3.4 SERVICES AT FERRY AND AIRPLANE LINKS

For ferries and airplane flights, information regarding service endowment on the link was incorporated in the IC graph. In doing so, the IC Module is able to consider changes within the mode and count them as separate journey steps (e.g. changing from one airplane onto another in a transit airport), and this provides the possibility to vary parameters of services provision and endowment.

Ferry services

Ferry links are integrated in TRANS-TOOLS' road and rail graph, representing connections between points located on opposite sides of water surfaces. For the IC graph, ferry links have been separated from the road and rail networks, and ferry services have been assigned onto those links, allowing for a more refined analysis on service endowment. Also, separating ferry links and road links will allow, in the framework of a multi-modal graph, to track modal changes making it possible to discuss and analyse land-sea interconnections.

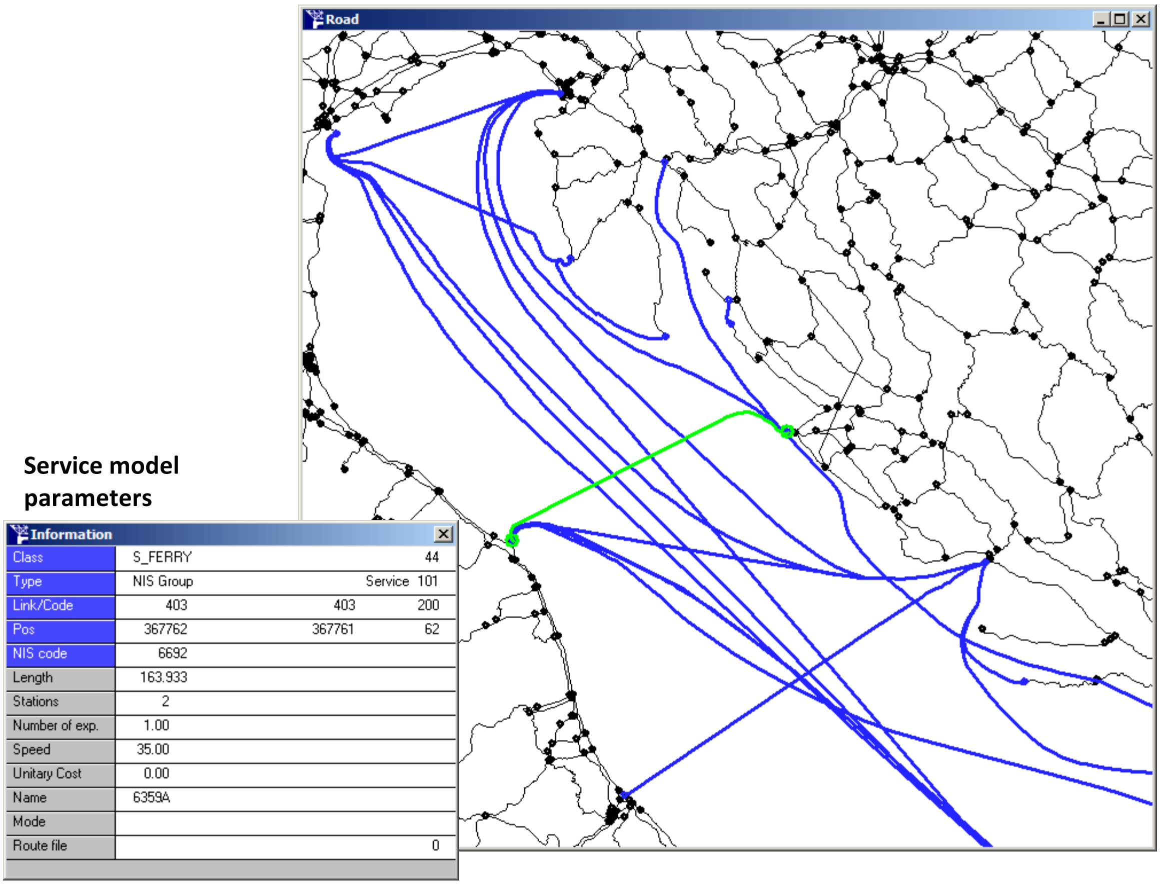


Figure 3-9 Example of ferry services in the Adriatic

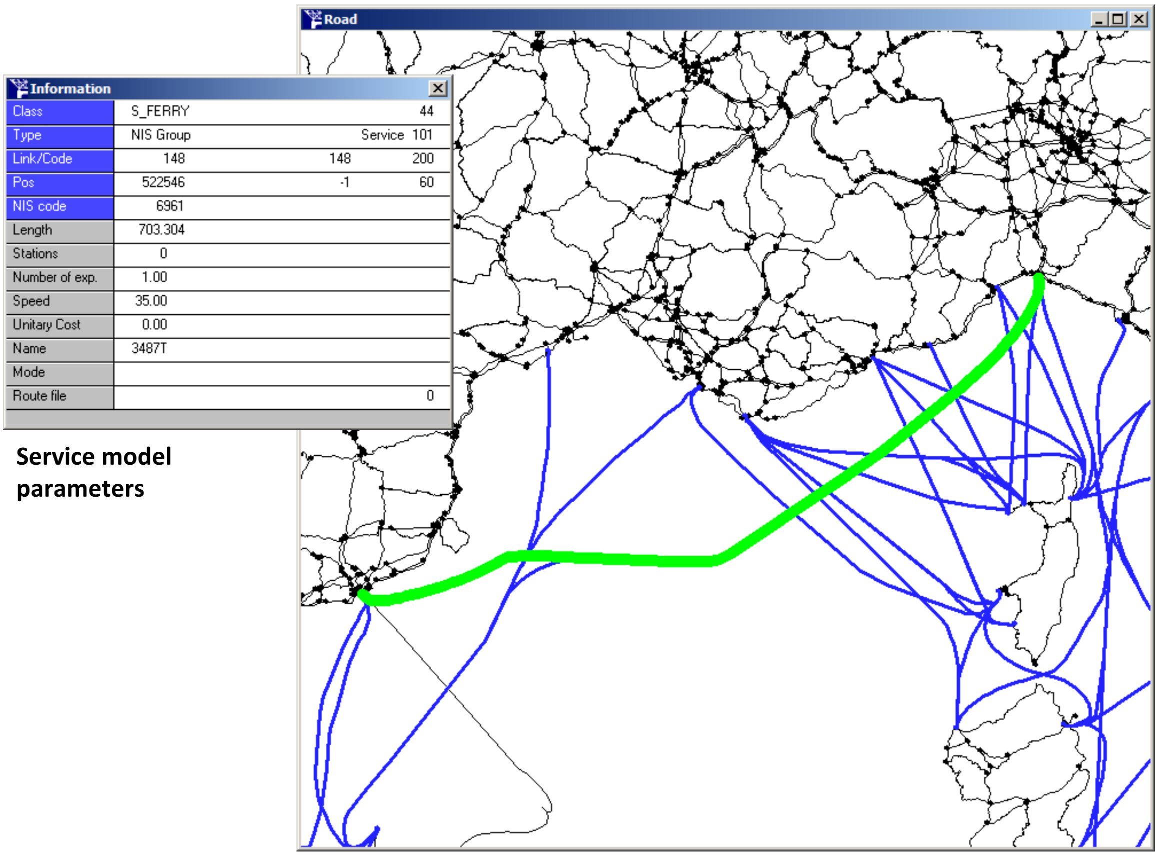


Figure 3-10 Example of ferry services in the Mediterranean

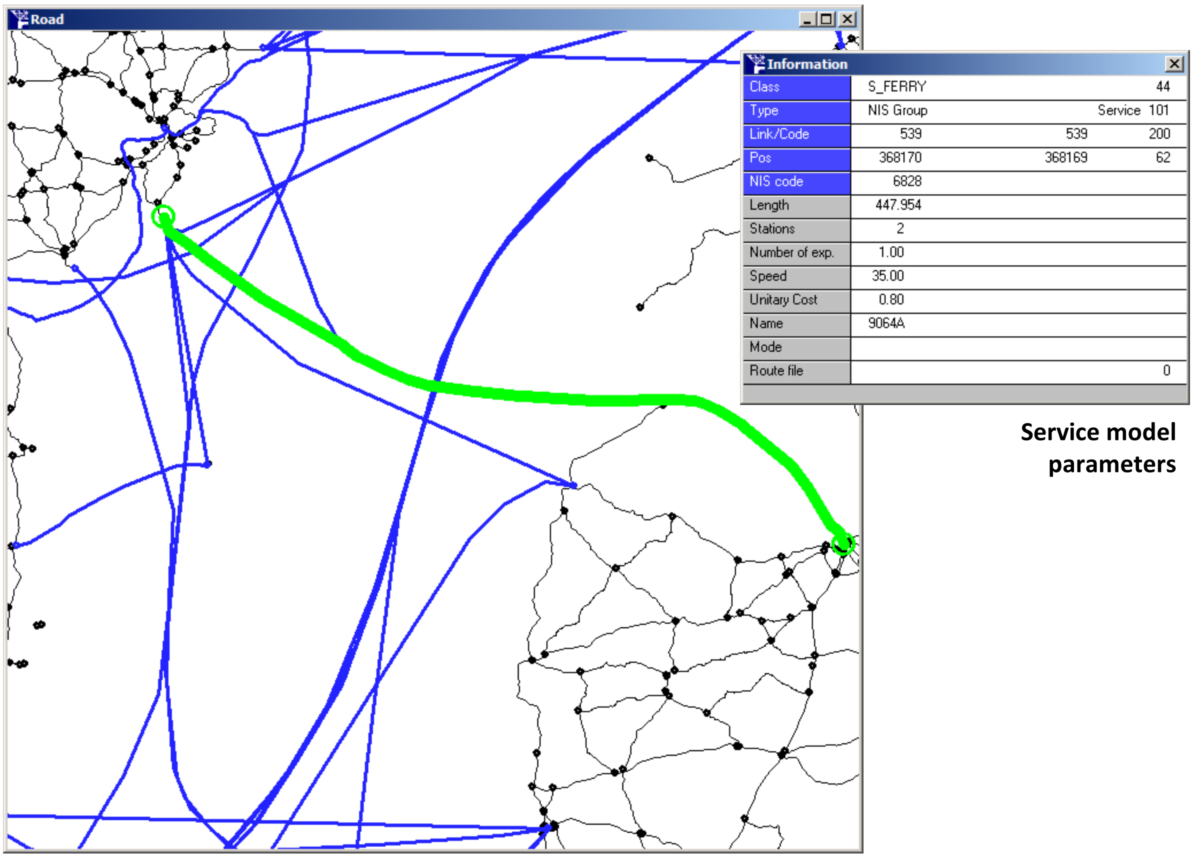


Figure 3-11 Example of ferry services in the Baltic

Air services

