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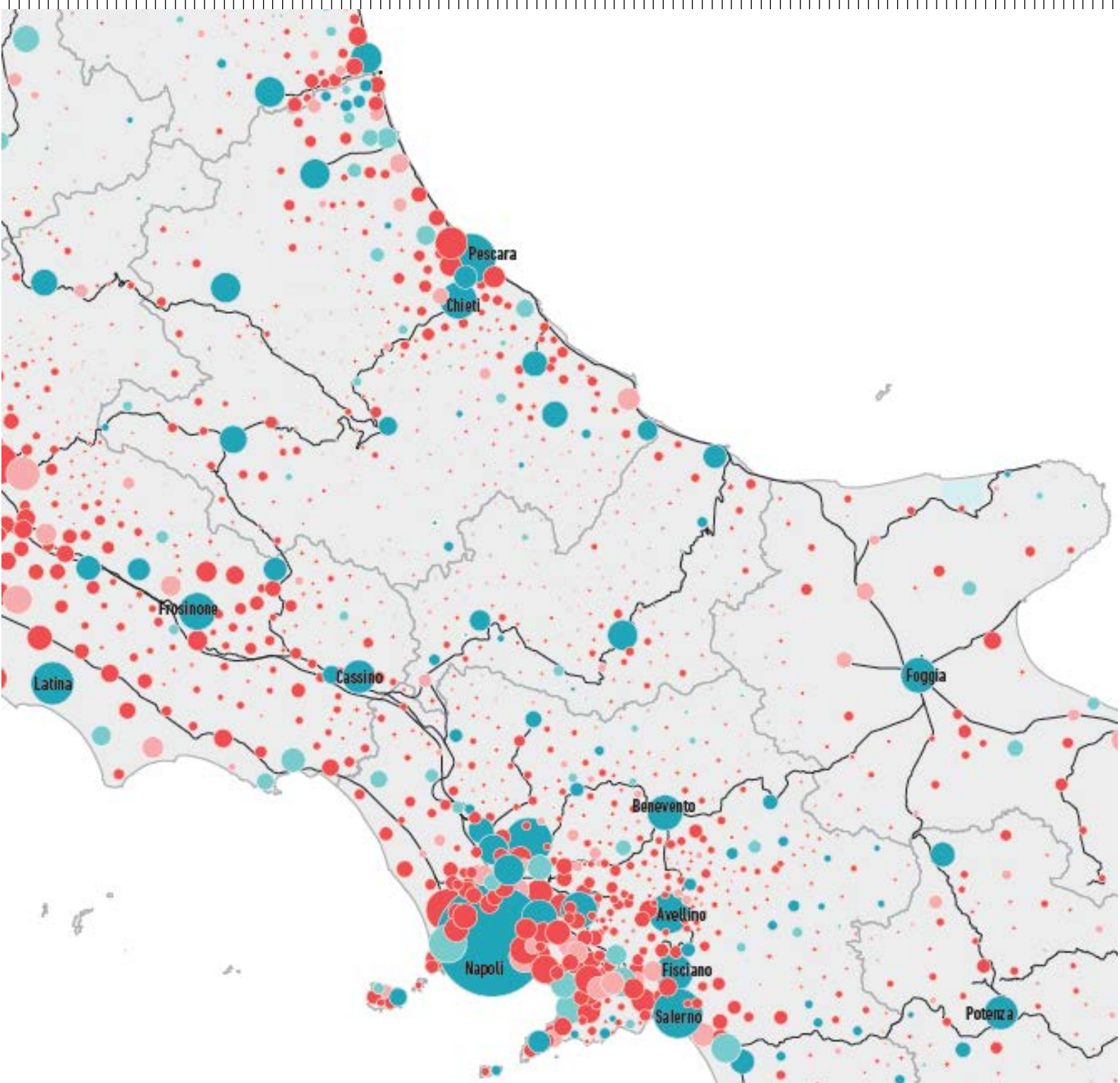
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LABORATORIO DI POLITICA DEI TRASPORTI  
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# QUAINT QUANTITATIVE ANALYSIS OF ITALIAN NATIONAL TRANSPORT

D3 - FINAL REPORT – 30/03/2019

**Q** QUANTITATIVE  
ANALYSIS  
ITALIAN  
NATIONAL  
TRANSPORT



**QUAINT - QUantitative Analysis of Italian National Transport**  
D3 – Final Report – 30/03/2019

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Il presente rapporto contiene la descrizione delle attività del progetto QUAINT (MIUR, finanziamento SIR, rif.: RBSI14JR1Z), di cui il prof. Paolo Beria è titolare.

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## Table of contents

1.	Introduction to QUAINT .....	5
1.1	Aims .....	5
1.2	Background .....	5
2.	Database contents and structure.....	7
2.1	Introduction.....	7
2.2	Demographics.....	7
2.3	Infrastructure .....	12
2.3.1	Road network.....	15
2.3.2	Ferries .....	22
2.3.3	Rail network.....	22
2.4	Land use.....	24
2.5	Timetables database (“BDO”).....	26
2.5.1	Sources.....	26
2.5.2	General structure of the supply module.....	26
2.5.3	Internal structure of BDO.....	27
2.5.4	Flowcharts .....	31
2.6	Traffic counts database (“POSTRA”) .....	33
2.6.1	Sources.....	33
2.6.2	POSTRA structure .....	35
2.6.3	Extraction and use.....	37
2.7	Other modes demand database (“CONDA”) .....	37
2.7.1	Air transport: route flows database.....	38
2.7.1	Rail transport: sources and type of data.....	39
2.7.2	Maritime transport: sources and type of data .....	39
2.8	Fares .....	40
2.8.1	Data sources.....	40
2.8.2	An analysis of prices .....	43
2.8.3	Fare functions for the model .....	46
2.9	Alternative mobility (Blablacar, sharing, cycling).....	56
2.10	Tourism .....	56
2.11	Health and Student mobility.....	58
3.	The structure of the model .....	61

3.1	General structure and state of the art .....	61
3.2	Zoning.....	62
3.3	Connectors .....	65
3.4	Road Graph .....	66
3.5	BDO procedures and public transport graph .....	67
3.6	Generalised cost calculation.....	68
3.7	Frequency-based graph and Hypergraph.....	71
3.8	Mobility demand modelling .....	78
3.8.1	General structure of the model .....	78
3.8.2	Passenger demand step 1: generation.....	81
3.8.3	Passenger demand step 2: distribution.....	81
3.8.4	Passenger demand step 3: modal split.....	82
3.8.5	Highway assignment.....	83
3.8.6	Public transport assignment.....	83
4.	Results.....	84
4.1	Current scenario simulation .....	84
4.2	Calibration report.....	89
4.3	Accessibility.....	90
4.4	Scenario analysis: the potentialities of the model .....	92
4.1	Description of analysed scenarios .....	92
4.1.1	Fuel price increase.....	92
4.1.2	Highway pricing.....	93
4.1.3	Speed limitations.....	94
4.1.4	Rail prices.....	95
4.1.5	New infrastructure: completion of the A12 Tirrenica highway.....	95
4.1	Test Scenario 1 – Fuel price increase .....	96
4.2	Test Scenario 2 – Highway pricing .....	100
4.3	Test Scenario 3 – Speed limitations for environmental policies .....	104
5.	Bibliographical references.....	108

# 1. Introduction to QUAINT

The project QUAINT, which stands for “QUantitative Analysis of Italian National Transport plans and policies” is a research project aimed at filling the gap in the quantitative knowledge of Italian transport system, in particular the long-distance segment. This segment is mostly unknown due both to the complexity of data collection, commercial sensitiveness, fragmentation of operators. On the other side, it is of primary interest in the planning of national transport investments, usually justified in terms of strategic impact on national mobility and accessibility.

## 1.1 Aims

The QUAINT research project aims at:

1. creating a **unique database of all Italian long distance transport components** (infrastructure, services, market conditions, demand);
2. developing a **quantitative and spatial tool** for the analysis of passenger long distance transport plans and policies and at the national level;
3. analysing the **existing situation**, through maps, simulations and complex accessibility indicators;
4. effectively visualise current transport trends and the effect of future policies, with the creation of an **Atlas of Italian transport**;
5. **evaluating a broad range of projects, plans and policies**, both included in current official planning or alternative. The assessment will consider many different terms (assessment of environmental, social and economic impacts and sustainability, spatial distribution of the effects, costs and benefits).

The innovations and impacts of the project are of different nature. Firstly, the project will build a comprehensive and huge database of transport sector, currently not existing in Italy. Secondly, a forefront tool for the detailed spatial analysis and assessment will be developed and used for the analysis of scenarios, plans and policies. In addition, numerous specific methodological innovations will be introduced: the construction of a multimodal timetables based hyper-graph, the direct connection between simulation model and economic assessment, the use of data mining techniques for market structure analysis, etc. Ultimately, the most interesting impact of the project lays in creating an independent tool to ground the public debate and possibly support transport knowledge and decisions.

## 1.2 Background

Transport planning at any scale is commonly based, in many countries, on a deep knowledge of the current demand and on a detailed description of all dimensions of supply, namely infrastructure, services (for public transport) and market conditions.

However, in Italy, the national scale of transport is barely known and decisions are not based on comprehensive simulations of alternatives. Planning is often left to the infrastructure companies, being them public (FSI, for example) or private (Autostrade per l'Italia, for example). Moreover, the long distance mobility is not known as a whole, except for specific components such as commuters mobility (e.g. ISTAT) or air routes (e.g. ENAC or Assoaeroporti documents) or the aggregated data of the “Conto Nazionale Trasporti”. Consequently, a single-mode vision based on infrastructure investments is prevailing, ignoring the transport services supply and without a clear representation of the market structure. This causes the loss of the opportunities of a

multimodal approach and, moreover, of a more rich coordination of physical investments, technology and soft policies (pricing, etc.). Also scientific research is focusing on specific problems and tends to lack in comprehensiveness: the lack of data, except very aggregated measures or analyses of single cases, biases the approaches. Scholars are thus forced to concentrate on punctual problems, missing the opportunity to propose a general and independent vision.

Transport simulation tools, especially 4-steps models, are commonly used in many European countries to back the national transport planning decisions. Countries such as Netherland (“NMS” model), Sweden (“SAMPERS” model), UK (Department for Transport “National Transport Model”), base their transport planning on model simulations of the entire national transport system, usually with a multimodal perspective. More advanced applications, such as the Swedish planning documents (Jonsson et al, 2011) or the Eddington Transport Study (Eddington, 2006) explicitly use modelling to prioritise policies in terms of effectiveness, efficiency and also spatial and distributive impacts. A specific chapter is that of European simulation models, extremely complex and overcoming the sole transport sector involving economic activities and the land use component (STREAMS, TRANS-TOOLS, ASTRA, for example) (Schade, 2004; Fiorello et al 2010).

In Italy, the main modelling exercise at the national scale started in the 90s, with the first version of the SIMPT and some successive updates. The model was very ambitious and detailed, being capable of simulate both mobility choices and single trip choices. The model is based in the Ministry of Transport and it is currently under update. Some first elements are included in the recent *Documento di Economia e Finanza 2016*, where it is described as the basic tool for future transport planning documents.

A database similar to ours is also under construction internally in the Ferrovie dello Stato, under the name of SIMS. It collects all existing public databases and includes also classified company information. The database is not publicly available.

## 2. Database contents and structure

### 2.1 Introduction

A significant share of QUAINT work consisted in a huge work of data collection and homogenisation, to feed the model database. Such data come from various sources:

- i. Official statistical data (e.g. census)
- ii. Other databases (e.g. land use maps, air timetable)
- iii. Ad-hoc surveys (e.g. fares)
- iv. Manual input (e.g. rail timetables, coach timetables)
- v. Manual redraw of existing sources (e.g. rail and road networks are redrawn on the basis of Openstreetmap).

The data do not always refer exactly to the same period, but all information are available at least in the last three years-period (2015-2018), which can be considered as relatively homogeneous. However, given that the census OD data refer to 2011, some of the main dataset (e.g. rail supply) are available also for that year.

It is worth mentioning that the most challenging aspect was to guarantee homogeneity in the level of detail of all data, for the entire country. In other words, any information included in **the database is exhaustive of the phenomenon at the country-level**. For example, rail timetables include all passenger rail operators, all long-distance coach companies are included, land use maps and demographics cover the entire country, etc. In fact, typically local aspects are not included, such as the local public transport, for which the existence of hundreds of companies and regulators would have made virtually impossible any homogenisation exercise.

In the following, the main components of the database are described.

### 2.2 Demographics

Most of socio-demographic characteristics are provided, at the municipal level or at the micro-scale of census precincts by ISTAT (*General Census* and *Industry and Services Census*). These data are useful to “represent” the territory, but also to feed the generation and distribution steps of the modelling parts.

All census data have been collected since 1981, every 10 years. The most time consuming activity deals with the creation of correspondences among municipalities across the time series (**Comuni**), in case of merges or split of municipalities.

<i>Database</i>	<i>Description</i>	<i>Scale</i>	<i>Source</i>
<b>CensPop</b>	Census data (1981-1991-2001-2011)	Municipality	ISTAT
<b>PopEta</b>	Age classes (1982-2011)	Municipality	ISTAT
<b>AddCom2011</b>	Workplaces and Units per municipality and ATECO (2011)	Municipality	ISTAT (CIS 2011)
<b>SezCens</b>	Census data (2011, 2011)	Census precincts	ISTAT

Table 1. Socio-demographics databases

When clean and complete, the databases (see Table 1) is joined dynamically (i.e. by means of queries, for example on the year of data) to a geographical representation of 2011 territorial units, completed by some basic indicators (e.g. population density). Basic data (population, workers, etc.) are mapped both at the **census precinct** and **municipality** level. Further data (e.g. trip generation factors, GDP, etc.) exist only at the **municipality** level.

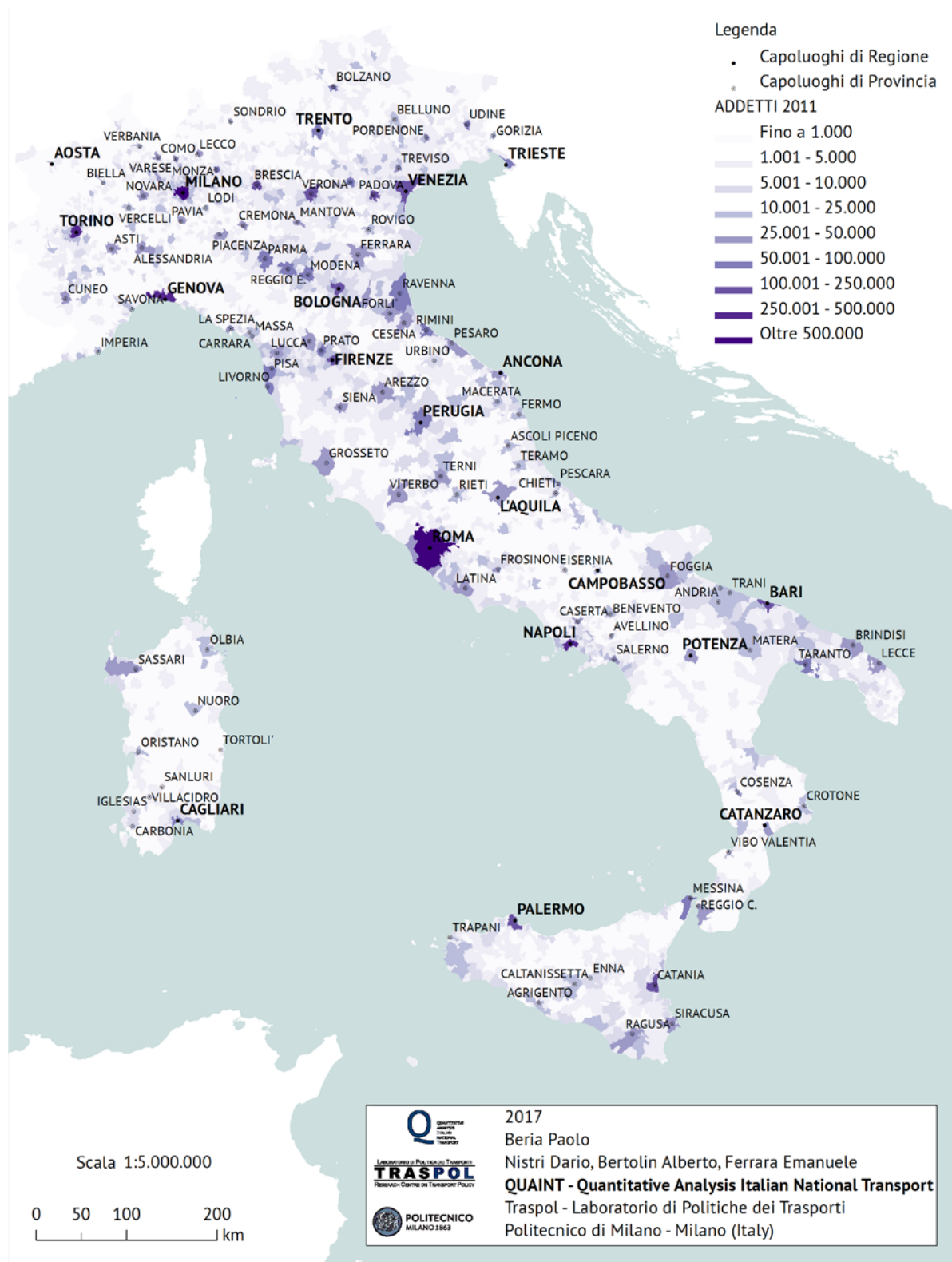
The following Table 2 details the single data included in the municipalities shapefile [BaseTerr](#). The next Table 3 merges into [SezCens](#) all data available at the census precinct. An example of the geographical representations is in Figure 1 and Figure 2.

<i>Field</i>	<i>Description</i>	<i>Source</i>
<b>PROCUM</b>	Municipality key	Istat 2011
<b>COMUNE</b>	Municipality name	Istat 2011
<b>COD_REG</b>	Region key	Istat 2011
<b>COD_PRO</b>	Province key	Istat 2011
<b>ADD_IND_71</b>	Number of workers in the industry sector - 1971	Industry Services Census 1971
<b>ADD_IND_81</b>	Number of workers in the industry sector - 1981	Industry Services Census 1981
<b>ADD_IND_91</b>	Number of workers in the industry sector - 1991	Industry Services Census 1991
<b>ADD_IND_01</b>	Number of workers in the industry sector - 2001	Industry Services Census 2001
<b>ADD_IND_11</b>	Number of workers in the industry sector - 2011	Industry Services Census 2011
<b>ADD_TER_71</b>	Number of workers in the service sector - 1971	Industry Services Census 1971
<b>ADD_TER_81</b>	Number of workers in the service sector - 1981	Industry Services Census 1981
<b>ADD_TER_91</b>	Number of workers in the service sector - 1991	Industry Services Census 1991
<b>ADD_TER_01</b>	Number of workers in the service sector - 2001	Industry Services Census 2001
<b>ADD_TER_11</b>	Number of workers in the service sector - 2011	Industry Services Census 2011
<b>COL_SEM</b>	Hectares for arable land	Agricultural Census 2010
<b>COL_VITE</b>	Hectares for permanent crops - vineyard	Agricultural Census 2010
<b>COL_LEGN</b>	Hectares for permanent crops	Agricultural Census 2010
...		Agricultural Census 2010
<b>COL_NOCOL</b>	Unused Hectares	Agricultural Census 2010
<b>ALL_BOV</b>	Total cattle	Agricultural Census 2010
<b>ALL_SUINI</b>	Total pigs	Agricultural Census 2010
<b>ALL_OVI</b>	Total sheep	Agricultural Census 2010
<b>ALL_AVI</b>	Total poultry	Agricultural Census 2010
<b>MAN_COND</b>	Number of farm holders	Agricultural Census 2010
<b>MAN_CON</b>	Number of relatives of the holder working in the farm	Agricultural Census 2010
...		
<b>nLETTI_ALB</b>	Number of beds in hotels	Istat Tourism Statistics 2011
<b>nLETTI_OTH</b>	Number of beds in other accommodations	Istat Tourism Statistics 2011
<b>nARR_i_ALB</b>	Number of arrivals in hotels - Italians	Istat Tourism Statistics 2011
<b>nARR_s_ALB</b>	Number of arrivals in hotels - Foreign	Istat Tourism Statistics 2011
<b>nARR_i_OTH</b>	Number of arrivals in other accommodations - Italians	Istat Tourism Statistics 2011
<b>nARR_s_OTH</b>	Number of arrivals in other accommodations - Foreign	Istat Tourism Statistics 2011
<b>nPRE_i_ALB</b>	Number or nights spent in hotels - Italians	Istat Tourism Statistics 2011

<b>nPRE_s_ALB</b>	Number or nights spent in hotels - Foreign	Istat Tourism Statistics 2011
<b>nPRE_i_OTH</b>	Number or nights spent in other accommodations - Italians	Istat Tourism Statistics 2011
<b>nPRE_s_OTH</b>	Number or nights spent in other accommodations - Foreign	Istat Tourism Statistics 2011
<b>Fam1p</b>	Number of families with 1 component	Population Housing Census 2011
<b>Fam2p</b>	Number of families with 2 components	Population Housing Census 2011
<b>Fam3p</b>	Number of families with 3 components	Population Housing Census 2011
<b>Fam4p</b>	Number of families with 4 components	Population Housing Census 2011
<b>Fam5p</b>	Number of families with 5 components	Population Housing Census 2011
<b>Fam6np</b>	Number of families with 6+ components	Population Housing Census 2011
<b>CASAL</b>	Number of homemakers	Population Housing Census 2011
<b>IN_CERCA</b>	Number of unemployed	Population Housing Census 2011
<b>RIT_LAV</b>	Number of retired	Population Housing Census 2011
<b>STUD</b>	Number of students	Population Housing Census 2011
<b>OCCUP</b>	Number of employed	Population Housing Census 2011
<b>ALTR_COND</b>	In other condition	Population Housing Census 2011
<b>OCC_AGR</b>	Number of employed in the agriculture sector	Population Housing Census 2011
<b>OCC_IND</b>	Number of employed in the industry sector	Population Housing Census 2011
<b>OCC_COM</b>	Number of employed in the commerce sector	Population Housing Census 2011
<b>OCC_TRASP</b>	Number of employed in the transport sector	Population Housing Census 2011
<b>OCC_CRED</b>	Number of employed in the credit sector	Population Housing Census 2011
...		

