-speed rail lines to core airports) provides network benefits spread to travellers all across Europe, but no direct benefits to local travellers, who are not likely to transfer in their own city. Therefore, improving interconnections between long-distance terminals is more likely to be of European interest than of local or regional or even national interest. It is a genuine European scale policy, since most users will be not just long-distance but also international travellers.

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