For air links, services have also been drawn over the existing links. While the TRANS-TOOLS air graph did not require it, a multi-modal graph needs additional parameters to properly regulate the different steps in an airplane journey involving transits in intermediate airports. In disposing of air services instead of just infrastructure links, paths between OD pairs can be determined more accurately, thanks to the possibility to introduce waiting times and transit times at airports, and penalising airport scales. In doing so, the model is prevented from concatenating several airplane services when not necessary, as the model now perceives the costs of enchaining several services.

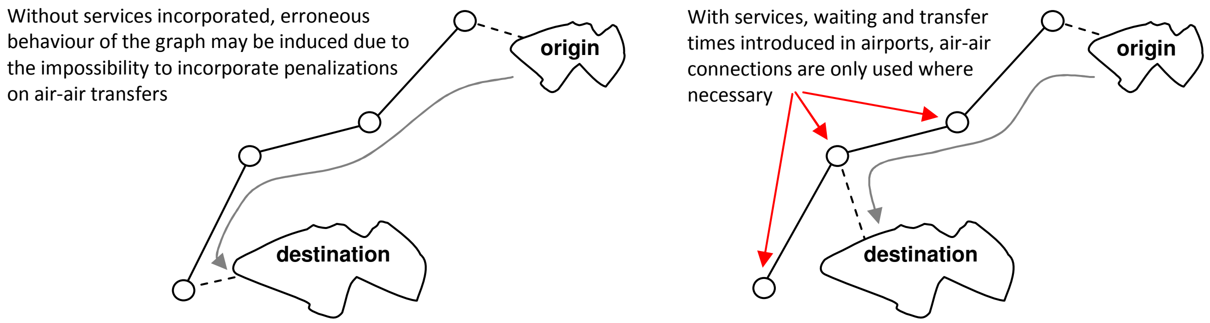
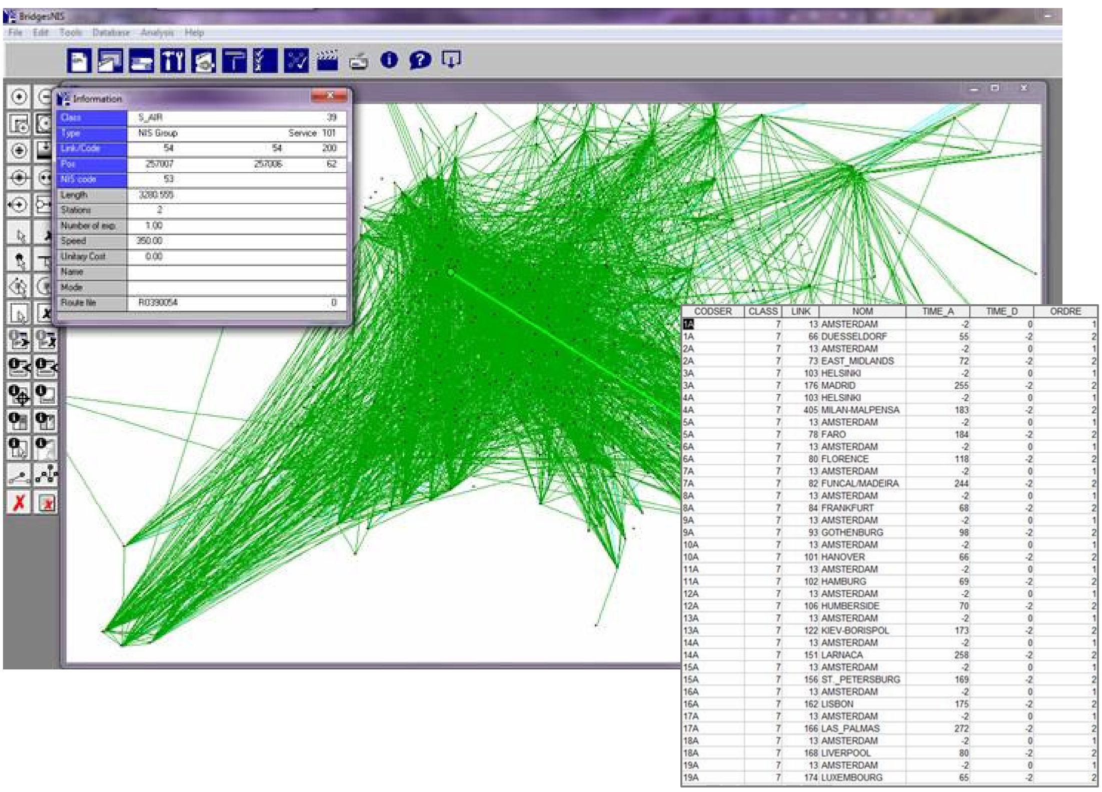


Figure 3-12 A service modelling approach for the air mode

A table with air services was created, with a total amount of services of 6,250 (2 for each pair of airports, 3,125 on each direction). Services were created considering a "smart behaviour" of the user, i.e. the user will plan his trip in advance in order to limit the elapsed time between the arrival in the waiting room of the airport and the airplane take-off. Check-in, security and passport control time requirements are synthetically considered in airport access connector speeds. Arrival times at destination have been determined in terms of the link length and an average airplane speed.