Table 2. Variables included in the municipalities shapefile [BaseTerr](#)

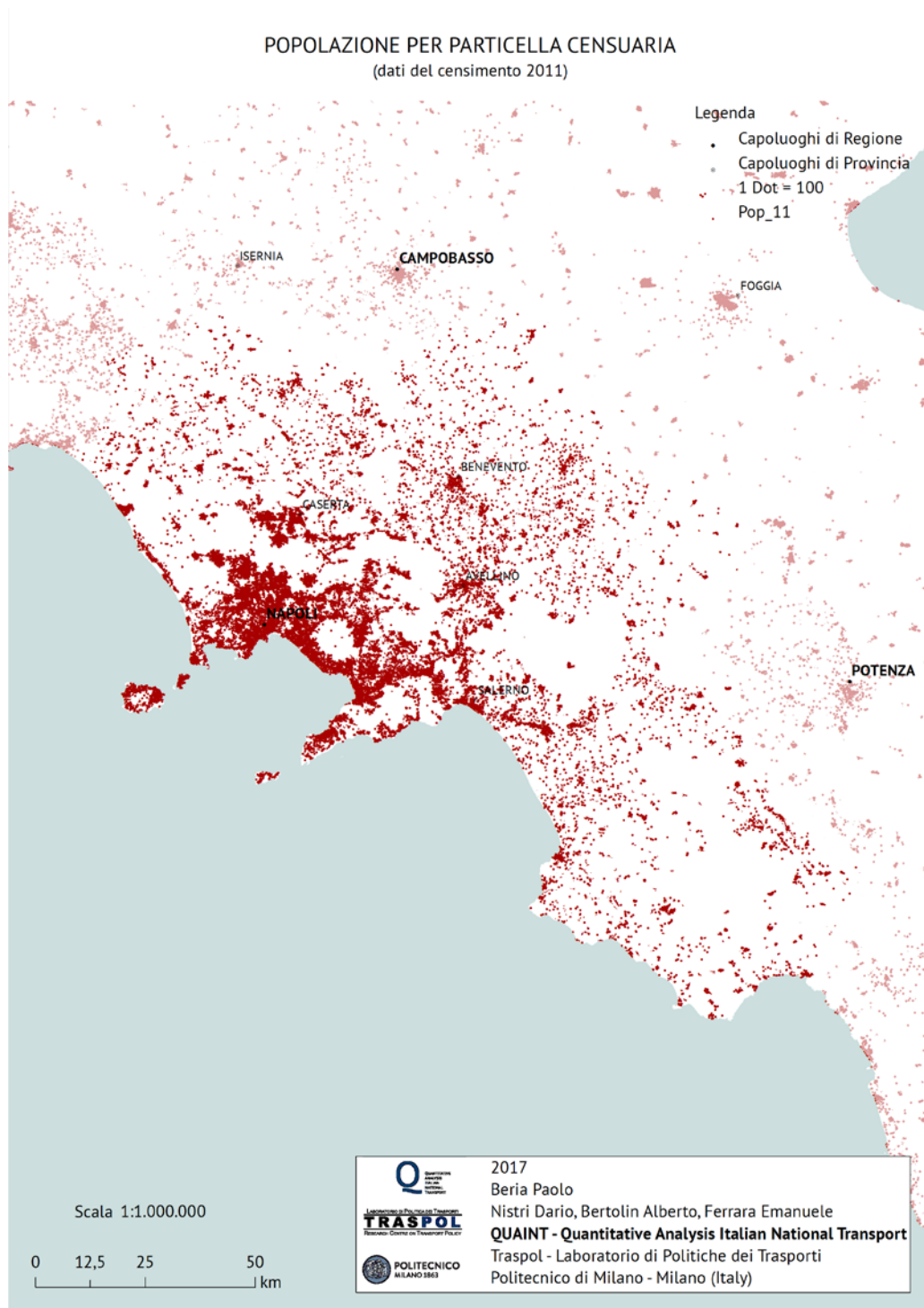
Figure 1. An example of communal-scale database: workplaces per municipality. Source: our elaborations on ISTAT census 2011.



<i>Field</i>	<i>Description</i>	<i>Source</i>
<b>COD_ISTAT</b>	Municipality key	Istat
<b>SEZ2011</b>	Census precinct key	Istat
<b>COD_LOC</b>	Locality key	Istat
<b>Area</b>	Area (Sqkm)	Istat
<b>POP_11</b>	Number of inhabitants	Population Housing Census 2011
<b>Dens_11</b>	Population density	Population Housing Census 2011
<b>Add_A</b>	Number of employed in the agricultural sector	Istat Tourism Statistics 2011
<b>Add_I</b>	Number of employed in the industry sector	Istat Tourism Statistics 2011
<b>Add_T</b>	Number of employed in the service sector	Istat Tourism Statistics 2011
<b>Q_Anziani</b>	Ratio of over 65 population on total population	Population Housing Census 2011
<b>Q_Min14</b>	Ratio of under 14 population on total population	Population Housing Census 2011
<b>Q_Stranieri</b>	Ratio of foreign population on total population	Population Housing Census 2011

Table 3. Variables included in the census precincts shapefile [SezCens](#)

Figure 2. An example of precincts-scale database: population per precinct. Source: our elaborations on ISTAT census 2011.



## 2.3 Infrastructure

Many vector infrastructure shapefiles exist. However, they suffer of different problems: incompleteness, excess of detail, incongruence, partiality. In addition, most of them are just a “graphical object” of an infrastructure, not directly usable in a transport model. The work done consist in:

- Collection of existing shapefiles (roads, highways, rail tracks, stations, airports, ports)
- Clean-up of redundant data (e.g. Openstreetmap is too much detailed)
- Integration of lacking parts

- d. Debug & check (e.g. unconnected segments)
- e. Input of relevant attributes (e.g. road segments are associated to a road type, used to estimate the capacity and a free-flow speed)
- f. Coding and construction of the coherency with the timetables (e.g. graphical object of stations must have the same code of the stations of the timetable).

Most of our graphical objects originally come from Openstreetmap, always subject to the above described treatment. Figure 3 shows both the simplification operated, but also the way roads are classified. For example, Bari is not crossed by class 3 roads, as we suppose that no long-distance travellers would pass through the city. Consequently, the city orbital road is the only way to cross Bari at NUTS-3 level. Instead, when zoning is more detailed and which part of Bari is reached matters, also urban roads appear. Similarly, towns unconnected at level 3 are places belonging to a zone where a larger centre represents the centroid.

Figure 3. Comparison between OpenStreetMap road network and model road network.



Our network database include the following networks, described by a **class** attribute:

- i. Navigation routes (sea and internal)

- ii. Rail networks (including metro&tram)
- iii. Road and highway network
- iv. Pipelines
- v. Air navigation routes
- vi. Zonal connectors
- vii. Other connectors (e.g. connectors within airports).
- viii. Centroids
- ix. Nodes

All of these networks are grouped in two parts, in addition to a table for the nodes (centroids or stops), included in the **BDO** (see below).

- **rete**, including all networks except rail;
- **link**, including rail networks only.

### 2.3.1 Road network

Italian road network comprises about one million of km. Of these, our model includes about 88.000 km, described by 103.000 edges (links) and 50.000 nodes. Road network, due to its extension, but also to the different functions, has been divided into five **classes**, not related to the physical characteristics (rather described by a **type** parameter), but to their function into the model. This allows to switch on only the classes of network necessary for the level of detail required. Typically, national-scale simulations can run at the NUTS-3 or -4 level, while for local applications NUTS-5 or -6 might be necessary. **QUAINT will work at the NUTS-5 detail.**

<b>Class</b>	<b>Road function</b>	<b>Coverage</b>
2	Highway network (always present)	All of Italy
3	Primary network, connecting provincial centroids (NUTS-3 level)	All of Italy
4	Secondary network, connecting intermediate centroids (NUTS-4 level)	All of Italy
5	Connection network, connecting local centroids (NUTS-5 level)	All of Italy
6	Local network, connecting local centroids (NUTS-6 level)	Locally complete (Piedmont, Lombardy, etc.)

Table 4. Road classes

The **rete** shapefile is completed by the following parameters, partially imputed manually for the entire country, partially computed.

<i>Field (selection)</i>	<i>Description</i>
<b>Classe</b>	Road class, functional classification (see Table 4)
<b>TipoArco</b>	Road type, geometric: used to calculate capacity and free flow speed
<b>Corsie</b>	Lanes of the road
<b>Lungh</b>	Road segment length
<b>Anno_ini</b>	Opening year
<b>Anno_fin</b>	Closing year
<b>Tar_A (/R)</b>	Fare applied (0 for free roads, €/km for toll roads)
<b>Cbase_AR (/R)</b>	Baseline capacity (calculated)
<b>V_calc_A (/R)</b>	Segment speed (calculated)
<b>T_calc_A (/R)</b>	Segment travel time (calculated)
<b>Lunghurb...</b>	Length of the segment in urban, plain, hills, mountain context
...	

Table 5. Main fields of the *rete* shapefile

On the basis of the road type (**TipoArco**), lanes, context, capacity and speed are calculated. The correct typization is very important and a number of road types have been defined. Types are described in sample sheets like the following one.

Figure 4. Example of a sample-sheet for road types.



Figure 5. Italian road network, classes 2+3 (connection among Provinces).



Figure 6. Italian road network, class 4 (connection among NUTS-4 zoning, subprovincial).



Figure 7. Italian road network, class 5 (connection among NUTS-5 zoning, subprovincial). Example of Perugia area.

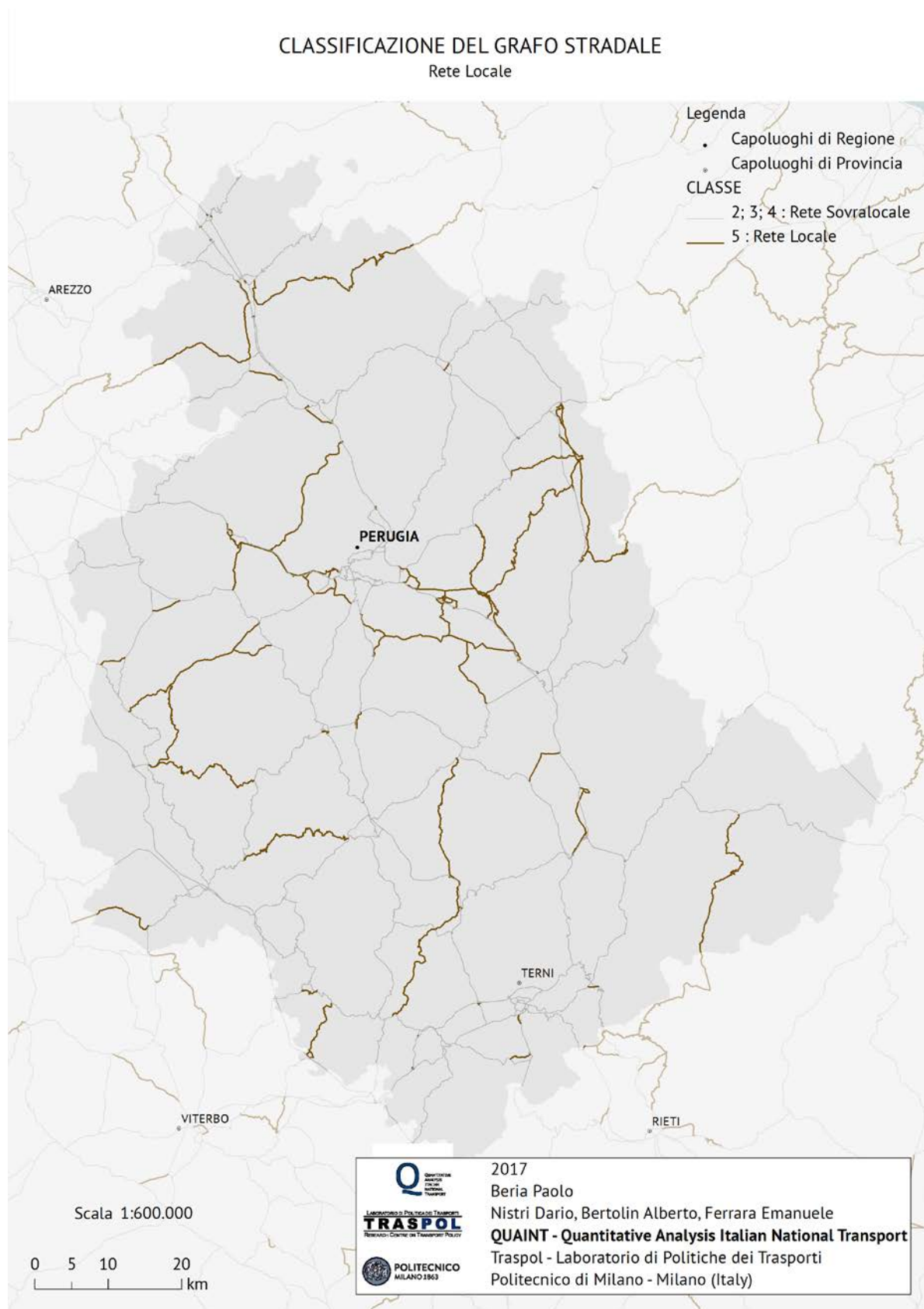
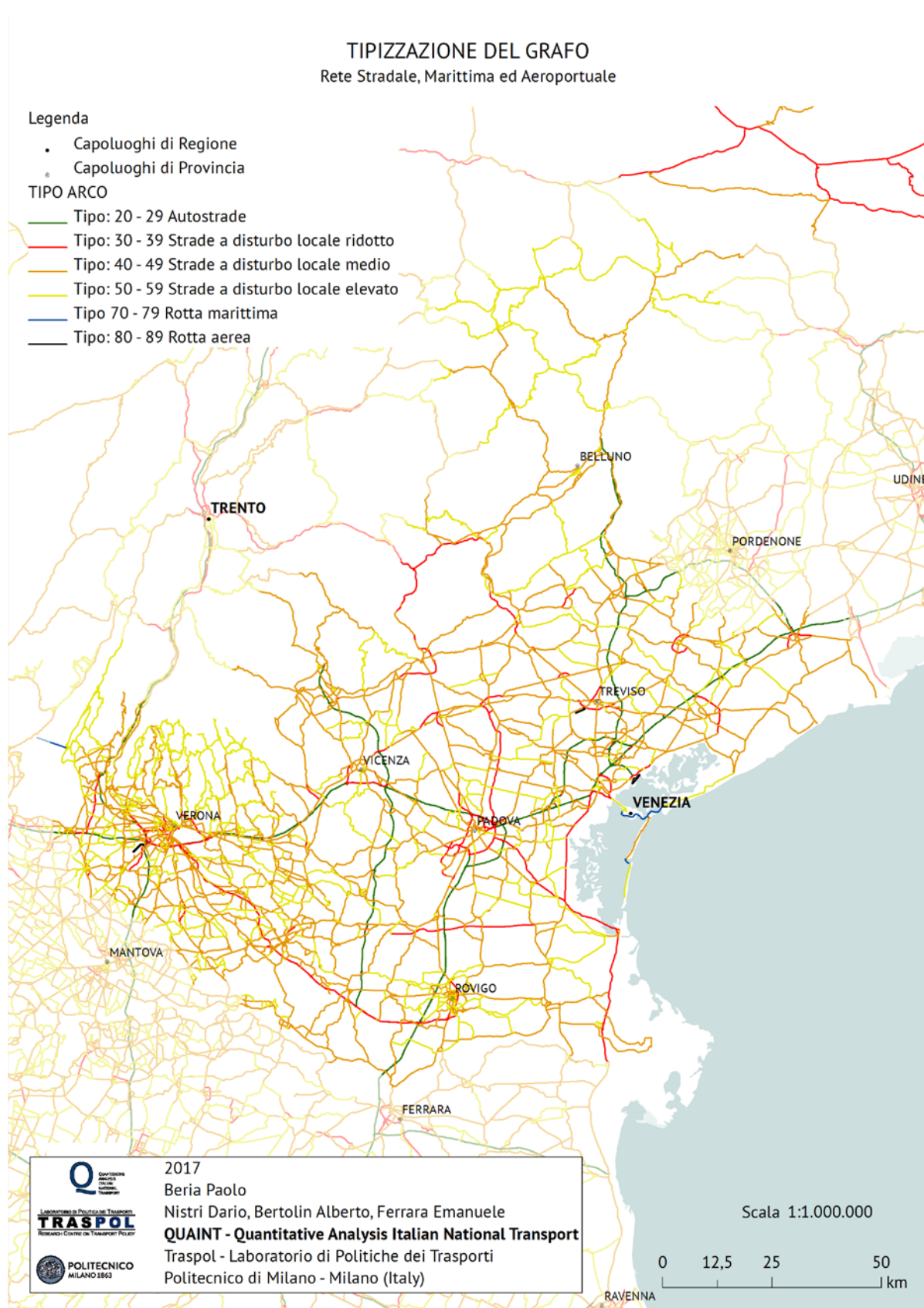


Figure 8. Italian road network, road types. Example of Friuli-Venezia Giulia Region.



In addition, for the toll-road network only, further information are associated to **rete** by means of a field **idAiscat**. They include the type of toll, the name of the concessionaire, and (for the demand part) also yearly traffic flows.

### 2.3.2 Ferries

Ferries are not intended as a mode per se, but as a complement to road network. This means that the network is not associated to a timetable, and that lines work as a “land bridge”, with a low speed and a fixed access and egress cost. Of course, if needed, the network can be uploaded with services timetables similarly to what happens to rail network.

### 2.3.3 Rail network

The [link](#) database includes the line objects describing the entire Italian rail network. In particular, it includes:

- RFI network
- Conceded railways
- Existing underground lines
- Existing tram networks
- Funiculars and cable cars (excluding those internal to sub-provincial zones NUTs-4).

Similarly to road networks, also rail networks are derived from the graphic objects of Openstreetmap, redrawn and simplified, but also coded with the relevant characteristics and made coherent with real stations, stops and movement points. This operation is necessary to guarantee the interface between the shapefile and the rail timetable. To date, rail network modelled includes 11.500 edges and 5.000 nodes, for a total of 21.755 km.

Table 6 lists and describes the main fields of [link](#).

<i>Field (selection)</i>	<i>Description</i>
<b>Tipo</b>	Arc type (see )
<b>Gestore</b>	Owner/manager of the line (e.g. RFI)
<b>Traz</b>	Power type (0 = diesel, >1 = electric, various types)
<b>Lungh</b>	Rail segment length
<b>Anno_ini</b>	Opening year
<b>Anno_fin</b>	Closing year
<b>Scart</b>	Gauge
...	

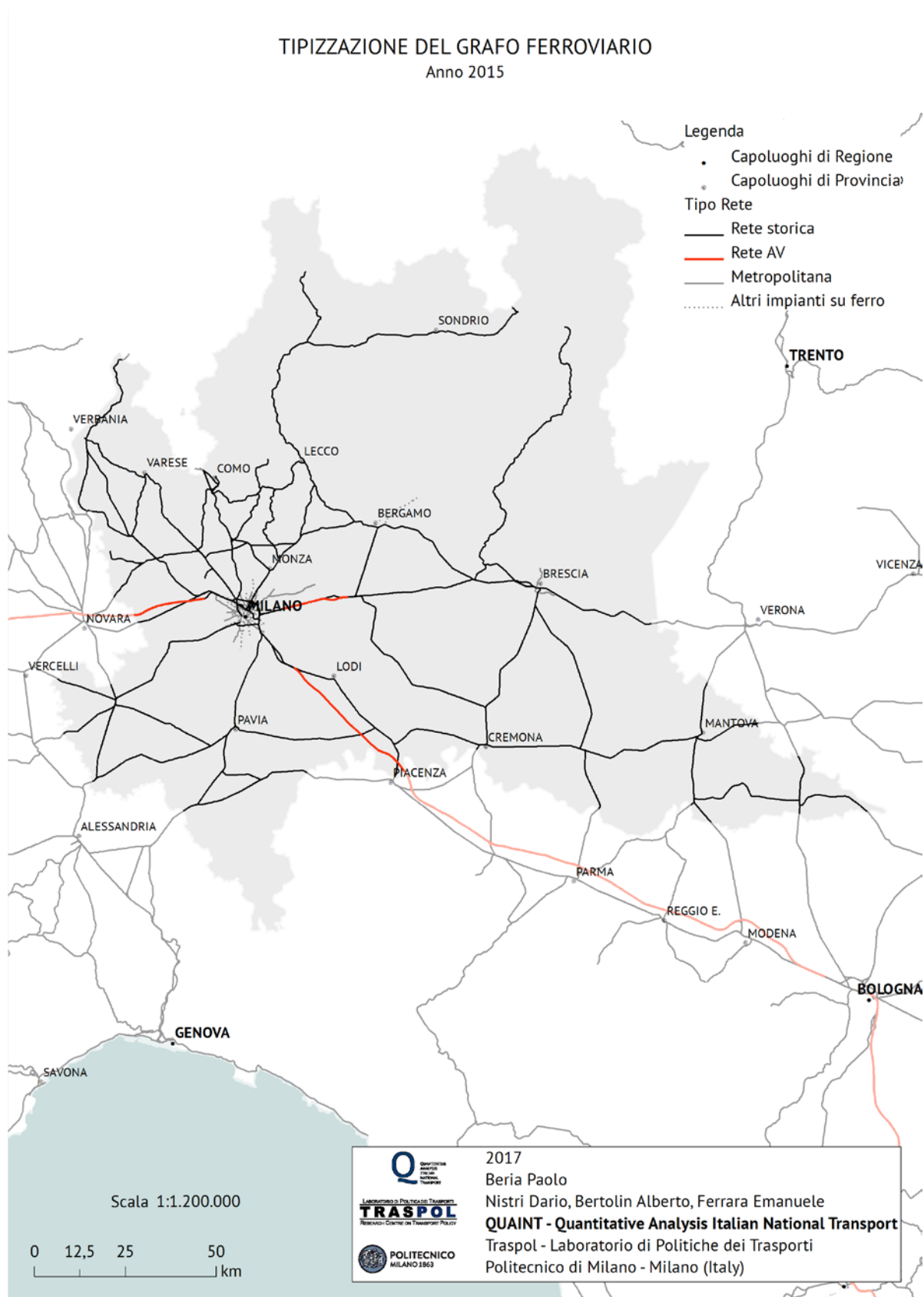
Table 6. Main fields of the [link](#) shapefile

<b>Tipo</b>	<b>Arc type, for rail network</b>	<b>Coverage</b>
10	Rail line (generic=conventional)	All Italy
11	Rail line (high-speed)	All Italy
16	Metro line	All Italy (TO, MI, BS, GE, RM, NA, CT)
17	Tram line	All Italy (TO, MI, BG, PD, VE, TS, FI, RM, NA, ME, PA, SS, CA)
18	Funicular	All Italy (TO, BG, EG, VE, NA, CZ)

Table 7. Rail types

The following map depicts rail network according to the type (rail, metro..., Figure 9).

Figure 9. Italian rail networks types (rail, high speed rail, metro, tram, funicular). Example of Lombardia region.

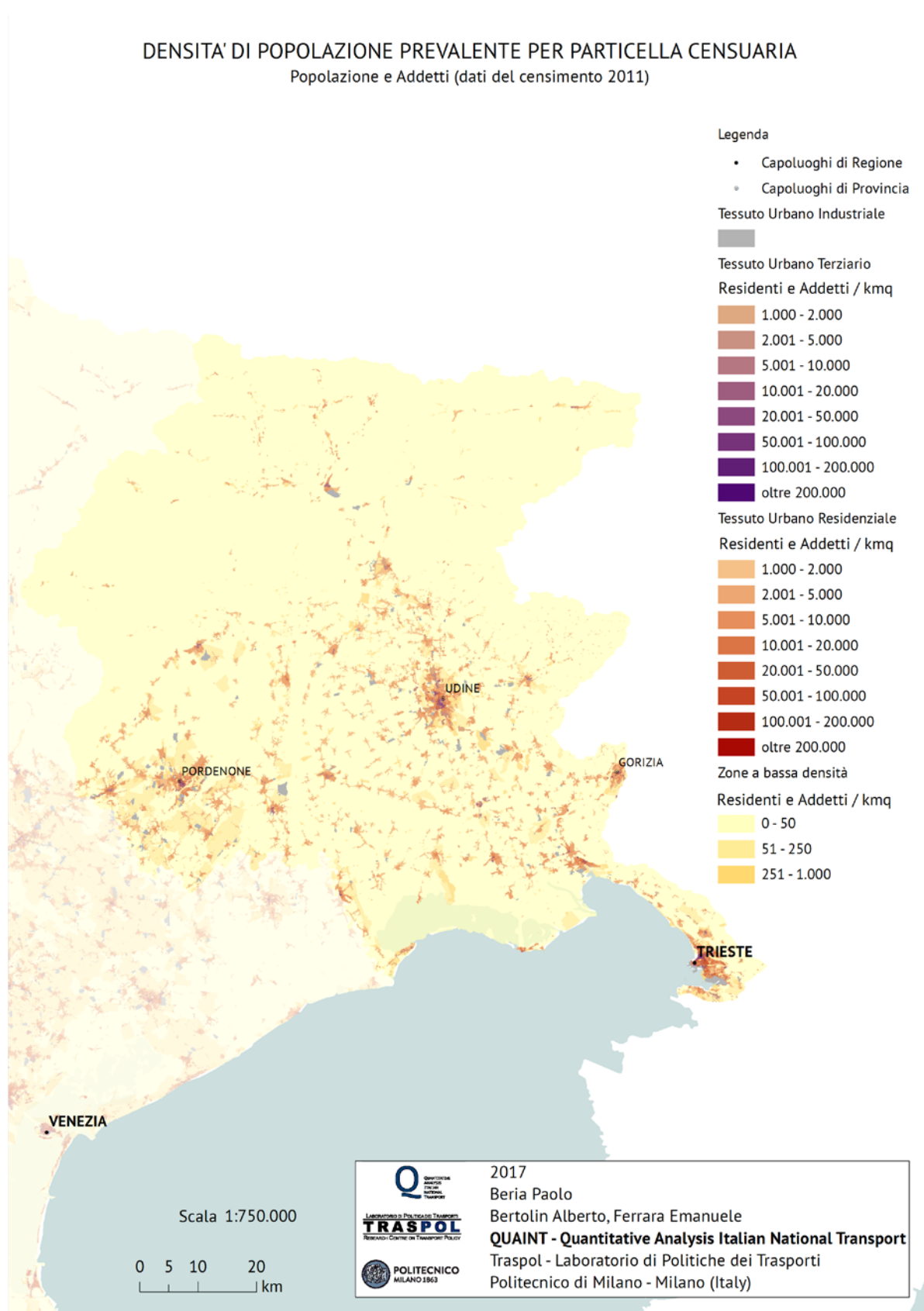


## 2.4 Land use

The land use component is extremely important for a sound description of the mobility phenomena. Land use is also the main input for generation models. The land use section includes to date two national-scale sources, plus some local ones where available (e.g. Regione Lombardia DUSAF):

- i. ISTAT census precincts: a number of data can be mapped, including population, population density, main function. Typically it is not a strict land-use source, but given the level of detail it can be used to show the built-up parts of the country, together with census data. For a sample, see Figure 10.
- ii. SDI4Apps project. It is a Europe-wide representation based on CORINE land cover and Urban Atlas (Directorate-General Enterprise and Industry (DG-ENTR), Directorate-General for Regional Policy <https://www.eea.europa.eu/data-and-maps/data/urban-atlas#tab-metadata>).

Figure 10. Land use representation, based on ISTAT census data.



## 2.5 Timetables database (“BDO”)

### 2.5.1 Sources

The BDO (*Base Dati Orario*, or Timetables Database) is the hearth of the modelling and of Quaint. It is collected in [BDO](#).

The BDO has been built in a number of ways:

- **Manual input of timetables.** This is the way used for smaller coach companies, where the extreme heterogeneity of the sources suggested a manual input;
- **Semi-automated input of timetables** (e.g. when repetitive Excel or Pdf files were available), through *ad hoc* built procedures. This is the way used for rail timetables;
- **Automated input from existing databases.** This is the procedure used for air timetables, where third-party databases exist (e.g. OAG database). The procedure consists in the homogenization of the source coherently with the BDO structure;
- **Automated input from GTFS.** Where available, the “General Transit Feed Specification” have been translated into DBO via *ad hoc* procedures. This is the case of some local networks, such as Trenord or GTT ones.

The BDO is built around four “layers”: **companies**, **lines**, **rides** and **timetables**. Each layer corresponds to one table in the [BDO](#) file. The coherency among the three layers must always be checked, for example any “ride” associated to a “timetable” must be assigned to a “line” a line to a “company”.

The following Table 8 shows the dimension of the database, counting the number of rides per mode present in the [BDO](#) in an average day of 2016.

<i>Average rides/day</i>	
High speed trains	285
Eurocity and Intercity trains	178
Regional trains	10.256
Flights	2.686
Coaches	943

Table 8. Contents of the [BDO](#).

### 2.5.2 General structure of the supply module

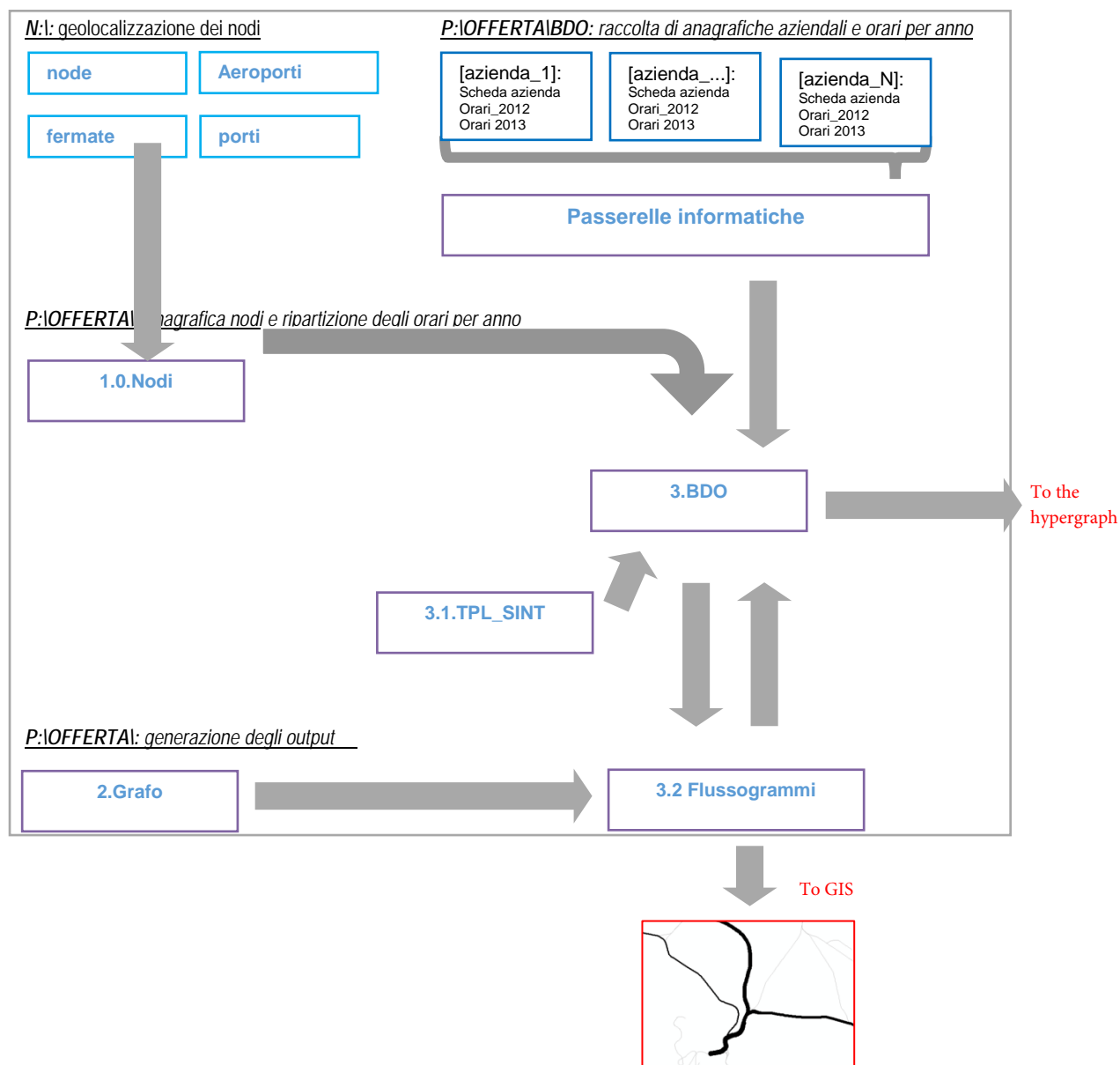
The BDO is part of the supply module, consisting in the description of network geometries, nodes and timetables. The three elements together are used to create the hypergraph or the frequency-based transit model, which are the base of simulations.

In particular (see Figure 11), BDO is made of **timetables**, **connecting a list of nodes**. These are included in the file [1.0.Nodi](#), while timetables come from individual data sources, bridged by means of a range of automated or semi-automated procedures, as described above. The nodes files itself is derived from modal files, where is included both the physical position and the relation with the networks.

The BDO is input for two further procedures:

- a. Mapping through flowcharts (described in Section 2.5.4);
- b. Hypergraph or frequency model (described in Section 3).

Figure 11. General structure of the supply module and the role of BDO.

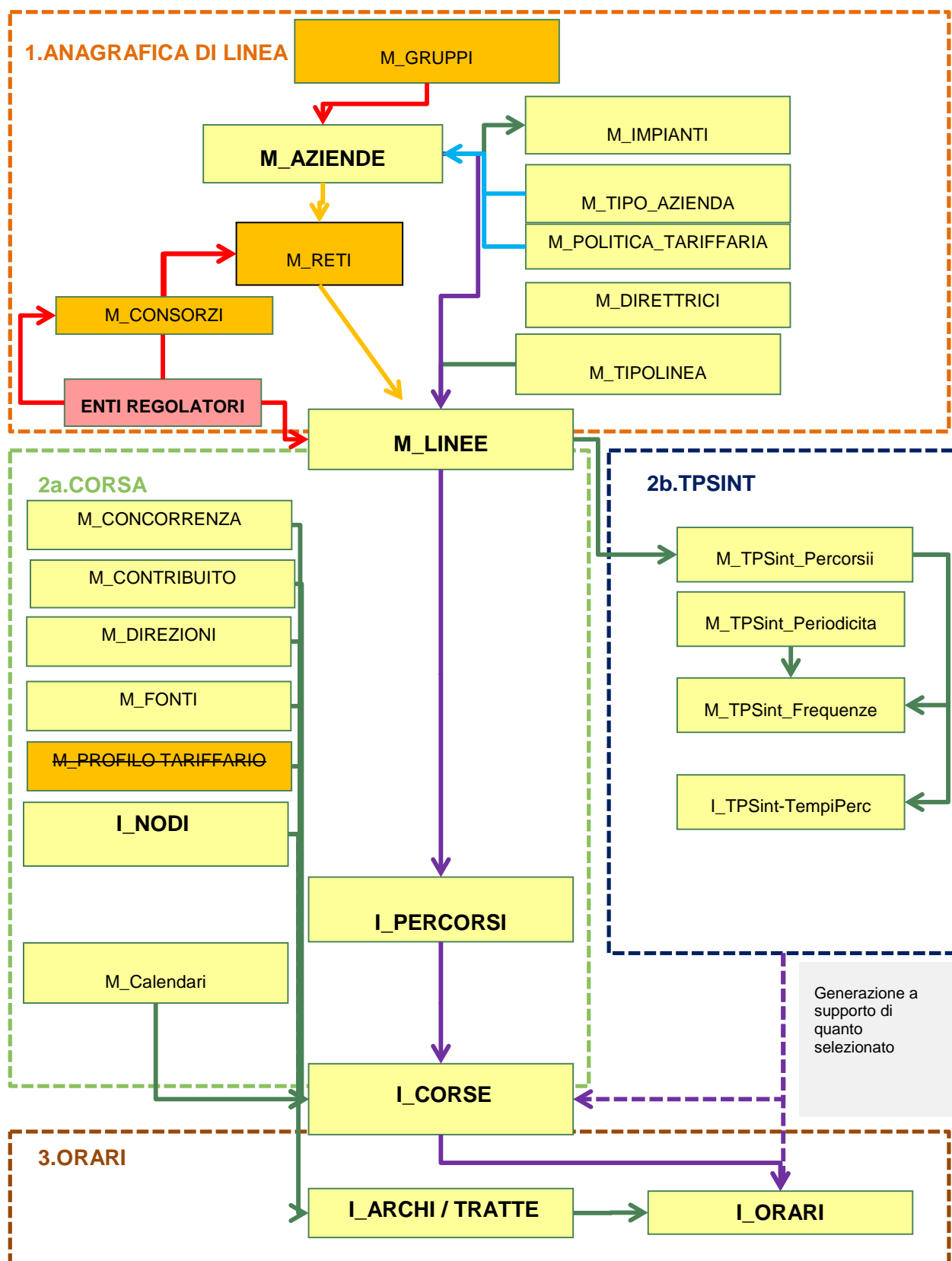


### 2.5.3 Internal structure of BDO

As previously mentioned, BDO is made of four parts, as represented in Figure 12:

- Companies database
- Lines database
- Rides database
- Timetable database

Figure 12. Internal structure of **BDO**



**Companies** table consist in the following information.

<i>Field (selection)</i>	<i>Description</i>
<b>ID_AZIENDA</b>	Key field
<b>COD_Azienda</b>	A synthetic code for each company
<b>Descr_Azienda</b>	Company name
<b>Gruppo</b>	[optional] Group of companies (e.g. Eurolines)
<b>Address</b>	[optional] Address reference about the company
<b>Noleggio, Linea</b>	[1/0] charter company; liner company
<b>Anno_ini</b>	Opening year
<b>Anno_fin</b>	Closing year
<b>Rilevatore</b>	Name of the operator who imputed the information
<b>Completo</b>	[1/0] if the company is fully described
...	

Table 9. Main fields of *M\_AZIENDE* table

**Lines** table is linked to the Company through the **ID\_AZIENDA**. It includes the following main fields.

<i>Field (selection)</i>	<i>Description</i>
<b>ID_LINEA</b>	Key field
<b>COD_Linea</b>	A synthetic code for each line
<b>Descr_Linea</b>	Line description or name
<b>ID_AZIENDA</b>	Company operating the line
<b>COD_Tipo_Linea</b>	Line type (e.g. urban service, airline...)
<b>Anno_ini</b>	Opening year
<b>Anno_fin</b>	Closing year
<b>Rilevatore</b>	Name of the operator who imputed the information
...	

Table 10. Main fields of *M\_LINEE* table

**Rides** consist in two tables, namely **paths** and **rides**. Path is used to group rides based on the same path. For example, the line Milan – Rome could be made of two different paths, e.g. Milan Centrale – Milan Rogoredo – Rome Termini and Milan Centrale – Rome Termini. For each path, exist different rides, for example the Milan – Rome (1) departing at 7:00, 8:00 and 9:00 and the Milan – Rome (2) departing at 7:30 and 9:30. The Rides table consist of the following fundamental data.

<i>Field (selection)</i>	<i>Description</i>
<b>ID_CORSA</b>	Key field
<b>Yeas</b>	Year of validity
<b>ID_LINEA</b>	Line to which the ride belongs
<b>ID_PERCORSO</b>	Path to which the ride belongs
<b>COD_CORSA</b>	Univocal code describing the ride
<b>ID_MODALITA'</b>	The transport mode (e.g. rail)
<b>ID_CONCORRENZA</b>	[1/0] if in competition
<b>ID_CONTRIBUITO</b>	[1/0] if subsidised or market driven
<b>ID_NODO_INI</b>	Departure node
<b>ID_NODO_FIN</b>	Arrival node
<b>Ora_ini</b>	Departure time
<b>Ora_fin</b>	Arrival time
<b>Tempo</b>	Total travel time of the ride
<b>Lungh</b>	Length of the ride
<b>Giorno_Anno</b>	Number of times/year the ride is operated
...	

Table 11. Main fields of I\_CORSE table

Finally, the timetable of the entire ride, including intermediate stops, is included in the table I\_ORARI.