CODSER	CLASS	LINK	NOM	TIME_A	TIME_D	ORDRE
1A	7	13	AMSTERDAM	-2	0	1
1A	7	66	DUESSELDORF	55	-2	2
2A	7	13	AMSTERDAM	-2	0	1
2A	7	73	EAST_MIDLANDS	72	-2	2
3A	7	103	HELSINKI	-2	0	1
3A	7	176	MADRID	255	-2	2
4A	7	103	HELSINKI	-2	0	1
4A	7	405	MILAN-MALPENSA	183	-2	2
5A	7	13	AMSTERDAM	-2	0	1
5A	7	78	FARO	184	-2	2
6A	7	13	AMSTERDAM	-2	0	1
6A	7	80	FLORENCE	118	-2	2
7A	7	13	AMSTERDAM	-2	0	1
7A	7	82	FUNCAL/MADEIRA	244	-2	2
8A	7	13	AMSTERDAM	-2	0	1
8A	7	84	FRANKFURT	68	-2	2
9A	7	13	AMSTERDAM	-2	0	1
9A	7	93	GOTHENBURG	98	-2	2
10A	7	13	AMSTERDAM	-2	0	1
10A	7	101	HANOVER	66	-2	2
11A	7	13	AMSTERDAM	-2	0	1
11A	7	102	HAMBURG	69	-2	2
12A	7	13	AMSTERDAM	-2	0	1
12A	7	106	HUMBERSIDE	70	-2	2
13A	7	13	AMSTERDAM	-2	0	1
13A	7	122	KIEV-BORISPOL	173	-2	2
14A	7	13	AMSTERDAM	-2	0	1
14A	7	151	LARNACA	258	-2	2
15A	7	13	AMSTERDAM	-2	0	1
15A	7	156	ST._PETERSBURG	169	-2	2
16A	7	13	AMSTERDAM	-2	0	1
16A	7	162	LISBON	175	-2	2
17A	7	13	AMSTERDAM	-2	0	1
17A	7	166	LAS_PALMAS	272	-2	2
18A	7	13	AMSTERDAM	-2	0	1
18A	7	168	LIVERPOOL	80	-2	2
19A	7	13	AMSTERDAM	-2	0	1
19A	7	174	LUXEMBOURG	65	-2	2

Figure 3-13 Air service modelling in the IC graph

3.5 Refining NUTS3 Centroids

The basic set of cities picked as a base layer for the IC Module correspond to TRANS-TOOLS', basically to NUTS3 centroids for EU-27 countries. These centroids are located in the geometric centre of NUTS3 polygons, giving important connector lengths to transport networks in some cases. They contain all condensed socioeconomic and transport information for their NUTS3 entity.

In order to improve the graph, and in the light of additional requirements by a multi-modal graph, the position of centroids was refined, moving them from polygon centres to real geographic positions. By doing so, connectors to transport networks adapt better to reality. This is a matter of substantial importance in the INTERCONNECT project, as these connectors represent the travel interface between long-distance transport networks and short-distance local networks, corresponding therefore in fact to interconnections.

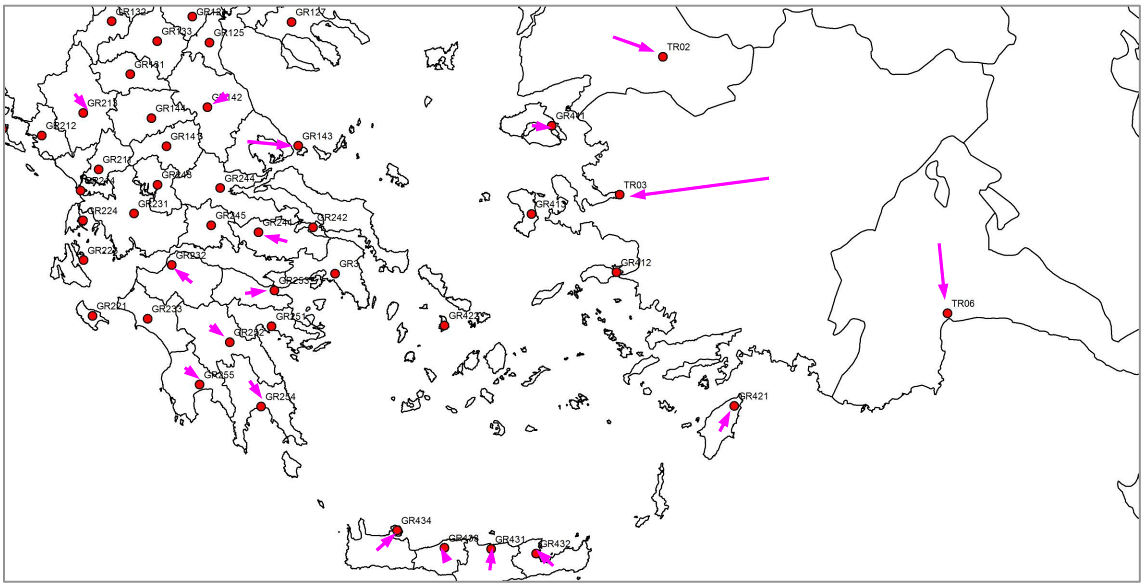


Figure 3-14 Refining position of NUTS3 centroids: from geometric centres to geographic locations

New cities were incorporated in the graph in the Balkans region where they were previously missing.

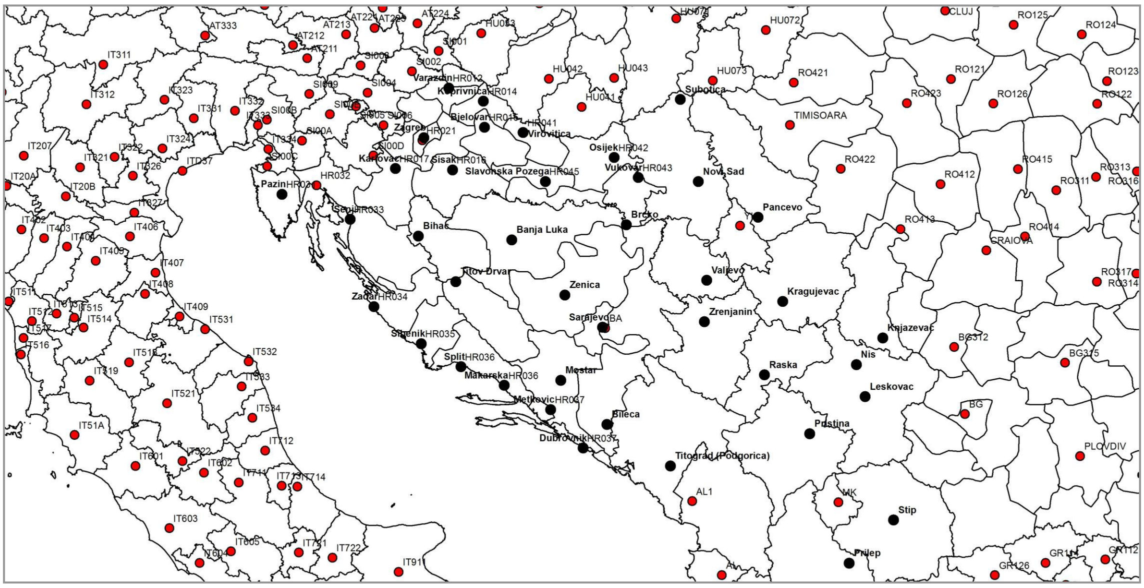


Figure 3-15 Incorporating missing city centroids in the Balkans

3.6 GENERATING CONNECTORS BETWEEN NETWORKS, AND WITH CITIES

With all transport terminals located in the graph (rail stations, airports and ferry terminals), and with city centroids relocated from geometrical NUTS3 polygon centres to precise geographic locations of NUTS3 capitals, connectors are required to interconnect all networks together and obtain a fully multi-modal graph.

Connectors are generated automatically. Each city or transport terminal has a maximum of one connector to each of the other transport networks. Connector lengths are limited within a reasonable range, so not every transport terminal may be connected to other transport networks, if the terminal is located too far (i.e. some airports may not have rail connections).

The following limits are imposed in order to prevent unrealistic connections of networks.

Table 3-1 Limitations to connector creation in the graph

Parameter	Maximal distance to create a connector to network
City connectors to transport terminals	
to rail stations	< 15 km
to road network	no maximal distance
Transport terminals to other transport networks	
airport to road network	< 5 km
airport to rail station	< 10 km
rail station to road network	no maximal distance

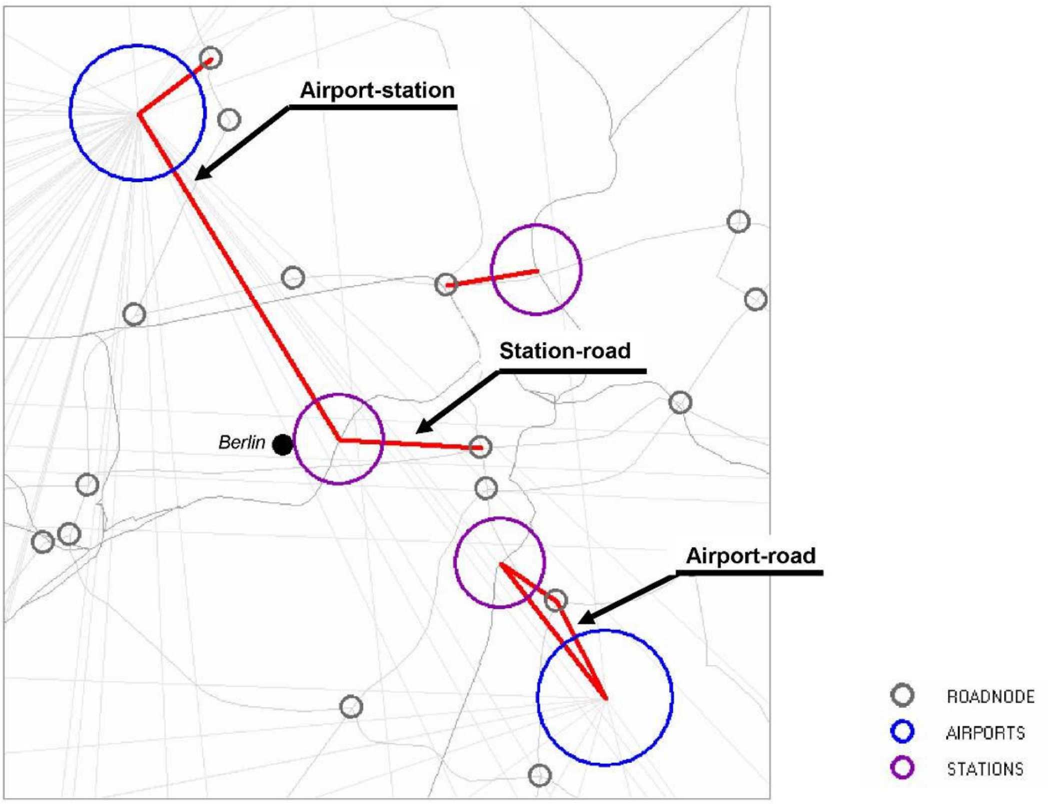
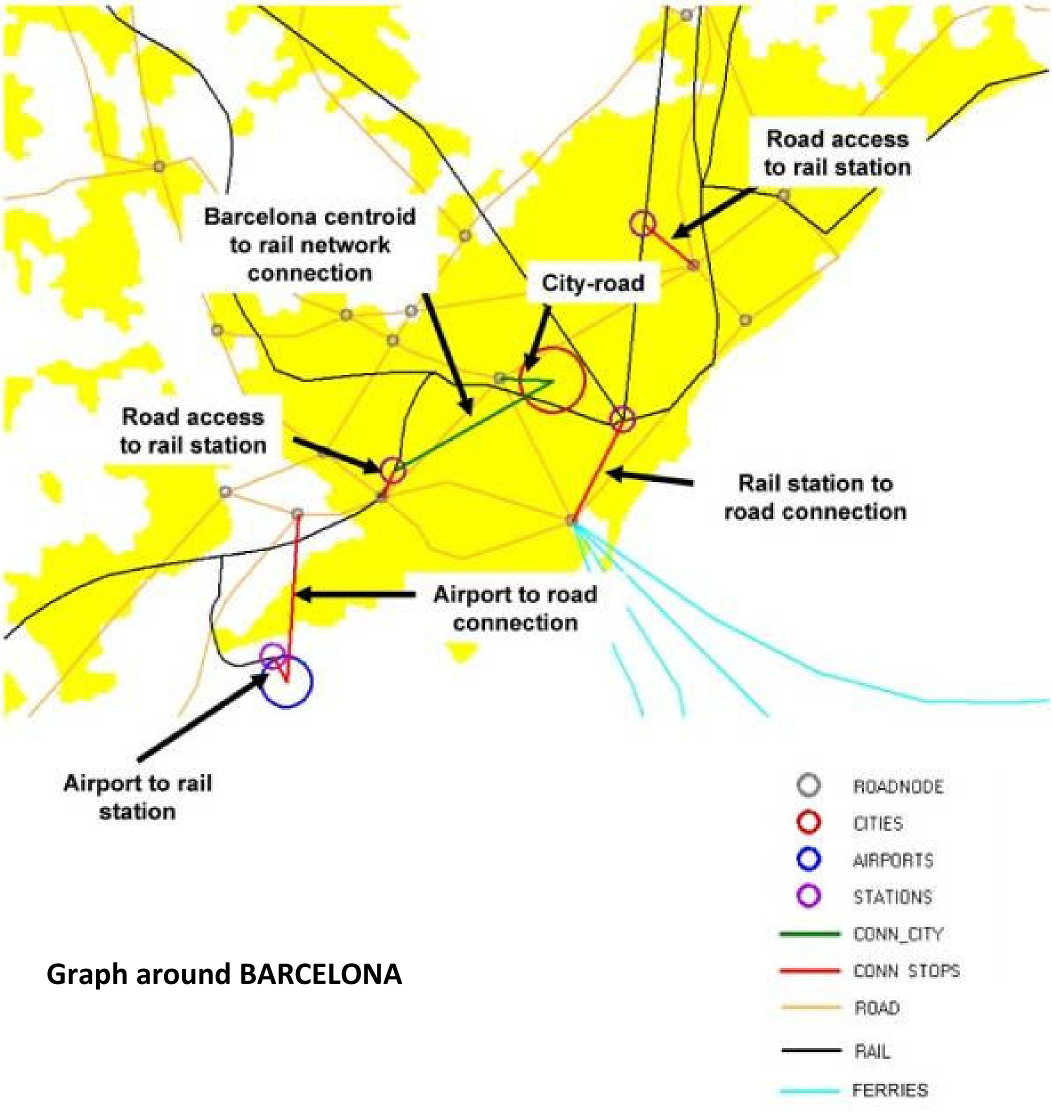