<i>Field (selection)</i>	<i>Description</i>
<b>ID_CORSA</b>	Key field
<b>PROG</b>	Progressive number of the stop (1,2,3...)
<b>ID_TRATTA</b>	Path to which the ride belongs
<b>ID_NODO_A</b>	Departure node
<b>ID_NODO_B</b>	Arrival node
<b>Ora_ini</b>	Departure time
<b>Ora_fin</b>	Arrival time
<b>Tempo</b>	Total travel time of the segment
<b>Salita</b>	[1/0] if it is possible to ride-in at the stop
<b>Discesa</b>	[1/0] if it is possible to ride-out at the stop
...	

Table 12. Main fields of I\_ORARI table

The following Figure 13 shows an example of how a single ride is described in the I\_ORARI table:

Figure 13. Example of a ride in the *L\_ORARI* table

<i>ID_CORSA</i>	<i>PROG</i>	<i>ID_NODO_A</i>	<i>ID_NODO_B</i>	<i>ID_TIPOTRATTA</i>	<i>ORA_IN I</i>	<i>ORA_FIN</i>	<i>TEMPO</i>	<i>LUNGHEZZA</i>	<i>SALITA</i>	<i>DISCESA</i>
773557	1	100283	100270	1	21:08	21:13	0,08	7,049	1	0
773557	2	100270	100063	1	21:13	21:18	0,08	9,08	0	0
773557	3	100063	100005	1	21:18	21:23	0,08	8,35	0	0
773557	4	100005	100071	1	21:23	21:27	0,07	7,019	0	0
773557	5	100071	100073	1	21:27	21:31	0,07	5,02	0	0
773557	6	100073	100113	1	21:31	21:33	0,03	1,144	0	0
773557	7	100113	100105	1	21:33	21:36	0,05	2,2	0	0
773557	8	100105	100076	1	21:36	21:39	0,05	0,348	0	0
773557	9	100076	100077	1	21:39	21:45	0,10	4,318	0	0

#### 2.5.4 Flowcharts

The BDO can be used to create dynamically flowcharts, to be represented under GIS. The operation done consists in transposing the timetable over the previously described networks shapefiles, transferring some attributes, typically the number of rides per segment in a given time period. In addition, thanks to the geometrical information available under GIS, it is possible to represent speed for each link.

Figure 14. An example of flowchart: Florence area, regional trains/day.

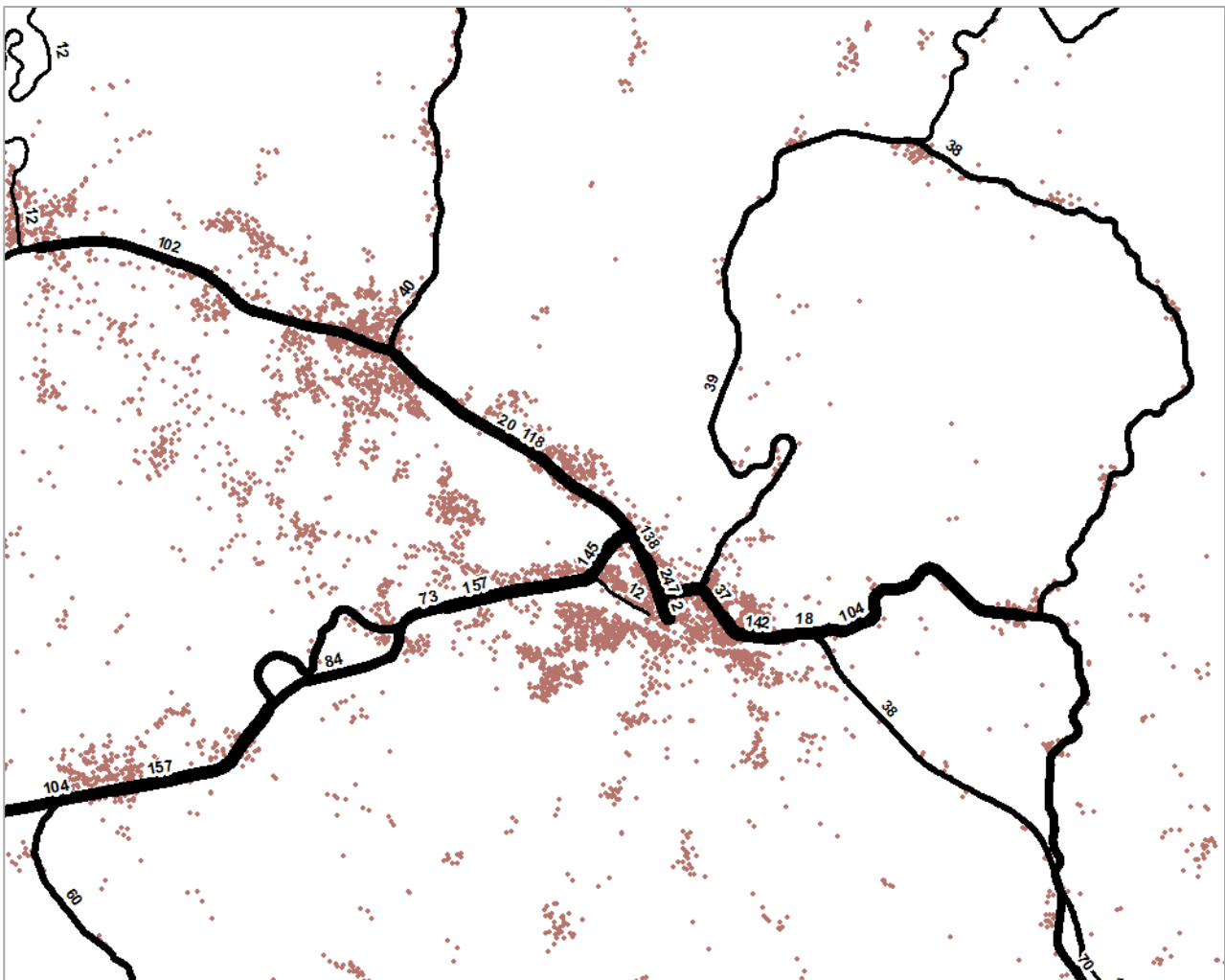
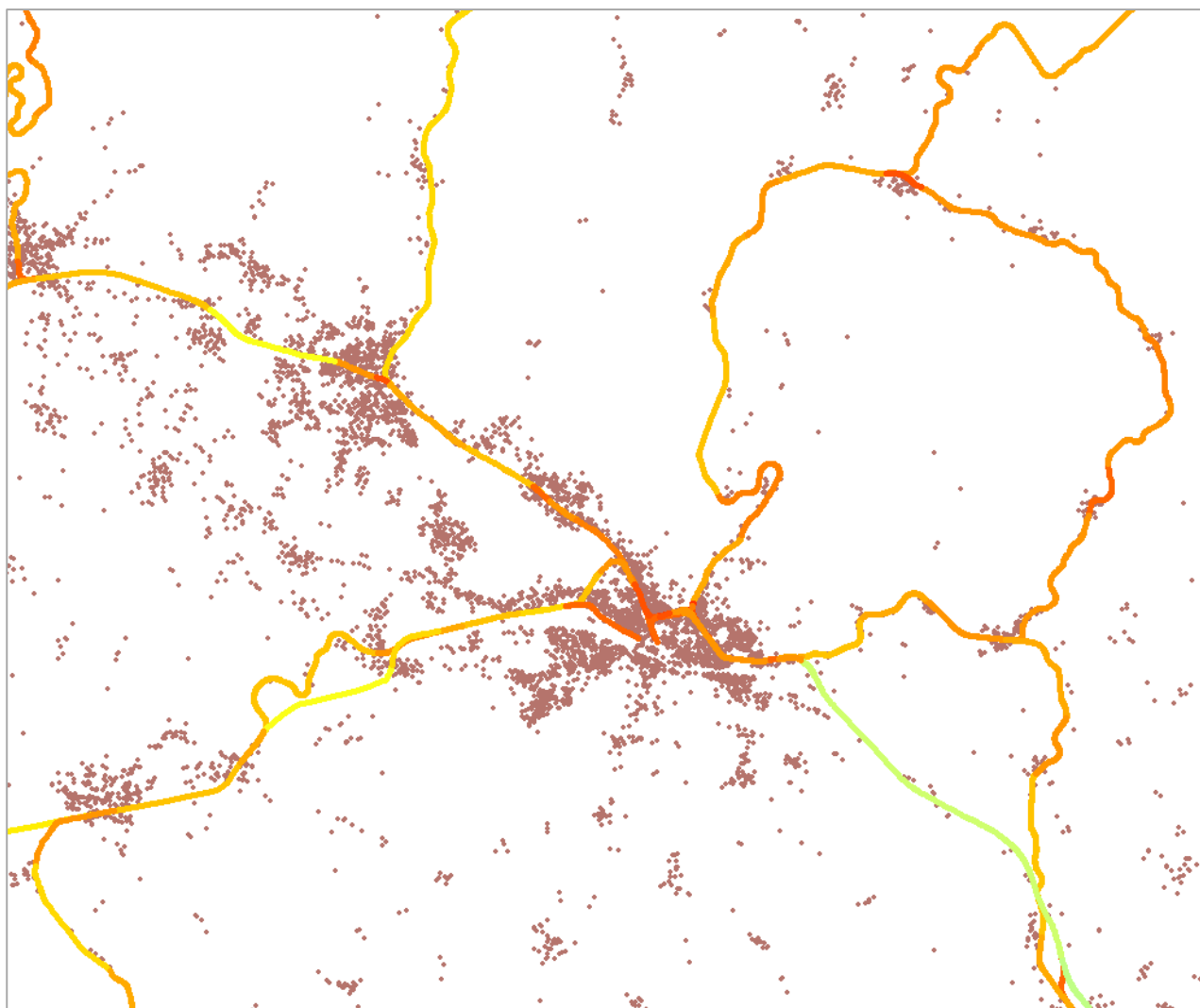


Figure 15. An example of flowchart: Florence area, speed of regional trains.



## 2.6 Traffic counts database (“POSTRA”)

Model calibration requires to compare model results with actual traffic counts and modify choice parameters until the two match (actually, until the error is minimised). This requires to collect as much as counts as possible, from different modes and from different areas. A database includes all available traffic counts and is used in the calibration phase. The database is called **POSTRA**.

### 2.6.1 Sources

**POSTRA** database collects and homogenise a number of different and heterogeneous sources, coming from concessionaire’s traffic counts, single documents (e.g. a city plan which includes also the data on traffic counts) and limitedly third party databases. The following Table 13 summarise the sources collected to date with some statistics of data size.

<i>Campaign</i>	<i>description of data</i>	<i>observations</i>	<i>type of count</i>
1041-ASTM_TO-MI	Statistiche del traffico (sistema chiuso)	17	TGM
ANAS	Conteggi automatici ANAS	767	TGM
ASPI	Statistiche del traffico (sistema chiuso)	6072	TGM
Autobrennero	Statistiche del traffico (sistema chiuso)	24	TGM
Autostrada dei Fiori	Statistiche del traffico (sistema chiuso)	50	TGM
Autostrade Centro Padane	Statistiche del traffico (sistema chiuso)	31	TGM
Autostrade in Emilia Romagna non Aspi		12	TGM
Regione Emilia Romagna	Sistema regionale di rilevazione dei flussi di traffico dell'Emilia-Romagna	79943	TGM
Serenissima	Statistiche del traffico (sistema chiuso)	84	TGM
SITAF	Statistiche del traffico (sistema chiuso)	144	TGM
SITAF-A32	Statistiche del traffico (sistema aperto)	336	TGM
SITAF-T4	Statistiche del traffico (sistema aperto)	216	TGM
Trafo Monte Bianco	<a href="http://www.regione.piemonte.it/trasporti/dati_valichi_alpini/index.htm">http://www.regione.piemonte.it/trasporti/dati_valichi_alpini/index.htm</a>	192	TGM
USTRA (dal 2010 in poi)	Conteggio automatico svizzero della circolazione stadale	135728	TGM
USTRA (fino al 2009)	Conteggio automatico svizzero della circolazione stadale	104296	TGM
Provincia di Bolzano	Censimento del traffico (periodico)	77024	TG
Provincia di Trento	Censimento del traffico provinciale	100153	TG
Calenzano		5587	TO
Comune di Firenze	<a href="http://opendata.comune.fi.it/mobilita_sicurezza/dataset_0371.html">http://opendata.comune.fi.it/mobilita_sicurezza/dataset_0371.html</a>	172274	TO
Lombardia	Censimenti del traffico provinciali	254443	TO
Provincia di Sondrio	<a href="http://www.provincia.so.it/lavori%20pubblici/viabilita/traffico/default.asp">http://www.provincia.so.it/lavori%20pubblici/viabilita/traffico/default.asp</a>	5304	TO
Regione Puglia		5204	TO
Sesto Fiorentino - Rilievi intersezioni	PGTU Sesto Fiorentino (Polinomia 2012)	570	TO

Table 13. Contents of the **POSTRA**

The following Figure 16 depicts the spatial coverage of traffic counts collected. Clearly, the database will grow over time, as long as new sources will be available.

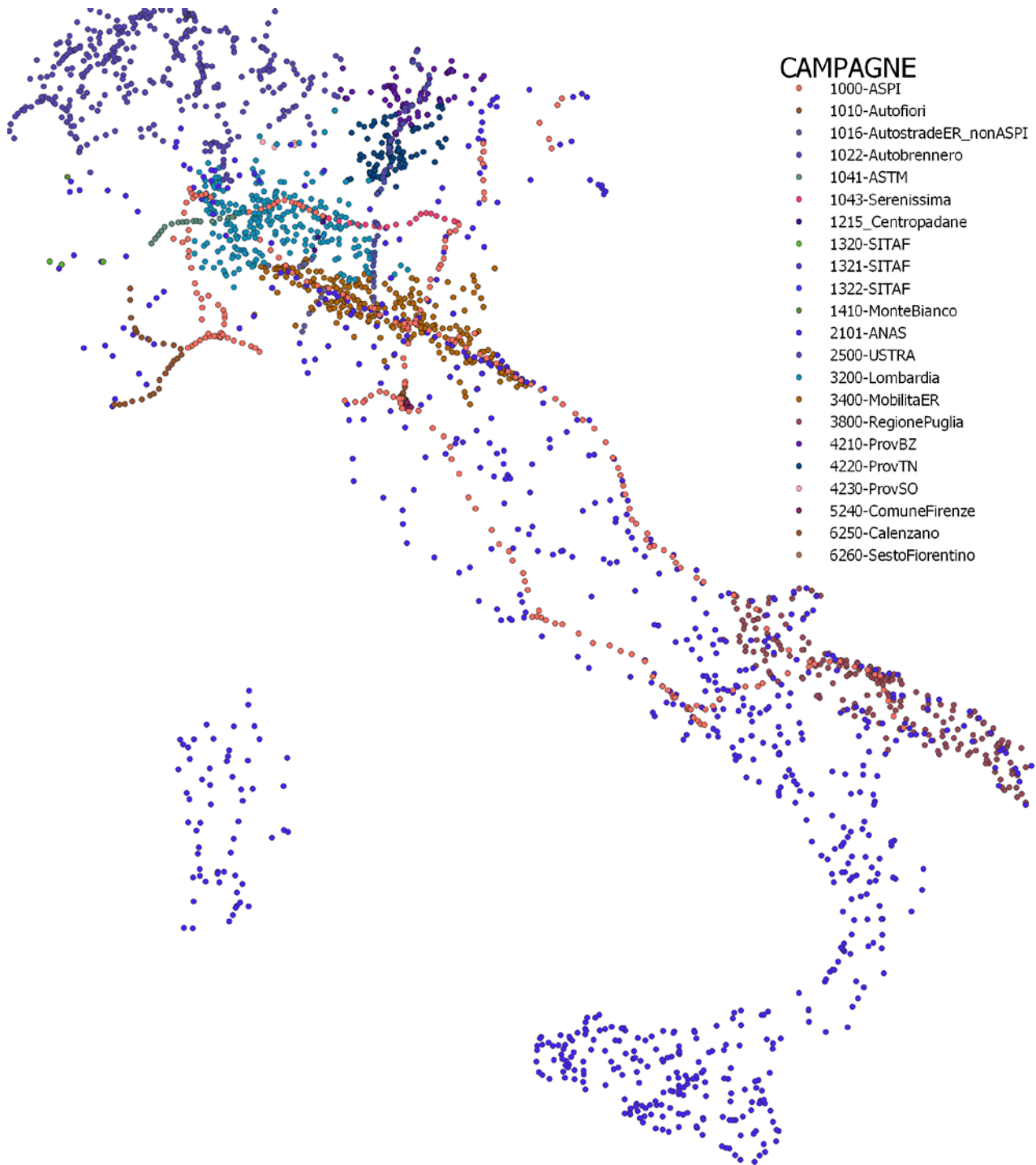


Figure 16. Positions of traffic counts and campaigns.

### 2.6.2 POSTRA structure

The general database structure is the one depicted in Figure 17. Every data source (“fonte”) contains one or more campaigns (“campagna”) and every campaign includes one or more georeferenced points and the related traffic counts. They are translated into a shapefile and a formatted dataset. Unfortunately, every campaign may differ for vehicle classification, period, time scale, etc. and consequently all data must be homogenised in space and data structure. In addition, the same point of the network can be present in different campaigns and sources and the matching has been done manually.

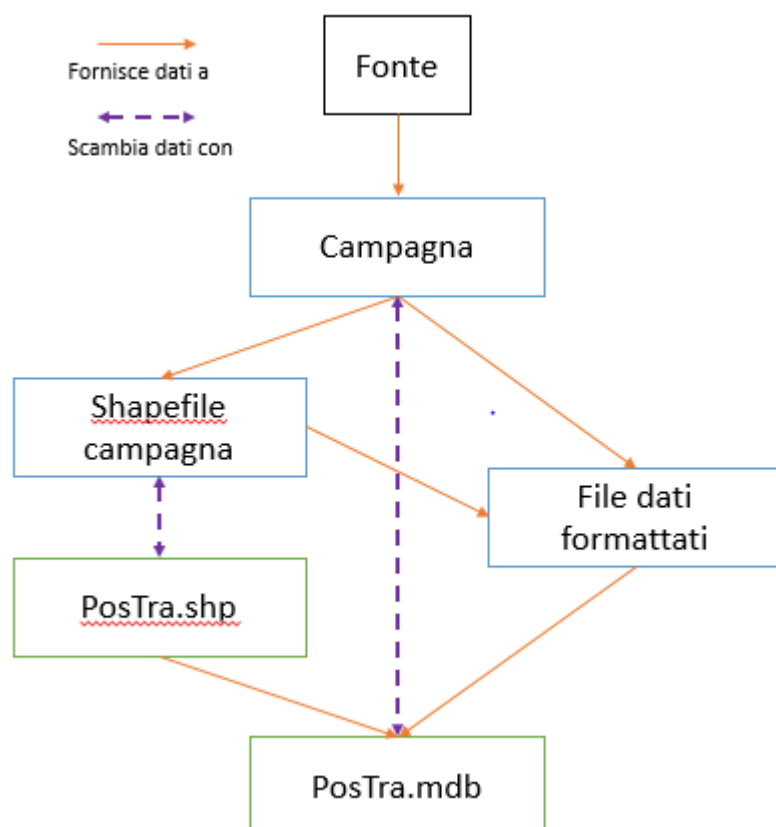


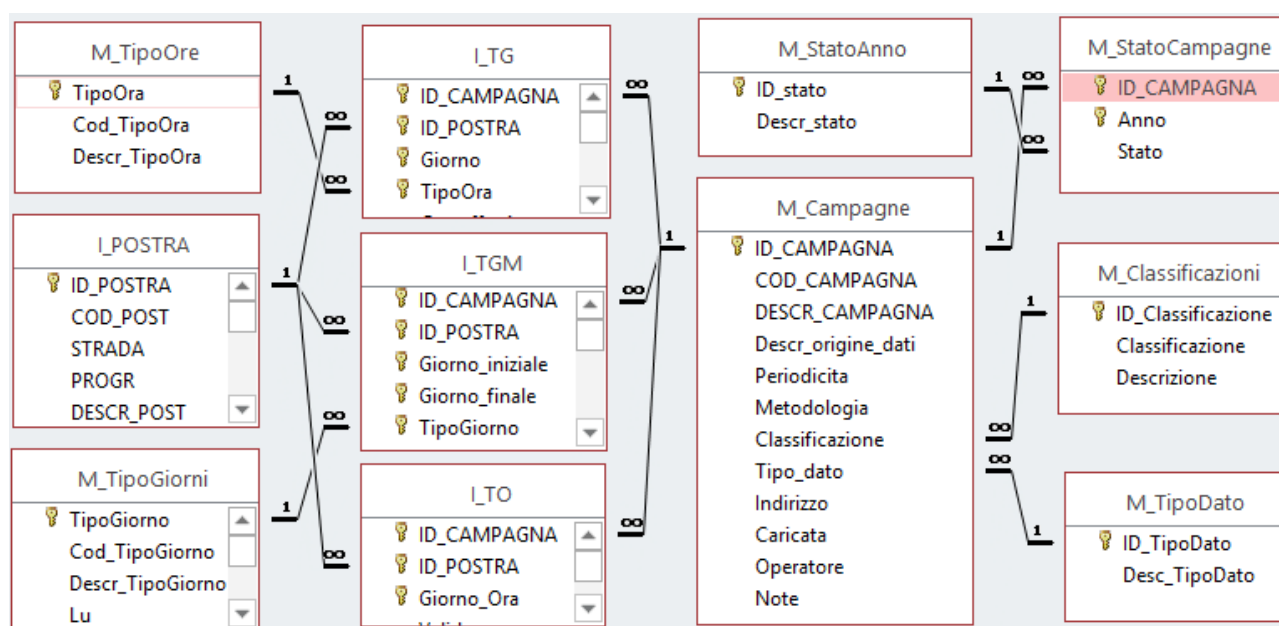
Figure 17. POISTRA database structure

The campaign's shapefile and dataset, formatted coherently, are piled up in the two general database **PosTra.shp** (with the graphical objects) and **PosTra.mdb** (with traffic counts).