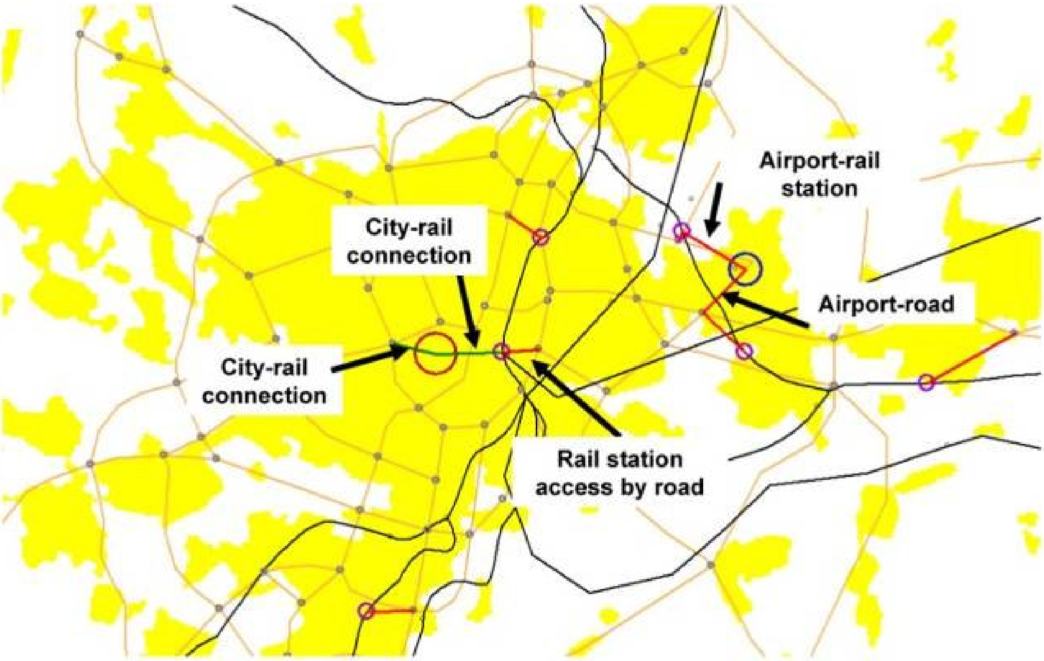
Figure 3-16 Structure of connectors from cities and transport terminals to other transport networks

This procedure implies a substantial simplification of reality. When automating the process of creation of connectors, these are created in all those situations where conditions in reality are sufficient to allow a connection, which is when networks exist and are close enough to each other. However, in reality the connection may or may not exist. To limit the impact of this, a review of the largest transport terminals in Europe was undertaken to correct maladjustments.

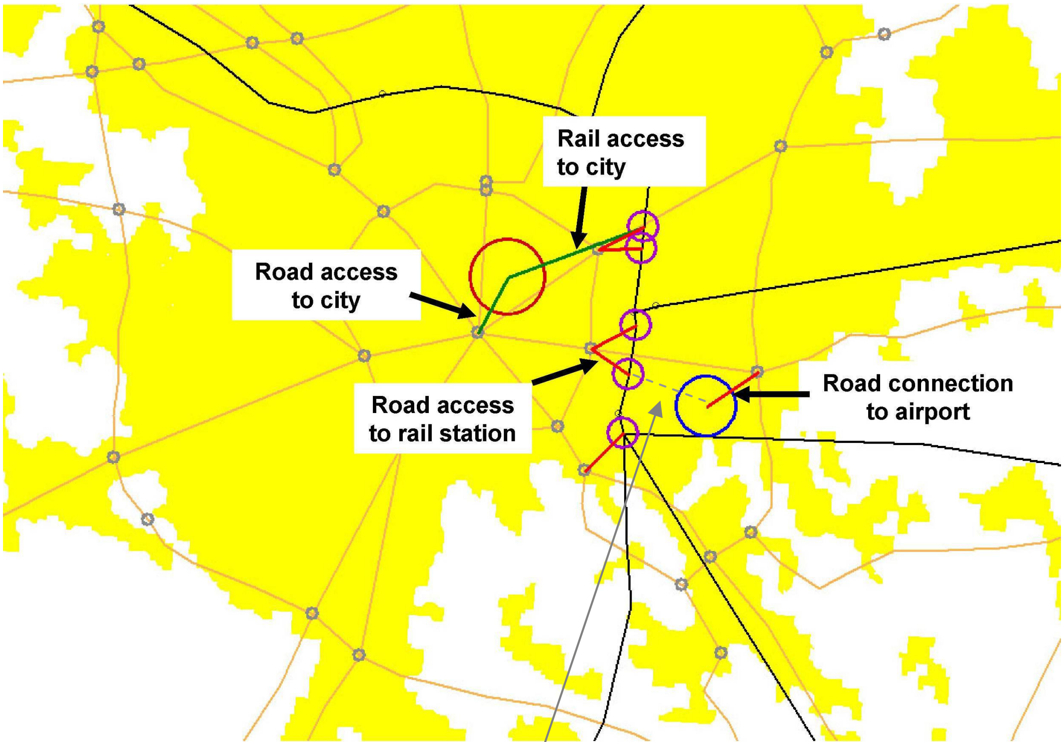
A close zoom to the graph around urban areas allows analysing the resulting structure of interconnections between several transport networks. Segments linking rail stations to airports represent access to airports by train (either long-distance or local trains depending on which segments are being considered). These links contain information on travel-time length, a parameter which considers the Euclidean length of the segment plus other penalties to be imposed such as transit walking time or check-in time requirements.



Graph around BARCELONA

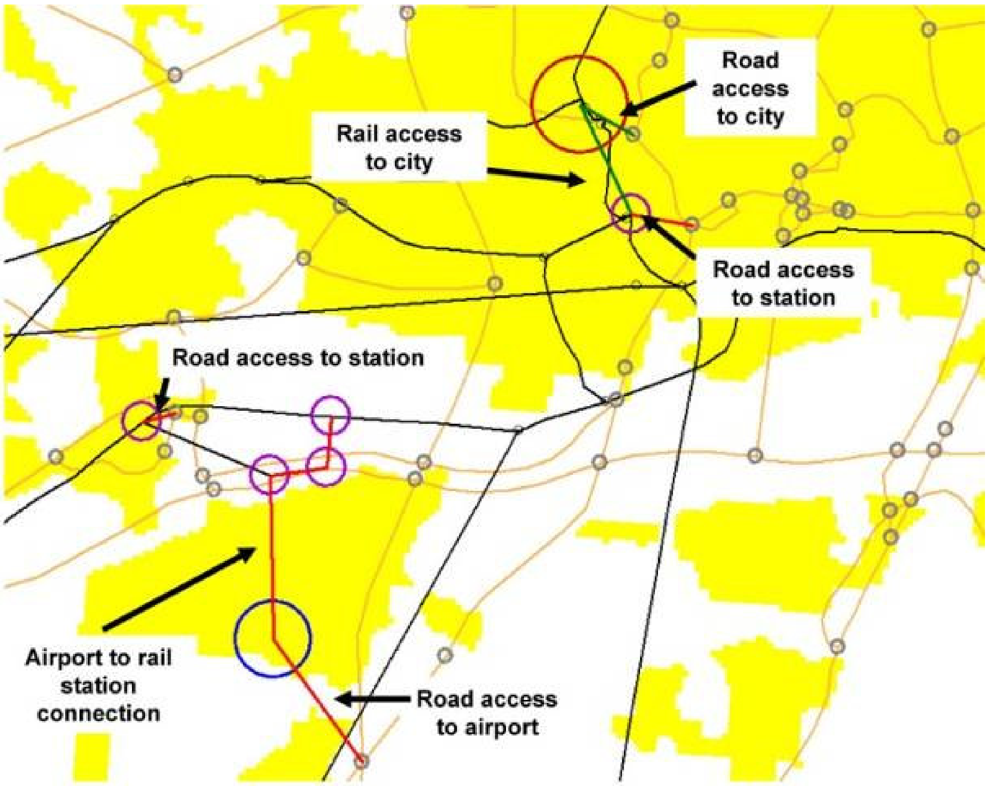


Graph around MADRID

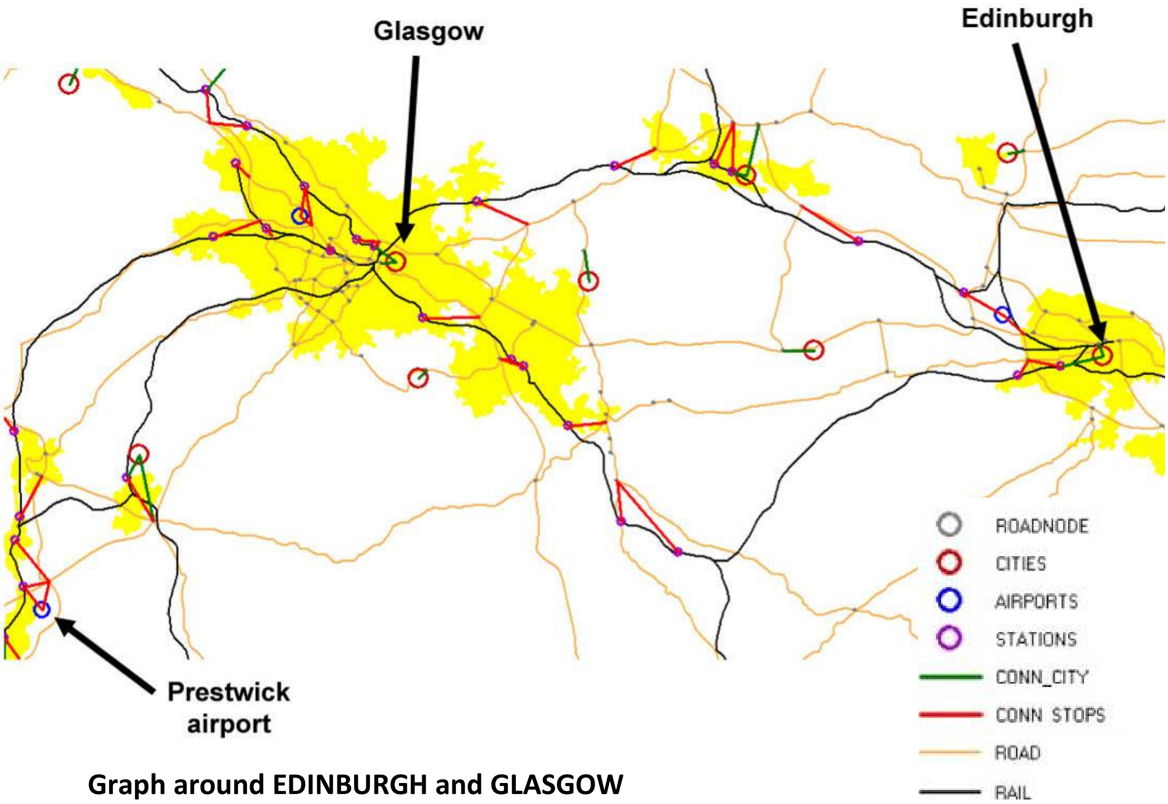


Graph around MILAN

Although a connector was automatically generated between Linate airport and the rail network, posterior revision of major transport terminals led to removal of this connection as it doesn't exist in reality.



Graph around FRANKFURT



Graph around EDINBURGH and GLASGOW

Figure 3-17 Zoom of the graph in Barcelona, Madrid, Milan, Frankfurt and Scotland, showing interconnections of networks (road, rail, air)

3.7 VALIDATION OF THE MULTI-MODAL GRAPH

In the process of building the IC multi-modal graph, shortest-path assignments in travel time were undertaken for several different and representative trips within the European space, to analyse the behaviour of the graph, detect errors (e.g. disconnected links and transport terminals, corrupt interconnections) and determine ways for further improvement.

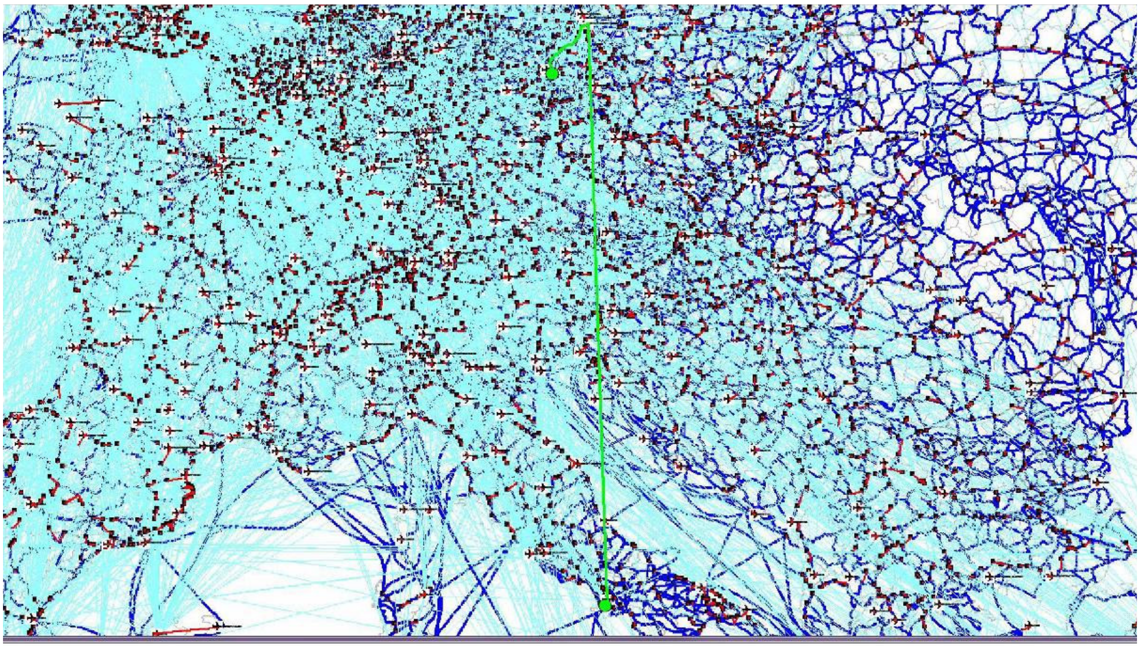
For each assignment, verisimilitude of the multi-modal chain was observed qualitatively in relation to modal choices and trip paths.

In this process, inaccurate behaviours were detected for the air mode, as no penalties had been established in transferring from one air link onto the next. This was the fact that led to the decision of altering the air network organisation by switching from a mere infrastructure graph scheme to a public transport scheme with service tables, as explained in previous chapters.

It was also at this stage that ferry services were separated from road networks, and that a similar approach to air mode based on service tables was introduced.

The tables shown below are examples of shortest path computations with several European city pairs, showing the resulting path and representing the resulting modal chains. In the left side of the table a complete summary itinerary is shown, whereas in the right side, connectors are included in feeding transport modes.

Table 3-2 Leipzig-Naples shortest path trip in IC multi-modal graph



Modal chain		Distance (Km)	Time (min)	Mode IVTT	Distance (Km)	Time (min)
Mode 1	City-Rail	0,08%	5,40%	Rail	11,10%	19,92%
Mode 2	Rail	11,04%	16,69%			
Mode 3	Airport access	0,09%	2,70%	Air	88,04%	72,19%
Mode 4	Air	87,55%	60,48%			
Mode 5	Airport Egress	0,02%	2,71%			
Mode 6	Road	0,86%	6,61%	Road	0,86%	7,89%
Mode 7	Road-City	0,36%	5,40%			
Total		100,00%	100,00%	Total	100,00%	100,00%

The example above shows that to travel from Leipzig (Germany) to Naples (Italy), the chosen path is mainly composed by an air segment between Berlin and Naples representing 86% of trip distance and the 60% of travel time. The rail mode is used from Leipzig to Berlin, while access to Naples form the airport is done on a brief road segment. Access and egress from transport terminals and cities represent in this assignment only 1.4% of total trip distance but 22.8% of total travel time.