The shapefile is structured as follows and includes the coordinates, the description, the direction of the flows, the road and road type.

<i>Campo</i>	<i>Tipo dati</i>	<i>Descrizione</i>
<b>ID_POSTRA</b>	Integer [9]	Position ID, univocal
<b>CODPOST</b>	String [9]	Position code
<b>STRADA</b>	String [65]	Road description
<b>PROGR</b>	Double [9]	Road position (progressive)
<b>DESCR_POST</b>	String [50]	Description of position
<b>Dir_1</b>	String [80]	Direction up
<b>Dir_2</b>	String [80]	Direction down
<b>[...]</b>		
<b>COD_COM</b>	Integer [9]	Municipality of the position
<b>ANNO_INI</b>	Integer [4]	Initial year of validity of data
<b>ANNO_FIN</b>	Integer [4]	Final year of validity of data
<b>x</b>	Double [18]	Coordinate x system WGS84-UTM32N
<b>y</b>	Double [18]	Coordinate y system WGS84-UTM32N

The database includes numerous datasets, as depicted in figure



At least one of the following three outputs that can be extracted for every point:

**O\_TO**: hourly traffic

**O\_TG**: traffic of a day

**O\_TGM**: average daily traffic

The Table 14 exemplifies the structure of the TGM.

<i>Campo</i>	<i>Tipo dati</i>	<i>Descrizione</i>
<b>ID_CAMPAGNA</b>	Long	Campaign ID
<b>ID_POSTRA</b>	Long	Position ID
<b>Giorno_iniziale</b>	Date/Time	Day of start of the average (es: ottobre 2018 = 01/10/2018)
<b>Giorno_finale</b>	Date/Time	Day of end of the average (es: ottobre 2018 = 31/10/2018)
<b>Giorni_effettivi</b>	Integer	Days
<b>TGMleg</b>	Long	TGM bidirectional passenger cars
<b>TGMpes</b>	Long	TGM bidirectional heavy vehicles
<b>TGMtot</b>	Long	TGM bidirectional all vehicles
<b>[...]</b>	Long	TGM direzione ascendente veicoli leggeri

Table 14. Output structure: TGM (average daily traffic)

### 2.6.3 Extraction and use

Data can be extracted in terms of TGM, TG, TO through an interface *frmCruscotto* and split into specific periods, campaigns, positions, etc. Data produced are always homogeneous.

TGM and other normalised figures are used in the calibration phase to verify the matching between modelled and real flows.

## 2.7 Other modes demand database (“CONDA”)

In this database calibration data for the public transport modes are collected. Using various and somehow different sources, data are structured in a calibration table for each mode of transport: air, train, ferry.

## 2.7.1 Air transport: route flows database

Among public transport modes, air transport is the only one having a variety of detailed statistics made publicly available by the Authority (ENAC). Since 2007, the Authority releases (annually and lately each trimester) a ranking of both national and international routes based on the number of passengers (>50.000 pax/anno). These data are collected in the **CONDA** database.

Passenger traffic data are accessible through the Authority webpage<sup>1</sup> as a list of various PDF documents. The route traffic source data are published in tables featuring the name of departure and arrival airport and the passenger volume. These are codified in our database adding IATA code to avoid issues with variability of airport names between different sources.

An example of data structure for the top 5 Italian routes is shown in the following Table 15. The table containing international routes is very similar.

<i>Year</i>	<i>Cod_Route</i>	<i>O_City</i>	<i>O_IATA</i>	<i>D_City</i>	<i>D_IATA</i>	<i>Pax</i>	<i>Contry</i>	<i>rank</i>
2011	CTA_FCO	Catania	CTA	Roma	FCO	1842431	IT	1
2011	FCO_LIN	Roma	FCO	Milano	LIN	1522184	IT	2
2011	FCO_PMO	Roma	FCO	Palermo	PMO	1497554	IT	3
2011	FCO_TRN	Roma	FCO	Torino	TRN	940297	IT	4
2011	CTA_LIN	Catania	CTA	Milano	LIN	809155	IT	5
[...]								

Table 15. Contents of the auxiliary input table for air transport in **CONDA**

In the same documents, the monthly volume of passenger traffic (all destinations) is available for each airport. This allows to compute the incidence of the month of October on the annual passenger traffic at each airport. To estimate this coefficient on each route, we take the max value between the origin and destination pair.

The matrix of incidence for October 2011 looks like the following:

<i>Airport O/D</i>	FCO	MLX	LIN	VCE	BGY	CTA	BLQ	[...]
FCO	9,08%	8,71%	8,95%	9,75%	8,94%	8,94%	8,81%	
MLX	8,71%	8,34%	8,59%	9,39%	8,58%	8,57%	8,44%	
LIN	8,95%	8,59%	8,83%	9,63%	8,82%	8,81%	8,68%	
VCE	9,75%	9,39%	9,63%	10,43%	9,62%	9,61%	9,49%	
BGY	8,94%	8,58%	8,82%	9,62%	8,81%	8,80%	8,68%	
CTA	8,94%	8,57%	8,81%	9,61%	8,80%	8,79%	8,67%	
BLQ	8,81%	8,44%	8,68%	9,49%	8,68%	8,67%	8,54%	
[...]								

The estimation of the average working day quota of airplane trips over the monthly amount is based on the data provided by the Milan airport company (SEA)<sup>2</sup> for the two airports of the city, Linate and Malpensa, of daily passenger during the month of October 2015. The average is based on the figures of Tuesday, Wednesday and Thursday, resulting in a coefficient of 3,16% trips during a single working day in respect to the month.

Therefore, the daily flows on 577 routes (both domestic and international) during the average working day are estimated as follows:

<sup>1</sup> <https://www.enac.gov.it/pubblicazioni>

<sup>2</sup> SEA (2017) Sistema Aeroportuale - Analisi dei dati di traffico del mese di OTTOBRE 2017

$$Pax_{OD} = Y_{OD} * M_{O,D} * D$$

Where:  $Y_{OD}$  = Passenger flow between Origin and Destination airports during 2011 (routes >50.000 pax only);

$M_{O,D}$  = MAX( $M_O, M_D$ ): i.e. the maximum value between the share of passenger in October compared to the annual total in the two Origin and Destination airports;

$D$  = Single average working day coefficient.

These data, aggregated according to zoning (for foreign destinations), are stored in a table in CONDA used in the calibration phase to verify the matching between modelled and real flows.

### 2.7.1 Rail transport: sources and type of data

Disaggregated data about passenger flows on the railway network are very scant, as commonly considered sensitive business data by railway operators. The main sources of disaggregated data are the (few) regional public administration that publish counts at the stations, either made by the railway operator under public service obligation, or by the regional council as a control tool on the operator of the service provider.

The collected data include the volume of passenger movements (regional services only) in a typical working day at the stations in Emilia-Romagna, Lombardia, Piemonte and Puglia, available either as a daily total or linked to specific trains.

Station	Line	Owner	November 2011		[...]
			Got on	Got off	
Alfonsine	Ferrara - Ravenna - Rimini	RFI	205	209	
Anzola Dell'Emilia	Bologna - Milano	RFI	155	130	
Argenta	Ferrara - Ravenna - Rimini	RFI	241	259	
Bertola Baggiovara	Modena - Sassuolo	Fer	16	15	
Baggiovara Ospedale	Modena - Sassuolo	Fer	105	116	
[...]					

Table 16. Example of extraction from an input table of passenger count at railway stations in CONDA

Each station is confronted with the nodes in the railway graph to associate the ID, then data from different sources are homogenised and stored in the output table for rail mode that is used in the calibration phase to verify the matching between modelled and real flows.

Field	Description
id_fonte	Campaign ID
fascia_rilievo	Time range of survey
anno	Year of survey
id_nodo	Station ID
pax_bhp_matt	Passengers during morning peak hour
pax_bhp_sera	Passengers during afternoon peak hour
pax_giorn	Daily passengers
[...]	

Table 17. Output table for rail mode

### 2.7.2 Maritime transport: sources and type of data

Data on maritime transport are available in the annual edition of the “Conto Nazionale delle Infrastrutture e dei Trasporti”, where, on the subject of passenger transport, are published aggregated annual data regarding

companies with predominantly public capital, while are excluded all the private companies operating in market regime, for which there are no available traffic data on the different routes. Therefore, these data give a limited picture of the actual passenger flows, and are excluded from use in the calibration phase.

## 2.8 Fares

A characterising aspect of QUAINT is to describe the supply not only in terms of infrastructure and services, but to consider also the market situation. This is relevant especially in the modelling of long distance trips, where the price (which is in turn depending on competition, market maturity and service characteristics) is often one of the main drivers of the users' choice.

To do that, different activities have been done, in order to collect the data needed from various sources to characterise every service with the correct fare profile. The outcome is a set of functions based on real-world prices.

### 2.8.1 Data sources

To obtain real fares observations for **rail** market in Italy we have programmed a web-crawler to automatically simulate and download both Trenitalia and NTV prices on a large number of routes. Routes include both conventional and HS lines, subsidised and market services, relations with or without intermodal competition. They also cover the whole Italy. Table 18 summarises the monodirectional routes surveyed. We did the survey with a certain regularity, but not daily. About two years of prices have been collected (June 2016 – February 2019), for about 51 Millions of observations for Trenitalia and 10 millions for NTV (covering less routes).

<i>ID</i>	<i>ID_ ORIG</i>	<i>NOME_ORIG</i>	<i>ID_ DEST</i>	<i>NOME_DEST</i>	<i>FILTRO_RICERCA</i>
1	24978	Milano Centrale	23291	Bologna Centrale	tutti
3	24978	Milano Centrale	8844	Torino Porta Susa	solo_frecce
4	24978	Milano Centrale	3265	Brescia	solo_frecce
5	24978	Milano Centrale	11640	Venezia Mestre	tutti
6	24978	Milano Centrale	21928	Genova Piazza Principe	tutti
7	24978	Milano Centrale	23202	Firenze S. Maria Novella	tutti
8	24978	Milano Centrale	21710	Roma Termini	tutti
9	24978	Milano Centrale	57	Napoli (tutte le stazioni)	tutti
10	24978	Milano Centrale	6470	Rimini	tutti
11	24978	Milano Centrale	763	Pisa Centrale	tutti
12	24978	Milano Centrale	9046	Ancona	tutti
13	23291	Bologna Centrale	9046	Ancona	tutti
14	23291	Bologna Centrale	23202	Firenze S. Maria Novella	tutti
15	11640	Venezia Mestre	23291	Bologna Centrale	solo_frecce
16	8844	Torino Porta Susa	3265	Brescia	tutti
17	8844	Torino Porta Susa	11640	Venezia Mestre	tutti
18	11510	Ferrara	21710	Roma Termini	tutti
19	9046	Ancona	13035	Bari Centrale	tutti
20	8844	Torino Porta Susa	21710	Roma Termini	tutti
21	4190	Verona Porta Nuova	21710	Roma Termini	tutti
22	23202	Firenze S. Maria Novella	21710	Roma Termini	solo_frecce
23	21710	Roma Termini	13035	Bari Centrale	tutti
24	21710	Roma Termini	13897	Reggio Di Calabria Centrale	tutti
25	21928	Genova Piazza Principe	21710	Roma Termini	tutti
26	11640	Venezia Mestre	21710	Roma Termini	tutti
27	23291	Bologna Centrale	21710	Roma Termini	tutti
28	24978	Milano Centrale	23727	La Spezia Centrale	tutti
29	11640	Venezia Mestre	17685	Firenze (tutte le stazioni)	tutti
30	409	Trieste Centrale	23291	Bologna Centrale	tutti
31	24978	Milano Centrale	11983	Udine	tutti
32	22844	Bolzano Bozen	23291	Bologna Centrale	tutti

Table 18. List of train origin-destination couples surveyed

The following Table 19 shows an example of output, for one single train-day-OD.

running_	travel_	delta_	id_	n_	orig	dest	descr_	ora_	ora_	durata_	flag_	flag_	nome_	nome_	prezzo	note
date_str	date_str	days	tratta	treno			treno	part	arr	viaggio	non_disp	posti_	tariffa	servizio		
												esauriti				
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Base	Business	76	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Base	Business Area Silenzio	76	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Base	Business Salottino	99	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Base	Executive	131	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Base	Premium	66	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Base	Standard	55	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Economy	Business	54,9	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Economy	Business Area Silenzio	54,9	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Economy	Business Salottino	76,9	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Economy	Executive	101,9	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Economy	Premium	49,9	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Economy	Standard	39,9	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	1	Super Economy	Business	-	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	1	Super Economy	Business Area Silenzio	-	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	1	Super Economy	Business Salottino	-	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	0	Super Economy	Executive	76,9	Posti in Esaurimento
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	1	Super Economy	Premium	-	-
31/05/2017	10/06/2017	10	14	9500	23202	24978	4	06:53	08:40	107	0	1	Super Economy	Standard	-	-

Table 19. Example of train prices collected for one day (10/6/17), on train (9500), purchased 10 days in advance, from Firenze SMN (23202) to Milano Centrale (24978).

The interest of such data is not limited to the variability across routes, trains and periods of the day, but also in the cases of discontinuity that occurred during the period. In particular we can check the effect of NTV entry on the Milan – Venice routes occurred in 2018. A similar work has already been done for the Milan – Ancona route (Beria et al., 2016).

**Coach** market require a different approach, due to its fragmentation (about 50 companies), making virtually impossible the collection (manual or automatical) of fares. By the way, their websites are often rudimental and routes change rapidly. On the other hand, the coach market is extremely interesting for a number of motives: it is not in equilibrium, being open since two years; mergers among companies have just started; the penetration of coach services is increasing.

For these reasons, we signed on July 1<sup>st</sup> 2016 an agreement with the platform [www.checkmybus.it](http://www.checkmybus.it) for an exchange of data. They provide us, every 6 months, the average prices of tickets sold for all of the coach companies they collect (most of the Italian market with few exceptions), for all origin-destination couples. To date we obtained 30 months of prices.

The data result more aggregated with respect to the previous case, but covers more routes, is associated to a volume of purchases and deals with *bought tickets* rather than with *shown prices*. The form of the database is shown in Table 20.

<i>Product</i>	<i>Operator</i>	<i>Quantity</i>	<i>Total revenues</i>	<i>Average price</i>	<i>Month</i>	<i>Year</i>
Venice – Istanbul	OrientExpress	100	8000,00	80,00	3	2016

Table 20. Example of checkmybus.it database

For public passenger transport services by rail and road a mean national fare is assumed, based on the fares established by the regulation authority (e.g. Ministry of Transport for long distance rail subsidised services , Regions for regional rail services, Municipality or Agenzie di Bacino for bus, tram, metro).

Finally, as will be described in Section 2.9, we have modelled also **carpooling** prices.

### 2.8.2 An analysis of prices

We initially use the data collected to compare prices of the three land transport modes considered and use literature sources for air transport. Figure 18 collects all unitary prices per km obtained for every OD couple, for rail and coach. To have a clearer picture of land transport, we added also carpooling prices, obtained from Blablacar platform. A similar overview of airfares in function of distance is included in Malighetti et al. (2014), where they obtain asymptotic functions of prices per km of Ryanair and easyJet ranging from 0.20-0.25 €/km for shortest 2-300 km routes, to 0.05 €/km or less for longer routes. The chart includes both discounted and non-discounted 2<sup>nd</sup> and 1<sup>st</sup> class prices, in order to have a better picture of price positioning of the different modes.

The Figure 18 contains:

1. The daily average of 1<sup>st</sup> class flexible fare (all available trains);
2. The daily average of 2<sup>nd</sup> class flexible fare (all available trains);
3. The daily average of the lowest discounted fare (all available trains);
4. The lowest daily fare available (the cheapest train);
5. The monthly average of coach fares;
6. The average of Blablacar “fares”.

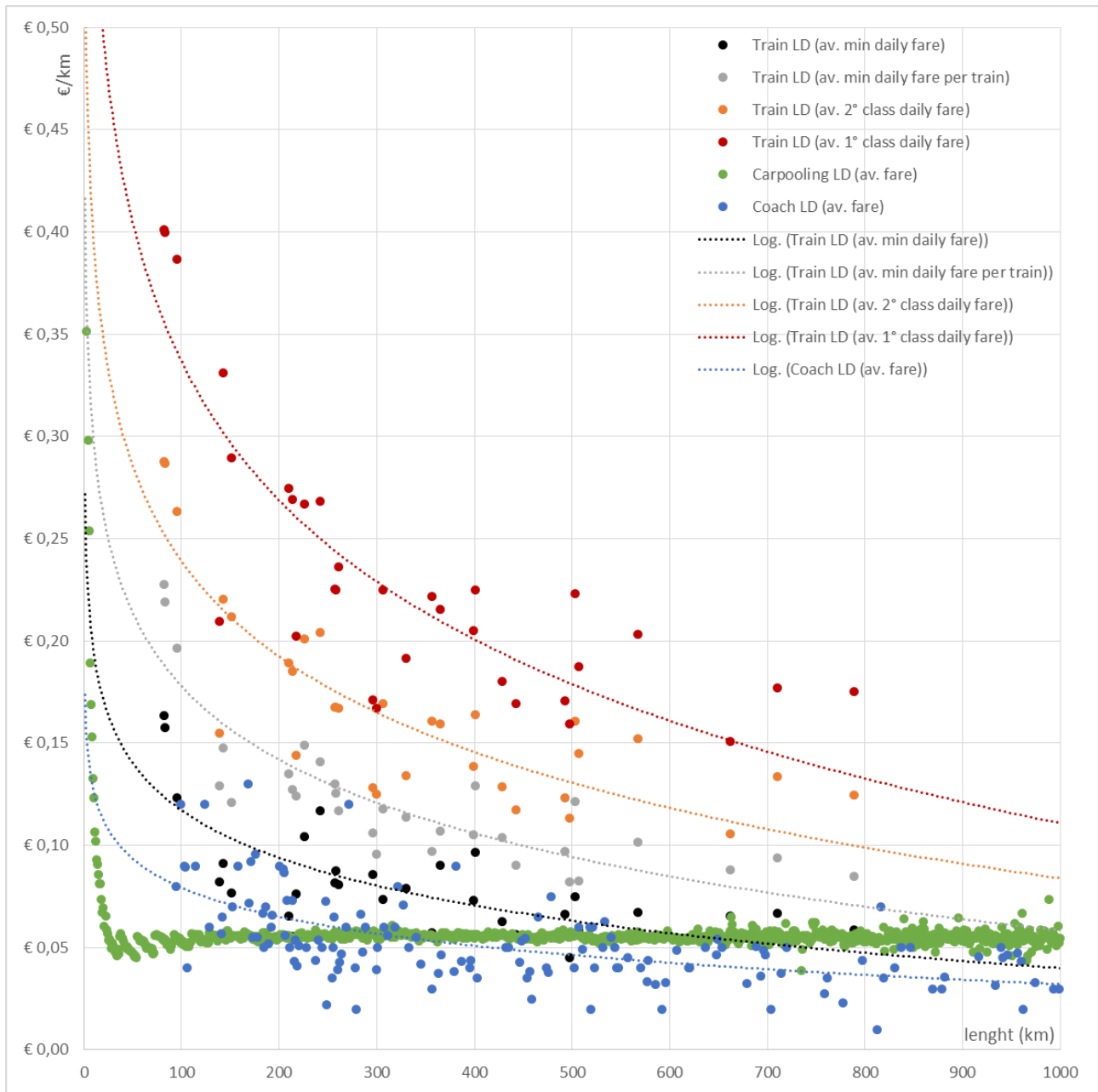


Figure 18 Distribution of fares (€/km) for all Italian long-distance services. Source: our elaborations.

A first point is that there is a partial overlapping between coach and rail markets, including high-speed one, as already found in literature (Beria et al., 2018b). In general, notwithstanding the natural variability of observations, we can recognise relatively clear price policies, approximated for readability's sake with a set of logarithmic functions describing a progressive reduction of €/km as distance increases.

Interestingly, rail fares are always above the two competing modes (with full fares even 4 or 5 times higher, according to distance travelled). However, looking at the lowest train fare, the trend becomes very similar to the average coach fare, ranging from +50% to +25% at 1,000km or more. What is more, looking at single prices, there are numerous situations in which the cheapest train option is well below a similarly long coach route. In other words, if one traveller is adaptable and have no train preference, he can find rail tickets that are sometimes not significantly higher than a coach option or even cheaper. Actually, it appears that coach companies assume the lowest train fare as the highest price that a possible user is willing to pay for their service.

Different are the considerations for carpooling. This “mean” of transport, by definition (Chan et al., 2012), is not intended to result in a financial gain. Consequently, the contribution depends linearly on distance through gasoline price plus, possibly, highway toll. This particular situation allow carpooling to be the cheapest option, both in respect to coach and train, only up to 200 km. In the range between 200 and 400 km coach becomes competitive and on higher distances carpooling prices more than the cheapest train tickets. In this sense, the claim that carpooling is threatening and competing on price with long-distance public transport is true limitedly to the shortest routes, while public transport returns cheaper for the longest.

Looking with more detail at rail market, Figure 19 shows the unit price per route in function of distance, both for Italo and Trenitalia’s services, classifying the routes of the latter between those under competition and not.

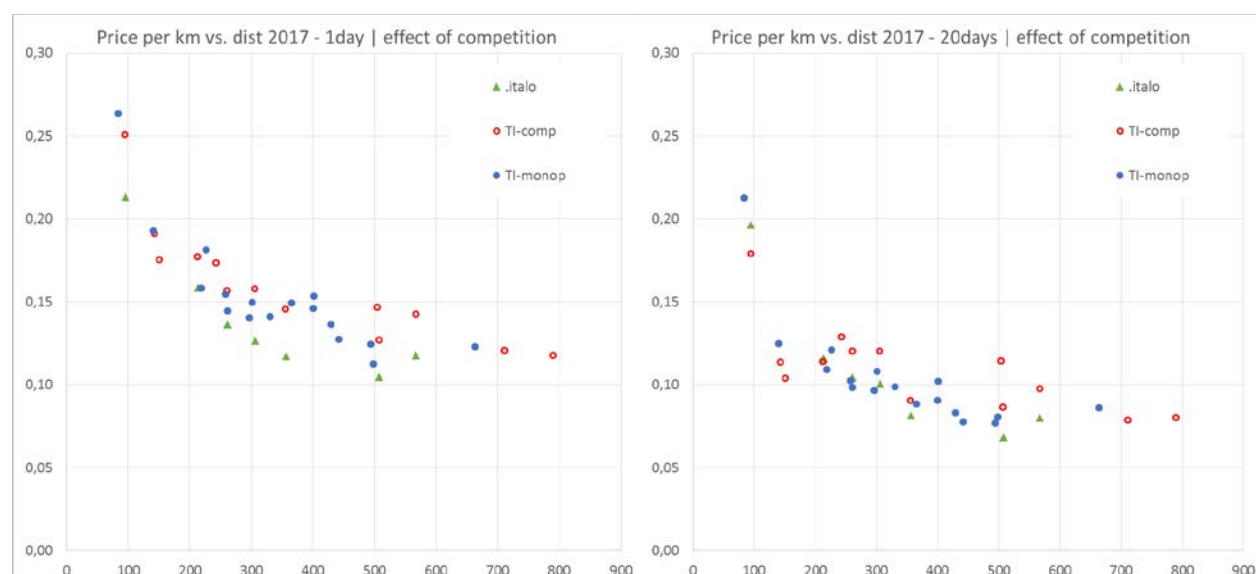


Figure 19. Effect of competition. Comparison of €/km between Italo, Trenitalia in competition and Trenitalia in monopoly routes. 20 and 1-days advanced purchase, Monday-Friday.

Prices are substantially affected by the distance, ranging from about 25 €cent/km on the shortest routes (Milan – Brescia and Florence – Bologna) one day in advance, to about 12 €cent/km on 7-800 km routes. Purchasing tickets in advance (20 days, in the example) allows saving about 5 €cent/km.

Looking at Italo’s prices, we see that it is, as expected, systematically cheaper than the incumbent (see Table 21), except for the two shortest routes 20 days before departure. Its slimmer organisation allows to lower production costs (Giuricin, 2018) and to stay on a lower price level, compatible with its minor market share and lower network effect.

Interestingly, Trenitalia’s prices are not significantly different between ODs in competition and in monopoly (rather the opposite). In other words, Trenitalia is *not* pricing, as one would expect, more on routes where it is alone with respect to routes where Italo is present. This apparently counterintuitive fact should be considered in the light of evolution of competition over years. Trenitalia prices *were* 20-30% higher before 2012, as already documented in literature (Cascetta & Coppola 2015; Desmaris, 2016), but this decrease is *now* stabilised and no price-war is taking place. Moreover:

- a. the routes analysed and in particular those where NTV is present, are among the “richest” in the country and where high-speed fostered the shift of business and tourism traffic<sup>3</sup> to rail, which is usually associated to higher prices;

<sup>3</sup> The above point at 500 km is the Rome-Venice OD, a typical route of international tourism.

- b. too high prices could push NTV to expand fleet and network, which actually happened between Milan and Venice;
- c. Trenitalia *learned* that yield management can be used everywhere maximising revenues despite lowering past prices.<sup>4</sup>

OD distance	OD	1 day before	10 days before	20 days before
95	Bologna - Florence	-15%	0%	10%
213	Milan - Bologna	-10%	-3%	2%
261	Rome - Florence	-13%	-11%	-13%
306	Milan - Florence	-20%	-14%	-16%
356	Rome - Bologna	-19%	-13%	-10%
507	Rome - Verona	-18%	-18%	-21%
567	Milan - Rome	-17%	-22%	-18%

Table 21. Comparison of NTV vs. Trenitalia prices, on selected routes. Average of 2017 cheapest tickets, 10-days advanced purchase.

In conclusion, we can affirm that competitors price differently, but routes under competition, in the particular case of Italy, are not necessarily cheaper than the monopoly ones, as already found in literature for air transport (Malighetti et al., 2014). Price-war is just one of the possible outcomes of competition (Tomes et al., 2014), and is not the case of Italy. The two companies behaved quite effectively (NTV after 2017) to maximise prices avoiding predatory practices, which were not necessary in a context of rising demand, shifted from air and private car.

### 2.8.3 Fare functions for the model

Fares are modelled using a linear function:

$$P = p_0 + p \cdot d \quad \text{Equation 1}$$

where  $d$  is the distance and  $p$  is the price component proportional to distance, plus a fixed component independent from distance  $p_0$ . The parameters are empirically determined on a case by case basis, as they typically depend on the combination of numerous elements:

Mode	Fare	Service	Operator	Market/PSO	Competition
Coach	Regional	Conventional	...	Market	In competition
Train	Long-distance	High-speed		PSO	Monopolist
Plane	Single ticket				
Car	Monthly ticket				
Local public transport					

All possible fares are associated to three levels of “fare profiles”, i.e. the type of fare that the user, for that particular travel purpose, chooses. These profiles allow the link between travel purposes and the fare function which depends from mode, company, market conditions, etc.

<sup>4</sup> This is not uncommon. French SNCF has introduced the low-cost Ouigo services, both to maximize its revenues from the lower willing-to-pay customers and to prevent the entry of competitors (Crozet, 2016; Crozet & Guihery, 2018).

<i>Trip purpose (EVERYDAY MOBILITY)</i>	<i>Fare profile</i>	<i>Trip purpose (OVERNIGHT)</i>	<i>Fare profile</i>
Study	Commuter	/	
Work	Commuter	/	
Business	Business	Business	Business
Shopping	Economy	Personal	Economy
Personal	Economy		
Accompanying	Economy		
Visit relatives/friends	Family	Holiday	Family
Leisure	Family		

The general rule of the four fare profiles are:

- **Commuter:** the fare is based on monthly tickets, as the user is a systematic user.
- **Business:** the fare is flexible and is purchased late, just before the travel. The traveller is alone.
- **Economy:** the fare is not flexible and purchased early. The traveller is alone or (for cars) load factor is 1,2.
- **Family:** the fare is the economy one, but the travel is done by a group of 3. Group fares seldom exist in Italy and consequently for public transport Economy=Family. Car prices, to the contrary, are shared.

The following table crosses the demand side, represented by fare profiles, with supply side, represented by the combination of four layers found to be influent in defining price levels:

- Mode: Coach, Train, Plane, Car, Local public transport
- Regulation: planned supply and prices at the “regional” scale, planned supply and prices for long-distance service (“PSO”), market
- Market: monopoly or competition
- Service type: for rail, conventional and HS services.
- Carrier: carrier or carrier type, such as traditional or low-cost in the air sector.

	<i>mode</i>	car	urban tr.	local buses	coach	coach	train	train	train	train	train	air	air				
	<i>regulation</i>						regional	PSO	market	market	market	market					
	<i>market</i>				competition	monopoly			monopoly	monopoly	competition	competition					
	<i>service type</i>							conv.	conv.	HS	HS	HS					
	<i>carrier</i>								Trenitalia	Trenitalia	Trenitalia	Italo	legacy	low cost			
<i>travel purpose</i>	<i>fare profile</i>																
Study	Commuter	1	4	6	x	x	10a, 10b	12	15	18		23	x	x			
Work	Commuter				x	x							x	x			
Business	Business	2	5	7	8	9	11	13	16	19	21	24					
Shopping	Economy	1						x	x	x	14	17	20a, 20b	22	25	x	x
Personal	Economy							x	x	x						x	x
Accompanying	Economy							x	x	x						x	x
Visit relatives/friends	Family							x	x	x						x	x
Leisure	Family	3	x	x													
Business	Business	2	5	7	8	9	11	13	16	19	21	24	26	28			
Personal	Economy	1															
Holiday	Family	3															

Figure 20. Fare profiles and fare functions according to mode and market conditions

In this section we will determine and describe the fare functions of Figure 20.

### One-way rail *economy* and *family* fares

To determine the fare functions for one-way fares for economy and family groups, we use the real fares of 2017 and assume that an economy user will book 20 days in advance and chose the best available price for each service category, usually not flexible.

From the database we analysed the price-differences and finally obtained the following classification of the 30 routes and services:

- PSO on conventional network:** all existing IC trains belong to this category, all provided by Trenitalia
- Market services on conventional network:** all Trenitalia Frecciabianca trains. There is no distinction between competition or monopoly, as to date competition is limited to HS network.
- Market services on HS network, in monopoly:** during 2017 all HS OD couples were offered both by Trenitalia and Italo except those on the Torino – Brescia sub-section, recently opened (dec 2016). Among the 30 OD routes monitored, Torino-Brescia and Milano-Brescia are the only HS market services provided in monopoly by Trenitalia and operated as Frecciarossa.
- Market services on HS network, in competition:** average price of Frecciarossa and Frecciargento trains for Trenitalia and the price of Italo.

The chart of Figure 21 show the results of the clustering.

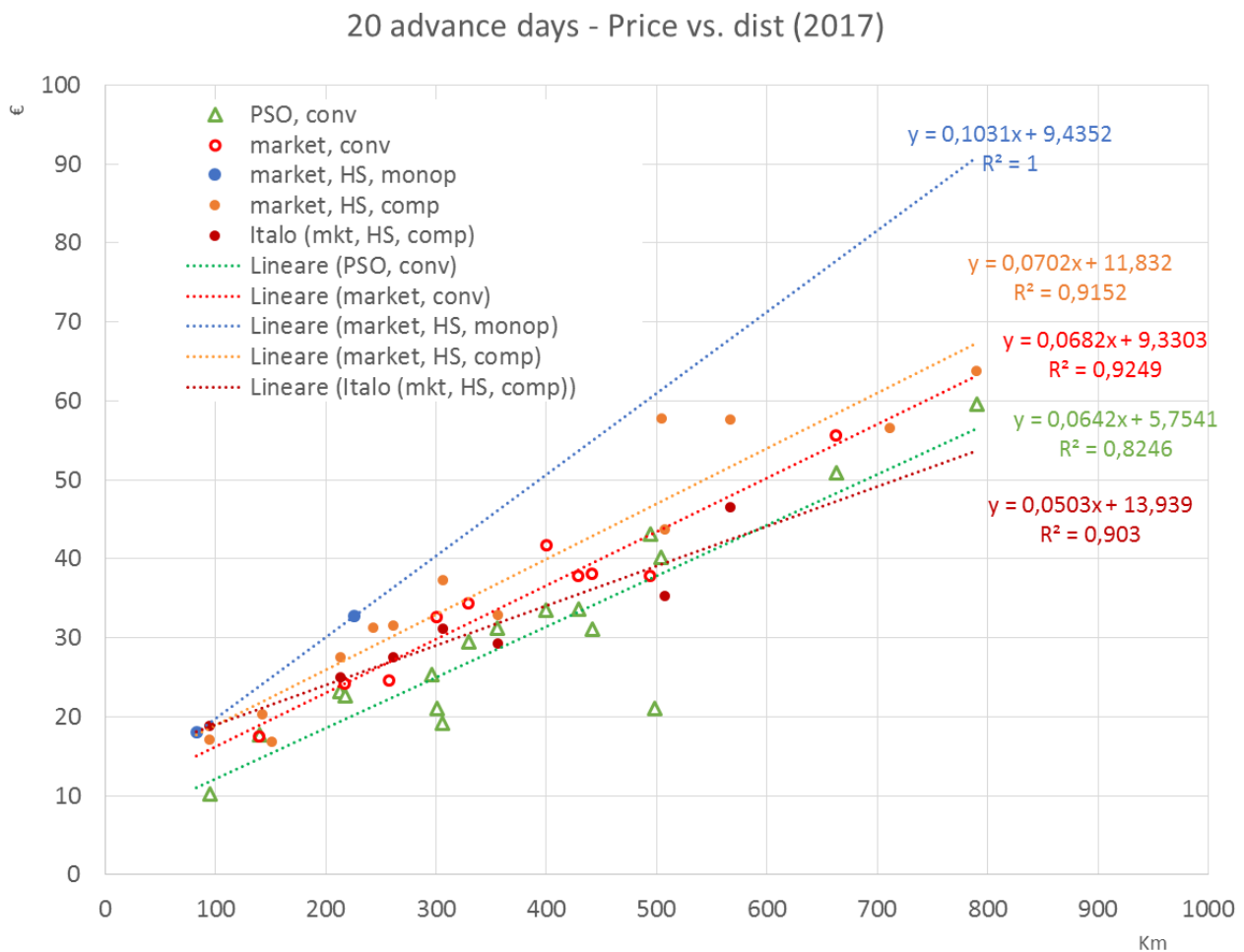


Figure 21. Clustering of Price(distance) functions for long-distance trains, 20-days before departure.

All series are well represented by linear functions, pointing out few outliers. The long ODs Milan-Naples and Torino-Rome (the rightmost point of the series *market*, *HS*, *comp*) stay well below the interpolation line as on both routes the air alternative booked in advance is cheaper and travel time competitive. The Rome-Bari (the lowest triangle at 500km) with intercity train has prices 50% lower than similar routes. In this case travel time is so uncompetitive and many coaches exist, that the train is not an option. Removing the three outliers and ignoring the *market*, *HS*, *monop* series, with too few points, we obtain Figure 22.

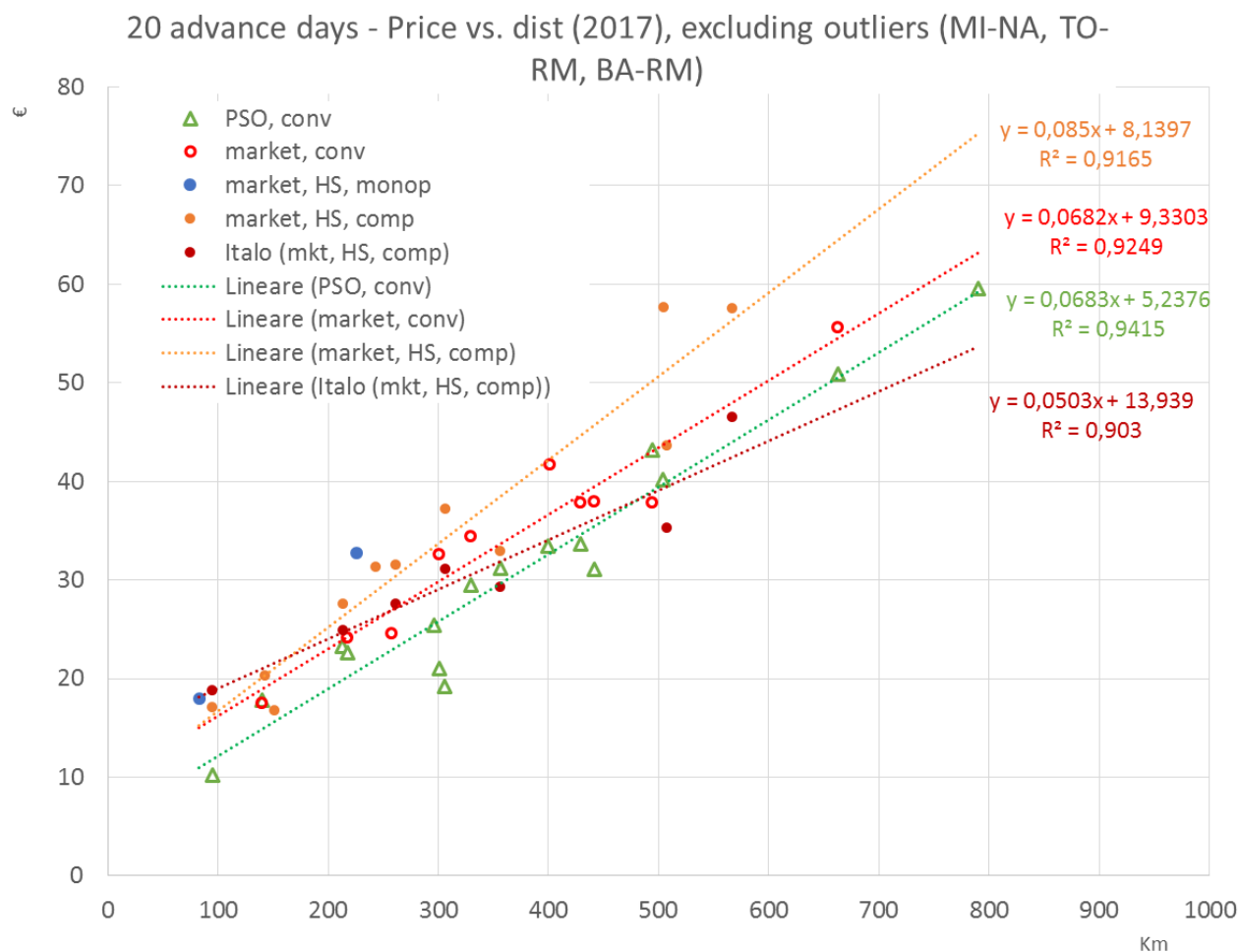


Figure 22. Clustering of Price(distance) functions for long-distance trains, excluding outliers, 20-days before departure.

Finally, we assume that (the few) monopoly HS services cost 20% more than those in competition and that above 700 km HS rail prices remain constant due to competition with air transport, obtaining the following functions (Table 22 and Figure 23).

<i>function</i>	$\alpha$	$\beta$	
(14)	5,2376	0,0683	$y = 5,2376 + x \cdot 0,0683$
(17)	9,3303	0,0682	$y = 9,3303 + x \cdot 0,0682$
(20)	8,1397	0,102	$x < 700$ : $y = 8,1397 + x \cdot 0,102$ $x > 700$ : $y = 79,54$
(23)	8,1397	0,085	$x < 700$ : $y = 8,1397 + x \cdot 0,085$ $x > 700$ : $y = 67,64$
(26)	13,939	0,0503	$x < 700$ : $y = 13,939 + x \cdot 0,0503$ $x > 700$ : $y = 49,15$

Table 22. Price(distance) functions for rail long-distance trains, economy and family profiles.