Table 3-3 Leipzig-Uppsala shortest path trip in IC multi-modal graph

Modal chain		Distance (Km)	Time (min)	Mode IVTT	Distance (Km)	Time (min)
Mode 1	City-Road	0,07%	4,70%	Road	**11,80%**	**23,18%**
Mode 2	Road	11,70%	19,10%			
Mode 3	Road-Rail	0,07%	0,49%	Rail	**7,63%**	**11,95%**
Mode 4	Rail	7,57%	9,84%			
Mode 5	Airport access	0,26%	2,35%	Air	**78,27%**	**59,62%**
Mode 6	Air	77,60%	49,13%			
Mode 7	Airport Egress	0,31%	5,36%			
Mode 8	Road	2,27%	4,33%	Road	**2,29%**	**5,26%**
Mode 9	Road-City	0,14%	4,70%			
Total		100,00%	100,00%	Total	100,00%	100,00%

Table 3-4 Leipzig-Mérida shortest path trip in IC multi-modal graph

Modal chain		Distance (Km)	Time (min)	Mode IVTT	Distance (Km)	Time (min)
Mode 1	City-Rail	0,05%	3,68%	Rail	**6,44%**	**12,80%**
Mode 2	Rail	6,42%	11,38%			
Mode 3	Airport access	0,05%	1,84%	Air	**74,86%**	**55,74%**
Mode 4	Air	74,66%	49,58%			
Mode 5	Airport Egress	0,10%	1,84%			
Mode 6	Road	0,36%	0,87%	Road	**0,36%**	**0,98%**
Mode 7	Rail	18,30%	27,11%	Rail	**18,34%**	**30,48%**
Mode 8	Rail-City	0,06%	3,68%			
Total		100,00%	100,00%	Total	100,00%	100,00%

Table 3-5 London-Leipzig shortest path trip in IC multi-modal graph

Modal chain		Distance (Km)	Time (min)	Mode IVTT	Distance (Km)	Time (min)
Mode 1	City-Rail	0,13%	6,70%	Rail	**1,77%**	**1,94%**
Mode 2	Rail	1,76%	1,64%			
Mode 3	Airport access	0,04%	3,35%	Air	**91,99%**	**80,70%**
Mode 4	Air	91,41%	68,22%			
Mode 5	Airport Egress	0,24%	3,35%			
Mode 6	Rail	6,20%	14,68%	Rail	**6,24%**	**17,36%**
Mode 7	Rail-City	0,22%	2,05%			
Total		100,00%	100,00%	Total	**100,00%**	**100,00%**

Table 3-6 Vinnytsya-Leipzig shortest path trip in IC multi-modal graph

Modal chain		Distance (Km)	Time (min)	Main mode IVTT	Distance (Km)	Time (min)
Mode 1	Egress city	0,06%	3,09%	Rail	0,77%	0,83%
Mode 2	Rail	0,77%	0,76%			
Mode 3	Airport access	0,02%	1,55%	Air	84,71%	66,67%
Mode 4	Airport	17,32%	24,27%			
Mode 5	Airport	67,07%	36,22%			
Mode 6	Aiport egress	0,23%	1,54%			
Mode 7	Road	14,46%	29,48%	Road	14,52%	32,49%
Mode 8	Road-City	0,07%	3,09%			
Total		100,00%	100,00%	Total	100,00%	100,00%

4 DEVELOPMENT OF THE IC MODULE

4.1 OVERVIEW

The IC Module is a tool to perform the mode choice and assignment steps of the classical four-step models, simultaneously on a multi-modal graph following the *supernetwork* approach. The IC Module uses OD matrices produced by TRANS-TOOLS, resulting from the generation and distribution steps of the model, and internal parameters of the IC Module have been adjusted in a process of validation to fit TRANS-TOOLS outputs: as the module uses its OD matrices it is assumed that the module should return compatible results with this model.

Figure 4-1 provides the framework of operation of the IC Module. Each of the processes will be developed in depth in the following sections.

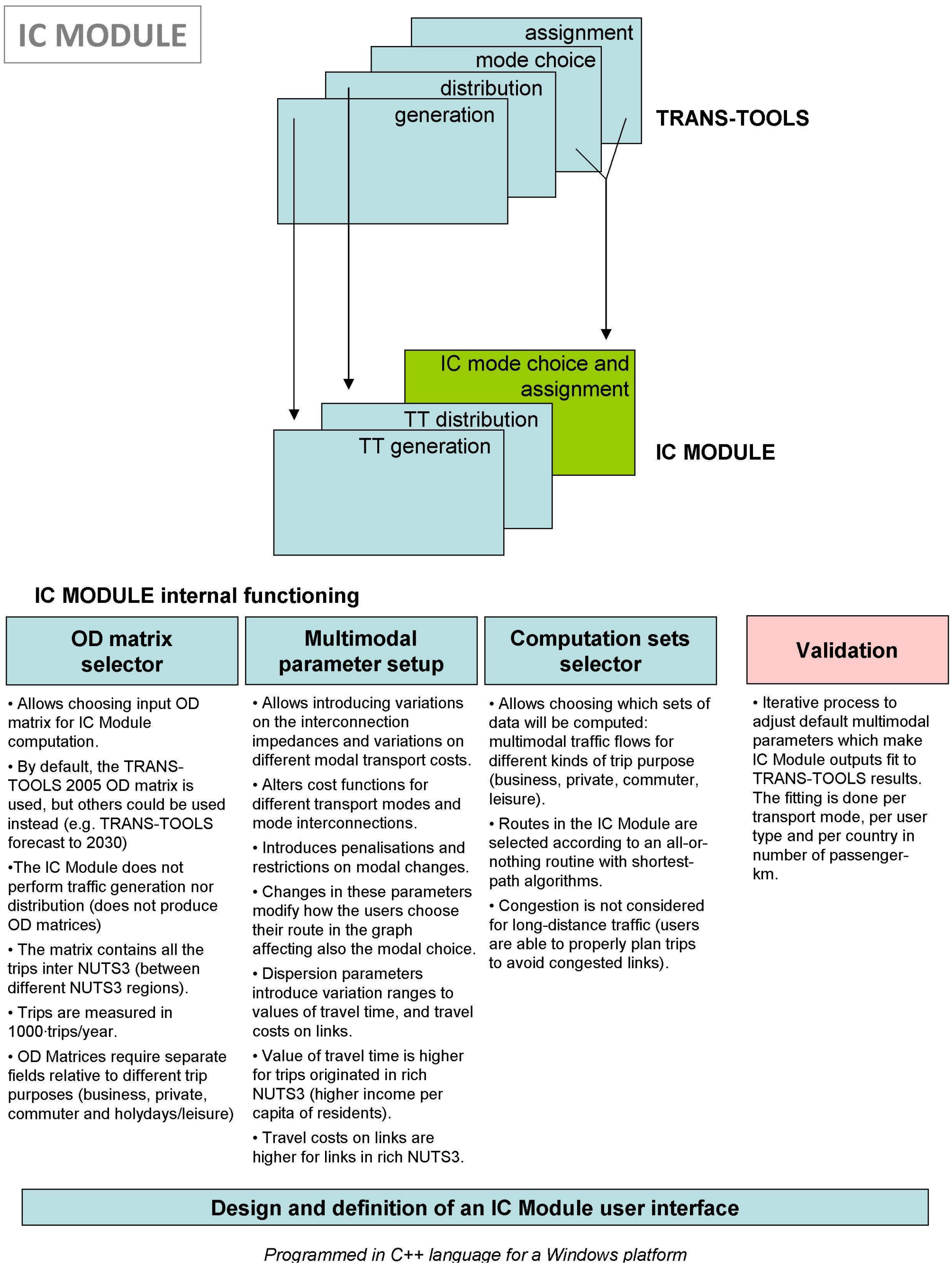


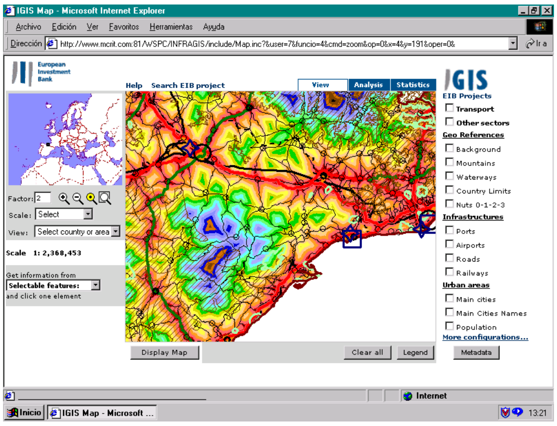
Figure 4-1 INTERCONNECT strategy to construct the IC Module

4.2 SOFTWARE OF THE IC MODULE

The IC Module has been developed in C++ on the BRIDGES platform.