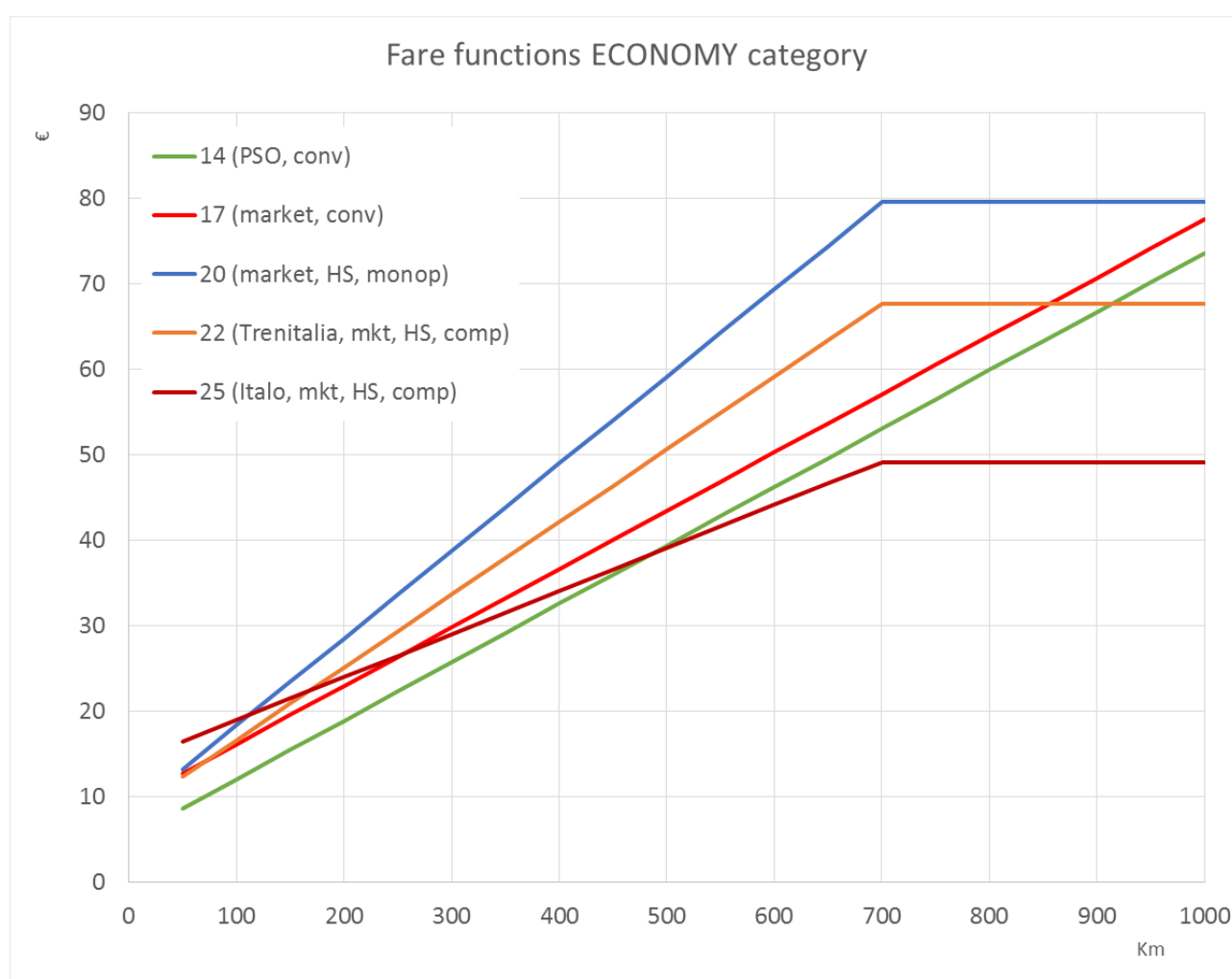


Figure 23. Price(distance) functions for rail long-distance trains, economy and family profiles (14, 17, 20, 22, 25).

Interestingly, looking at prices 1-day before departure (), all of the outliers evidenced are not such anymore: prices continue growing beyond 700km and Bari-Rome is almost perfectly aligned.

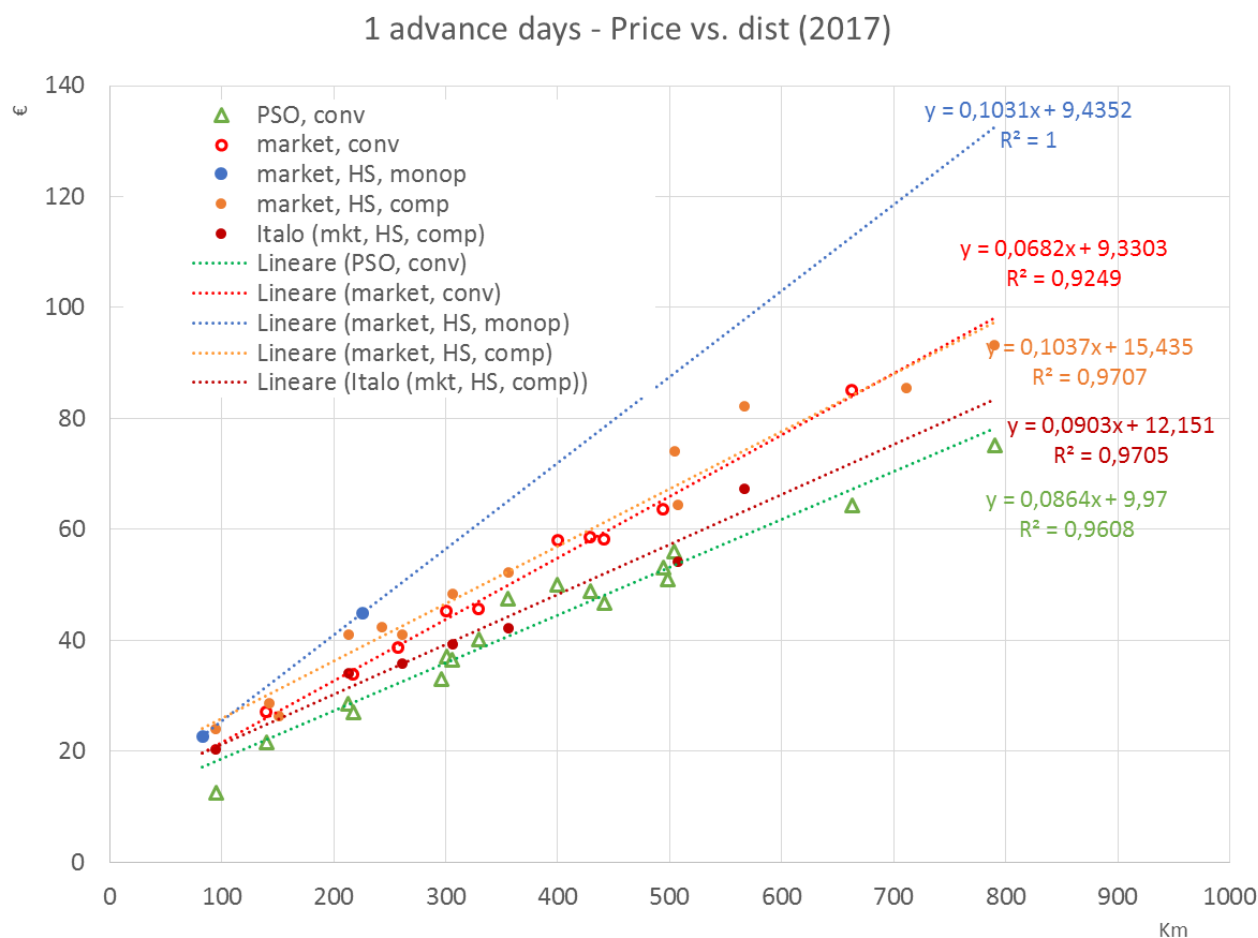


Figure 24. Clustering of Price(distance) functions for long-distance trains, 1-day before departure.

### Commuters rail fares

Rail commuters can use two different types of discounted tickets:

- Monthly or yearly tickets, allowing for unlimited travels on groups of trains (e.g. the Intercity ones or the Regional ones on one route);
- Carnets, available on market services only (both from Trenitalia and Italo), including a certain number of travels in a period of time (e.g. 20 travels in one month).

We assume that commuters use the monthly ticket making 20x2 travels a month for all train categories (and on limited distances), except HS for which we use the carnet option, assuming that they are not commuting daily.

A selection of Trenitalia's monthly tickets is depicted in Figure 25. As one can see, linear functions represent quite well the prices for every train type except HS ones (that in fact "prefer" carnets) and regional trains, split in two distance thresholds.

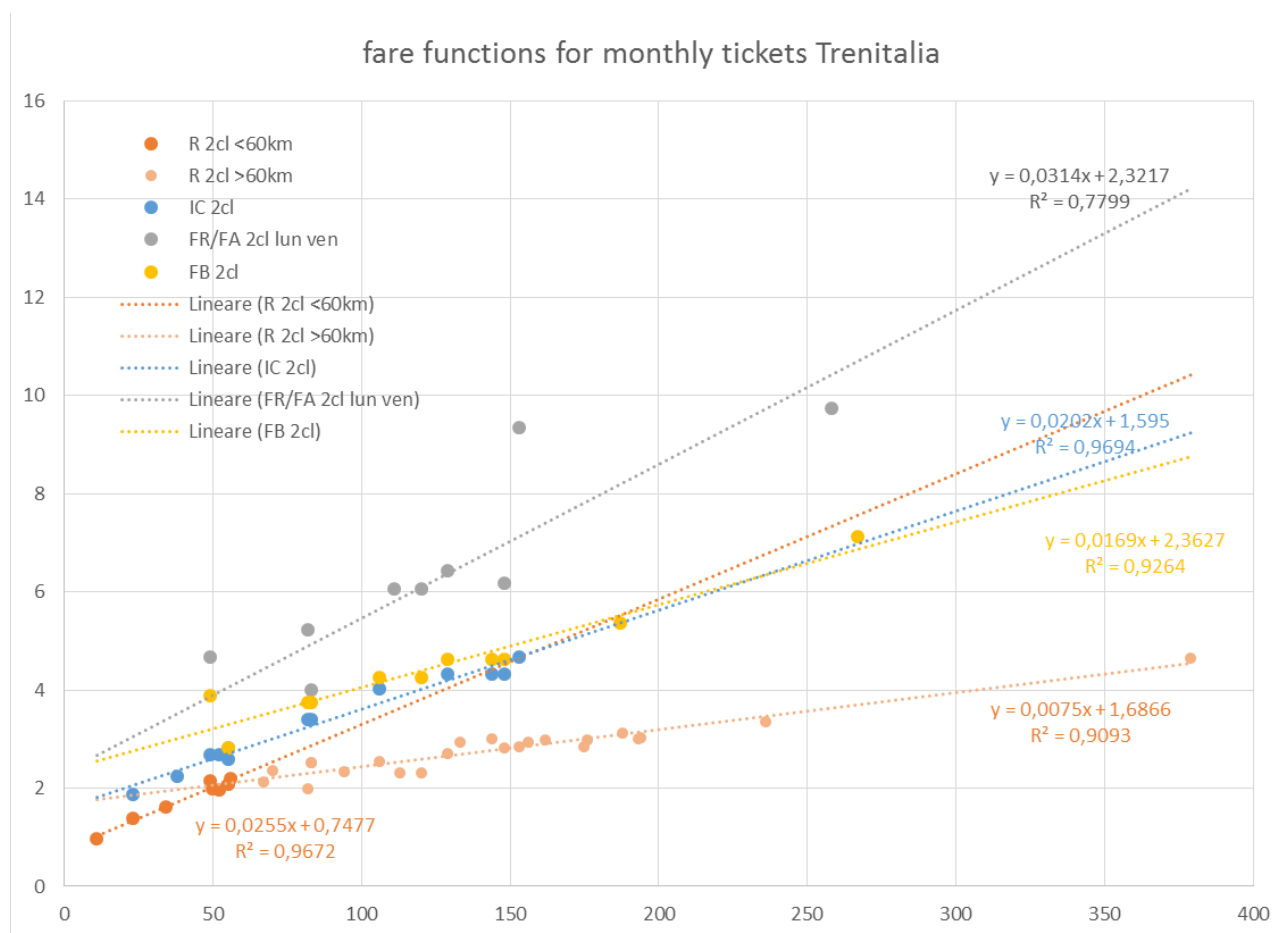


Figure 25. Trenitalia's monthly tickets. Price(distance) functions, assuming 40 trips per month.

If one is not commuting everyday, Trenitalia's carnets for HS are more convenient for commuters not commuting everyday (which makes sense, on the long-distance). Figure 26 shows a good representativeness of the linear interpolation. Variations depend on discrete distance thresholds rather than on different pricing policies of Trenitalia.

To the contrary, Italo's pricing is not rigorously following a linear function, not only because on the Milan-Venice services (recently opened) there is an extra discount (less than 5€ a trip).

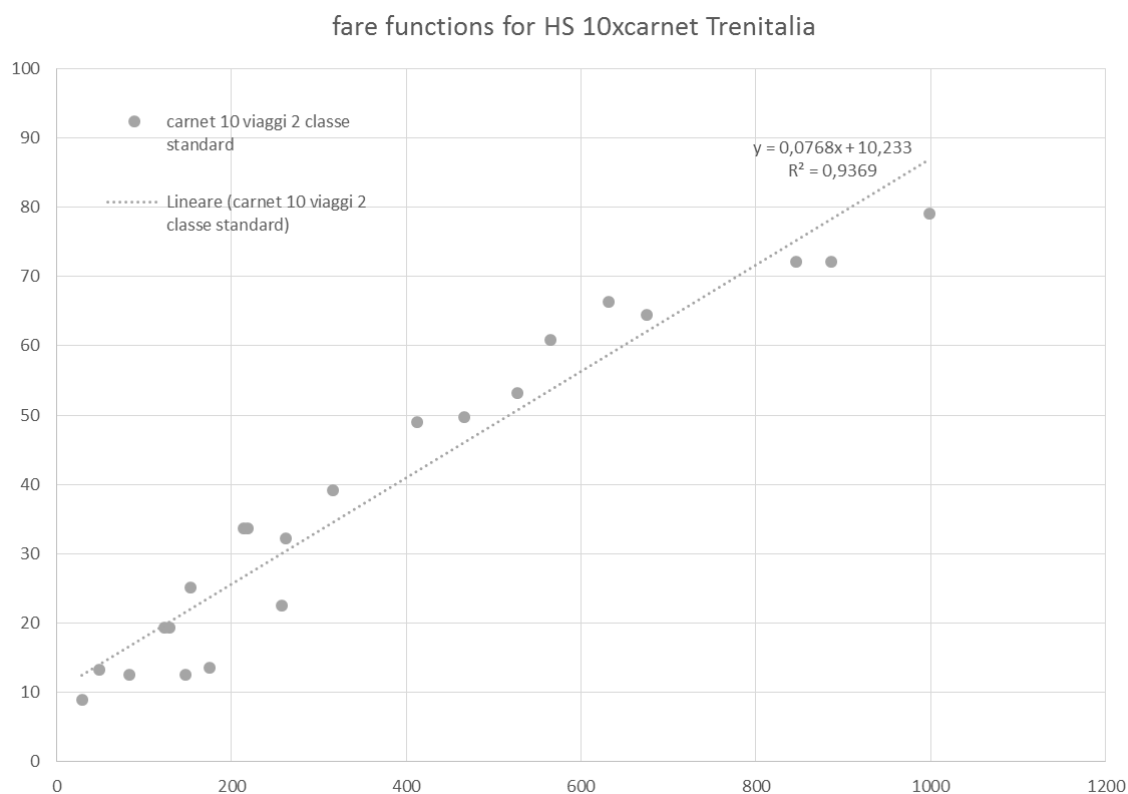


Figure 26. Trenitalia's HS carnets. Price(distance) functions, per trip.

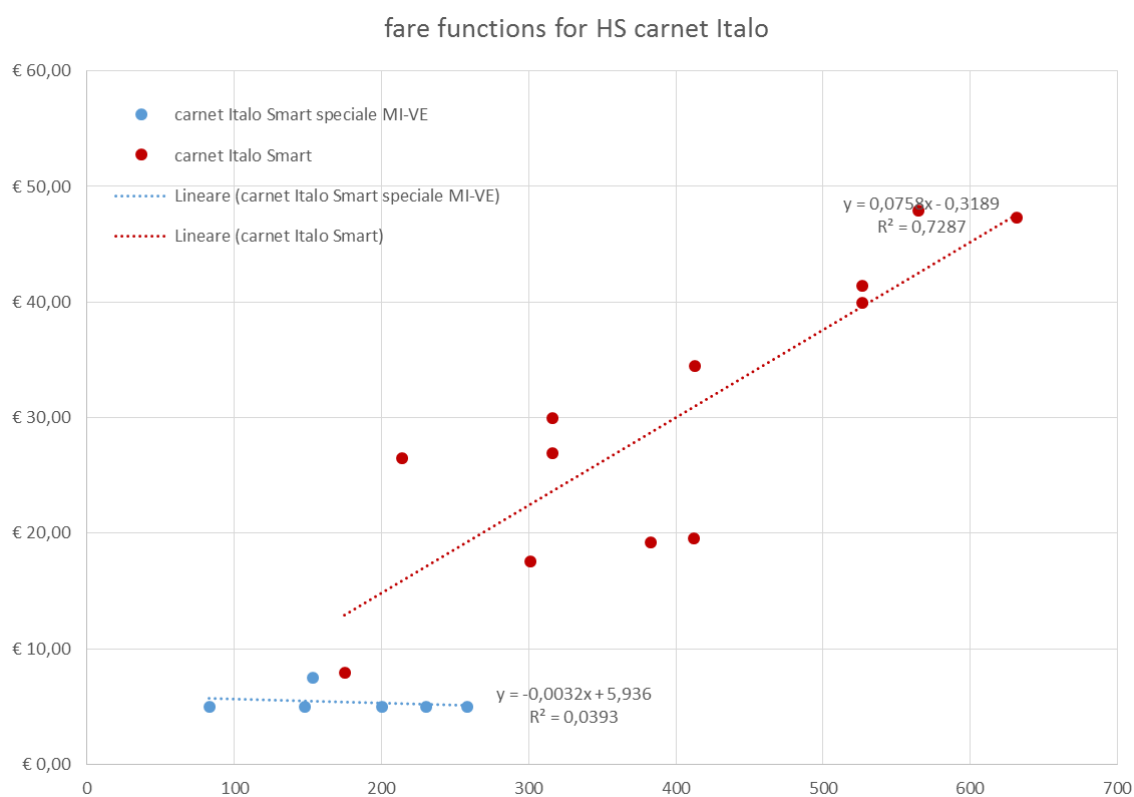


Figure 27. Italo's HS carnets. Price(distance) functions, per trip.

Overall, the functions chosen to represent commuters' rail prices are the following ones (Figure 28), limited to reasonable distance ranges.

<i>function</i>	$\alpha$	$\beta$	
(10)	0,748	0,026	$x < 60: y = 0,7477 + x \cdot 0,0255$
	1,687	0,008	$x > 60: y = 1,687 + x \cdot 0,008$
(12)	1,595	0,0202	$y = 1,595 + x \cdot 0,0202$
(15)	2,3627	0,0169	$y = 2,3627 + x \cdot 0,0169$
(18)	10,233	0,0768	$y = 10,233 + x \cdot 0,0768$
(23)	0,3189	0,0758	$y = 0,3189 + x \cdot 0,0758$

Table 23. Price(distance) functions for rail, commuters profiles.

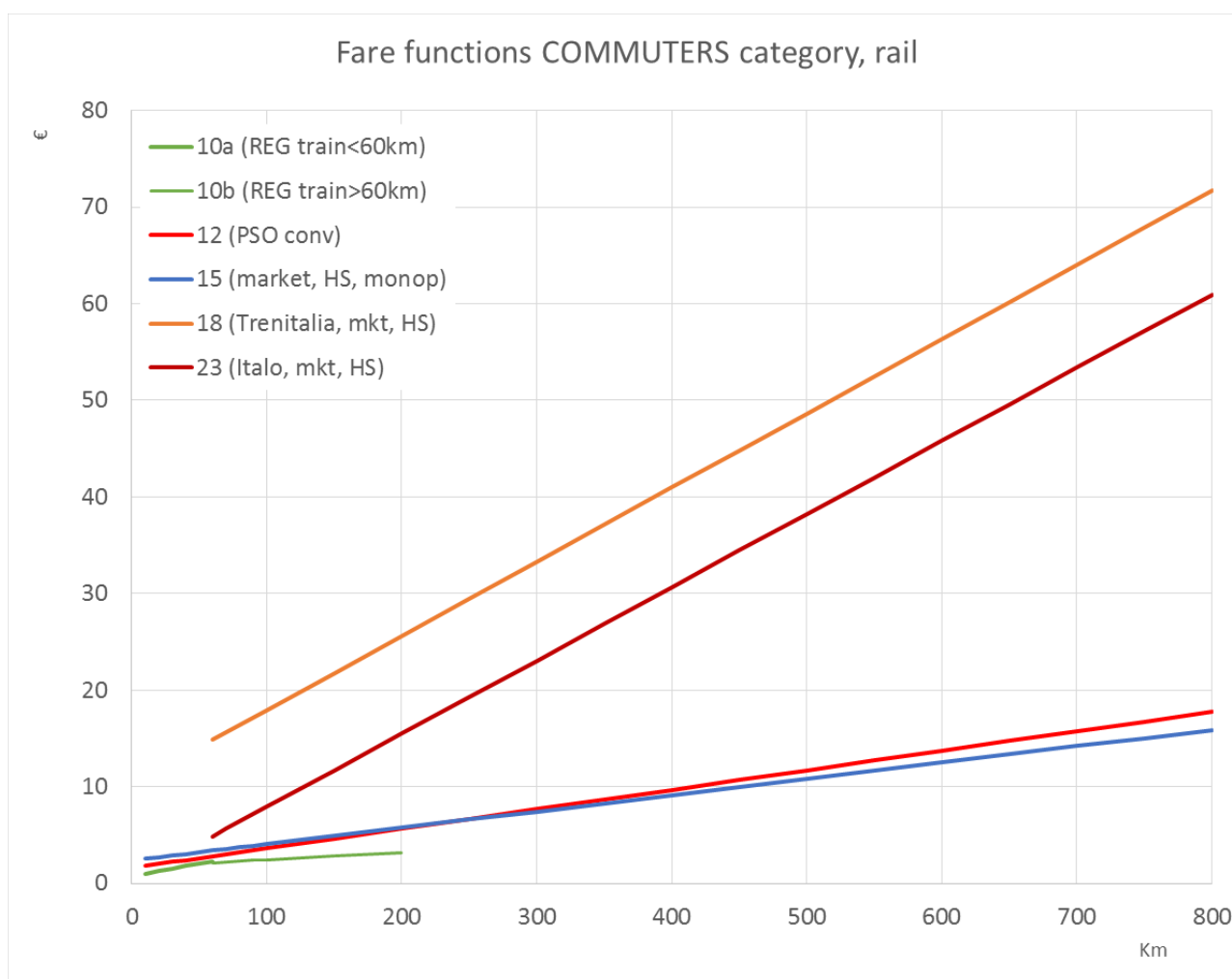


Figure 28. Price(distance) functions for rail, commuters profiles (10, 12, 15, 18, 23).