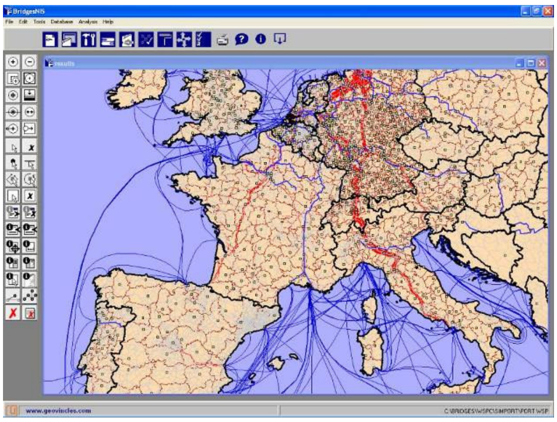
Bridges was developed within the Strategic Transport element of the 4th Framework Programme, between 1997 and 1999. The main goal of developing BRIDGES software technology was to empower policy-makers - in particular those responsible for European transport policies - with friendly and productive access to advanced decision-making tools, such as transport models and harmonised databases. BRIDGES research was defined in the context of the ideal user requirements for a European Transport policy Information System (ETIS) and the problems and opportunities presented by already existing or expected software applications, data formats and transport strategic models needed to fulfil the user requirements of an ideal ETIS.

BRIDGES is a software technology for experts to develop open multi-software support systems, particularly in the field of strategic transport planning. As a "technology", BRIDGES includes a number of tools, methods and procedures for using them, and the overall scientific know-how and vision behind them. Resulting from the use of such a technology, several support systems have already been developed and are operational in the hands of transport planners and decision-makers at European and local level (e.g. IGIS for the European Investment Bank; TEN-CONNECT, ASSEMBLING, Phare SPESP tools for the EC; ATMAX, SIMCAT, SIMPORT, BRAX, SIMU, SIET and others for different local and regional planning administrations). Even if none of these applications cover the whole range of BRIDGES capabilities, in total, they demonstrate the usefulness of BRIDGES research outputs[5].

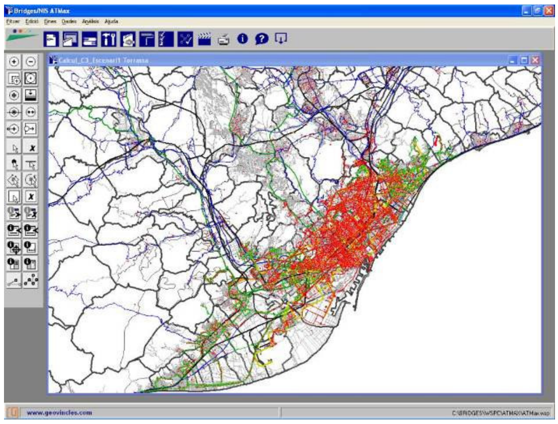


IGIS (IconGIS) application for the EIB, 2004

ASSEMBLING KTEN application for the EC, 2000



DESTIN application within the INCO-MED line of the 5th Framework Programme, 2005



ATMAX application for the Barcelona Metropolitan Transport Association, 2003

Figure 4-2 Applications of the BRIDGES technology since the late 90s

5 Once the research was formally over in terms of development and internal testing, all successive BRIDGES applications have been financed or co-financed by BRIDGES partners alone, independently from the 4th Framework Programme. This customising and testing process following real user demands, carried out after research, is consistent with the pre-commercial and pre-competitive character of the 4th Framework Programme.

BRIDGES technology is built on the Windows environment and programmed in C++ language with complementary Visual Basic routines. The main BRIDGES technology components are:

- Generalised Transport Format (GTF): A proposed standard data format for transport database exchange, aimed at the transport forecast and evaluation models area.
- GTF/Arcinfo Translator (GTF/GIS): An application for transferring data from Arcinfo GIS formats to a GIS version of GTF.
- Expert System/Decision Support System (ES/DSS): An application to define rules and criteria to simplify the interface between end users and complex transport models.
- NISystem (NIS): A set of routines able to handle advanced transport topologies and carry on graphs analysis.
- Communication System (CS): A technology to manage the transmission of commands between independent applications integrated into an open system by the use of multiple customised user interfaces (user work spaces) in an Intranet environment.

The GTF (Generalised Transport Format) data model is able to deal with the complex graph structures and topologies used by transport models (including demand, supply and specific modelling aspects). The defined entities are node, link, interchange, route service, zone, main mode, persons/goods, carrier, modal stage, and flow/movement. The GTF data model includes the categorisation of relationships. The adopted GTF format description is public, compatible with international standards (UN/GESMES) and complementary to other database and GIS standard formats. It includes both topological information related to transport entities and the statistical data attached to them.

The GTF/GIS data model is based on adding transport topology to conventional GIS structures, according to the GTF definition (e.g. routes-route segments, stops). The format description is very intuitive with simple ASCII files. GTF/GIS entities are compatible with GTF but can enrich public transport entities. Arc/Info, one of the most advanced GIS, is unable to handle the complex network topologies required for transport modelling (e.g. defining centroids' connectors, public transport routes and services etc.). Because of the high GIS productivity of Arc/Info tool, and its widespread use within European institutions, a specific "bridge" from Arc/Info's encrypted data format to GTF was developed. The translator converts the Arc/Info GIS format into GTF/GIS by adding transport topology. A GTF/GIS-Arc/Info translator was programmed based on MapObjects libraries, the only way to overcome the Arc/Info encrypted data format. The unavoidable use of such libraries makes the translator not totally royalties free.

ES/DDS (Expert System/Decision Support System) was developed and integrated into the BRIDGES toolbox to provide a tool to build intelligent translators between end users' questions and sophisticated transport model outputs. The BRIDGES Expert System helps users to establish legitimate queries to models and interpret the model results. ES/DSS architecture is composed of a user-interface (Object Oriented Interface, OOI) and the Expert System (ES). The main task of the Expert System (ES) is to analyse user queries, decompose them into queries to be passed on to other modules, and to combine results into a meaningful form for the user to understand.

NISystem (Bridges Core Utilities, Network Information System) has been developed as a set of external stand-alone applications to be linked to any system by the BRIDGES Communication System, just like any other stand alone application. This guarantees that systems developed by BRIDGES are fully scalable and independent even from BRIDGES own Core Utilities. The goal of NISystem Core Utilities is to complement transport modelling, GIS and DBS applications with missing utilities. The NISystem provides, among others, routines for harmonising heterogeneous transport oriented databases and graphs, graphic management routines for CAD, desktop mapping and GIS, database management applications, operational research and statistical algorithms for analysing transport databases.

The CS (BRIDGES Communication System) harnesses OLE/COM technology to integrate stand-alone applications. The BRIDGES CS is based on managing flows of command messages between stand alone applications. BRIDGES CS was designed to work in an Intranet, but its decentralised architecture allows the addition of a new bridge to the Internet.