## 2.9 Alternative mobility (Blablacar, sharing, cycling)

Alternative forms of mobility are gaining a larger role, also for long-distance transport. Moreover, they are a potential source of data, due to their strict link with mobile applications.

In QUAINT we focused on the main long-distance alternative transport mode, namely carpooling via BlaBlaCar. By means of a web-crawler, we extracted available trips on the web-platform for 81 days during 2015. Overall we collected more than 400.000 trips and 71.000 individual users. The interest for this data is twofold:

1. To map the phenomenon of long-distance carpooling in Italy
2. To provide potential calibration data for trip distribution and for modal share

With respect to the first issue, we completed a large geographic study, which was published in a report and presented at a national conference (followed by a small article). An article for publication in an international scientific journal is currently in elaboration and the submission is expected before July.

The use of such data as observations for a model calibration has not yet been implemented. The possibilities are two, not alternative. Distribution models usually adopt gravitational models or discrete choice models to decide how generated trips from a zone are distributed. However, this typically works for short-trips, but is evidently inadequate for long-distance trips. In fact, drivers of long-distance mobility are not just the generalised travel cost or the attraction power of the destination, but include for example touristic supply, patterns of internal migrations (e.g. out-of-home university students tend to choose the destination city also according to the existence of relations, such as friends or relatives). In this sense the BlaBlaCar trips could become a proxy of a general non-commuting attractiveness of zones.

A second use lays in the properly said calibration. In a function describing flows from  $i$  to  $j$ ,  $F_{ij}$  is split into  $m$  modes and subject to calibration. If the modal split includes also a mode “carpooling” with its own generalised cost, the data collected become a large number of observations to calibrate the parameters.

## 2.10 Tourism

Tourism is an important component of long-distance demand. Different sources exist, covering both touristic supply and demand and with a good level of geographic detail. Unfortunately most of sources do not cover the “transport” dimension of the phenomenon and thus it is hard to obtain modal matrices of touristic trips. In addition, tourism mobility is only in limited cases describable in terms of origin (home) and destination (touristic venue). Usually, tourism involves multiple destinations, both reached with day-trips and with displacements.

To date, the database includes the following information, all georeferenced using the municipality base and from them aggregated at NUTS4 or NUTS5 level.

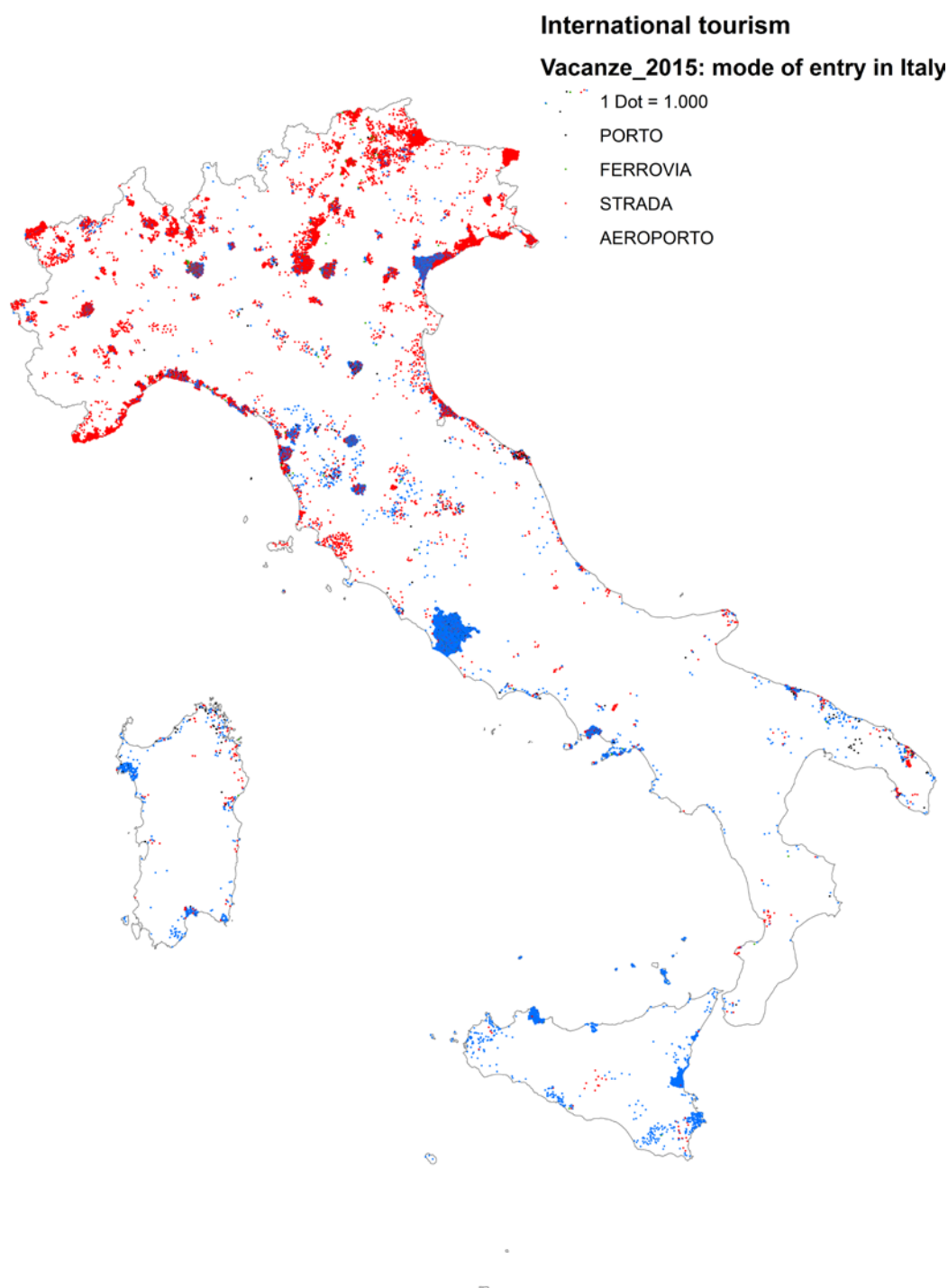
<i>Field (selection)</i>	<i>Description</i>
<b>nLETTI_ALB</b>	Number of beds, hotel-like structures
<b>nLETTI_OTH</b>	Number of beds, other structures (B&B, camping, ...)
<b>nArr_i_ALB</b> <b>nArr_s_ALB</b>	Touristic arrivals (Italians and foreigners), hotel-like structures
<b>nArr_i_OTH</b> <b>nArr_s_OTH</b>	Touristic arrivals (Italians and foreigners), other structures (B&B, camping, ...)

<b>nPre_i_ALB</b> <b>nPre_s_ALB</b>	Nights spent (Italians and foreigners), hotel-like structures
<b>nPre_i_OTH</b> <b>nPre_s_OTH</b>	Nights spent (Italians and foreigners), other structures (B&B, camping, ...)
...	

Table 24. Main fields related to ISTAT tourism database, of the *comuni* shapefile,

In addition, a systematic work has been done to analyse the data and the potential uses of the ONT (Osservatorio Nazionale Turismo) of the National Bank of Italy (BdI). The database is extremely rich, providing information also on the transport mode of entry in the country. Unfortunately, it deals with international tourism only and thus severely under-representative for the southern regions, more visited by Italians. On the other side, it is continuatively available since 1997. Figure 29 depicts the way foreign tourists entered Italy in 2015. It is clearly visible that northern regions, except for cities, are mostly accessed by car, even for those places where rail would be potentially interesting (e.g. Verona or Trentino provinces). Southern regions, instead, are reached by plane, showing that no land accessibility is needed to guarantee an international tourism. Tuscany and Umbria are, interestingly, the sole places where both modes coexist, both due to its relative vicinity to European markets and to the type of tourism having place there, characterised by spread and small attractors, impossible to enjoy without a private vehicle.

Figure 29. International tourism in Italy: main transport mode of entry in Italy, by municipality. Source: our elaborations on ONT.



## 2.11 Health and Student mobility

A last component of the database deals with two mobility niches, namely the long-distance mobility done for health purposes and the mobility related with out-of-home students.

The first one is represented by trips done by patients to hospitals others than the home-one, to reach otherwise unavailable services, but also the one related to relatives and friends visiting the patients. This mobility is partially known and collected by public sources, but the scale is only regional. We therefore know (for 2012) the number of patients cured out of their region, as exemplified in Figure 30. Apart some obvious border effects

(e.g. Novara patients cured in Milan), the long-distance patterns are clearly visible and involve mostly northern regions.

Figure 30. Patients originated from other regions and directed to Lombardy

## Health mobility 2012

Region of origin of admitted, per year

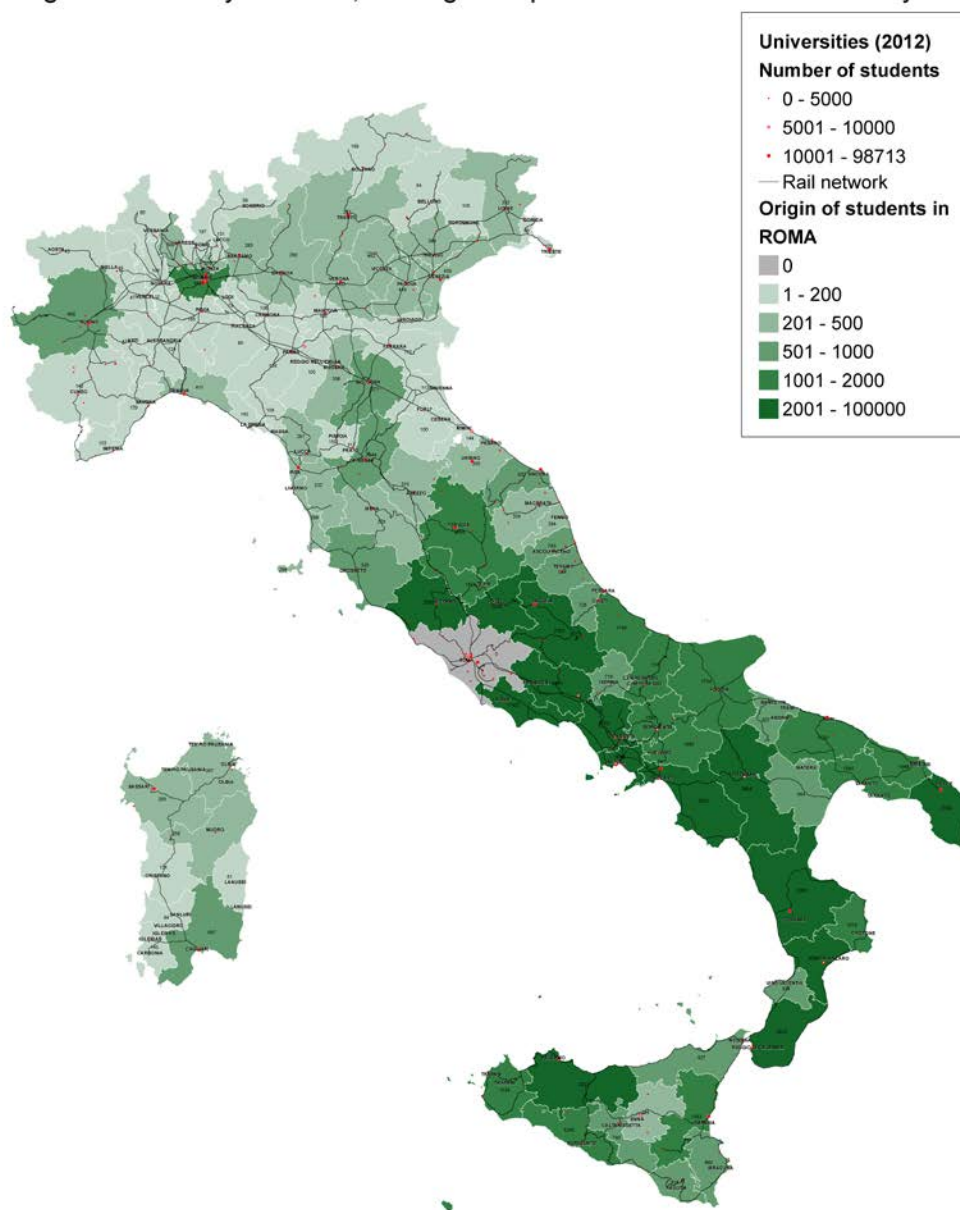


The second niche deals with out-of-home university students. In this case we do not know the number of trips they do, but just their home province and their study province. This could be a reasonable proxy to estimate their long distance trips, for example to visit parents and friends (e.g. weekends, bank holidays, etc.).

Figure 31. Origin of out-of-home university students. Example: Rome. Source: our elaborations on MIUR database.

## Mobility of students

Origin of university students, coming from provinces other than University one



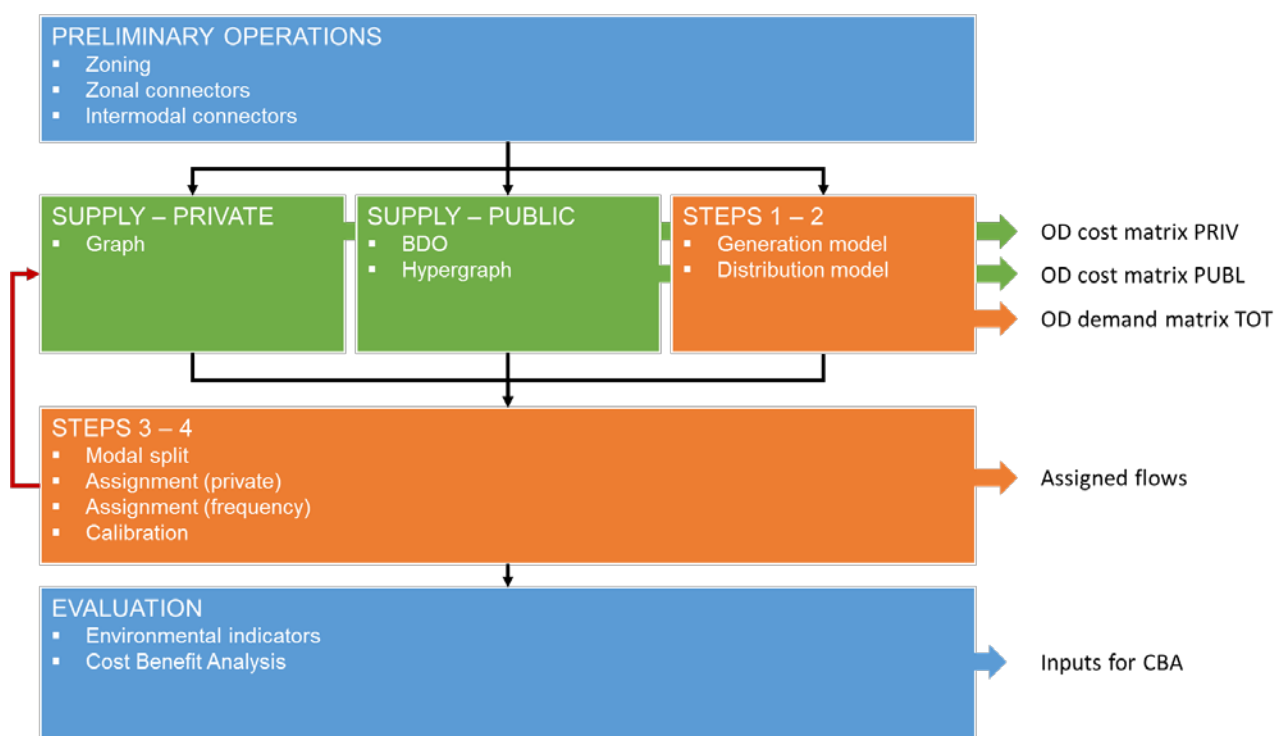
### 3. The structure of the model

#### 3.1 General structure and state of the art

The construction of the transport model involves numerous steps, whose logical structure is represented in Figure 32. **Preliminary** operations include zoning and the definition of connectors. Both operations are crucial to obtain good results. Of course the more are the zones, the better is the result, but “quantity” alone is not insurance of correctness. In parallel, **supply modules** are used to calculate generalised costs, initially for an empty network and later on, when assigned flows are available, also for the assigned network (congestion).

Independently, **generation and distribution models** are prepared, in order to obtain the total OD demand matrix. OD costs matrices and total demand matrix, together, are used by steps 3 and 4 to perform **modal split and network assignment** (including average speed). The last operations are done iteratively until calibration is satisfactory. Finally, assigned networks and the related cost matrices can be used as inputs by specific **evaluation modules**, such as environmental impact and cost-benefit assessment.

Figure 32. General structure of the model.



To date, part of the model structure is implemented. In addition, we decided to increase the zoning detail, in order to be able to simulate more properly urban nodes. The following Table 25 summarises the state of the art of the work and the following sections go more in deep in modelling choices.

		371 zones model	1764 zones model	software
Preliminary	Zoning	completed	completed	
	Zonal connectors	completed	completed	GIS
	Intermodal connectors	completed	completed	
Supply - priv	Graph	completed	completed	GIS + Access
Supply - publ	BDO	completed	completed	Access
	Hypergraph	completed	completed	Access + Python
1 – 2 steps	Generation	beta	completed	
	Distribution	beta	completed	Access + Excel
3 – 4 steps	Modal split	beta	completed	Access
	Assignment (private)	beta	completed	CUBE
	Assignment (frequency)	beta	completed	CUBE
	Calibration	beta	completed	Access + Excel

Table 25. State of the work - model structure

## 3.2 Zoning

Zoning is the most crucial of the preliminary activities because influences the entire modelling exercise. The previous version of 2009 of the official ministerial model (called SIMPT) was limited to just 267 zones, as visible in Figure 33.

Figure 33. The zoning of Ministerial SIMPT model, in the last 2009 version



Our **basic model** (called **NUTS-4**) is based on **371 zones**, which is already more detailed than the ministerial one (see Figure 34).<sup>5</sup> This model is already working both for private and public transport for the cost-side. Then, we decided to further detail the zoning, reaching **1764 zones**, corresponding to **NUTS-5** level (see Figure 35). Both levels do not have a direct correspondence with any Italian administrative boundary (intermediate between single municipalities and provinces). Each zone identifies a traffic catchment area that generally represents a homogeneous aggregation of municipalities based on their area and population.

<sup>5</sup> Moreover, our zoning overcomes the evident choice of SIMPT to separate the main city from the rest of the province, which is a reasonable proxy for rail transport, but not for road transport.

Figure 34. The 371-zones zoning ("basic model")





Figure 35. The 1764-zones zoning ("T5 model")

The picture below gives an idea of the impact of passing from the basic zoning to the 1764-zones zoning. In the example, at the NUTS-3 we have the entire province of Bologna. In the NUTS-4, which is the 371-zones level, the city of Bologna is one zone, surrounded by three suburban zones. The town of Imola is a separate zone, being a relatively autonomous centre not belonging to eastern Bologna zone. In the NUTS-5 zoning, even Bologna is split in four zones, and the rest of the province is divided in 22 further zones. At this level, each zone typically includes just one town (for example Crevalcore, coded BOL43, 13.000 inhabitants), surrounded by low population rural areas.

Figure 36. Example of NUTS-3-4-5 zoning around Bologna.



It is worth mentioning that the 371-zones model is perfectly **suitable for any long-distance simulation**, but may fail in correctly allocating flows for city-orbital roads or other specific situations. In the example of Bologna, the zone comprising the northern periphery of the city is including most the A1 and of the orbital road, which would eventually result empty of local traffic. However, local traffic generates congestion on those crucial road segments, possibly modifying also long-distance choices (e.g. a person going from Modena to Imola could decide for the Via Emilia road instead of the A1, if the A1 is too congested around Bologna). In general, our zoning allows us to catch the differences among main centres (e.g. Bologna, where most of services are concentrated), secondary centres (e.g. Imola, served by few direct long-distance services or served via one change) or rural/dispersed areas (e.g. the plains or the valleys, with no long distance services and consequent cost to access the main centres).

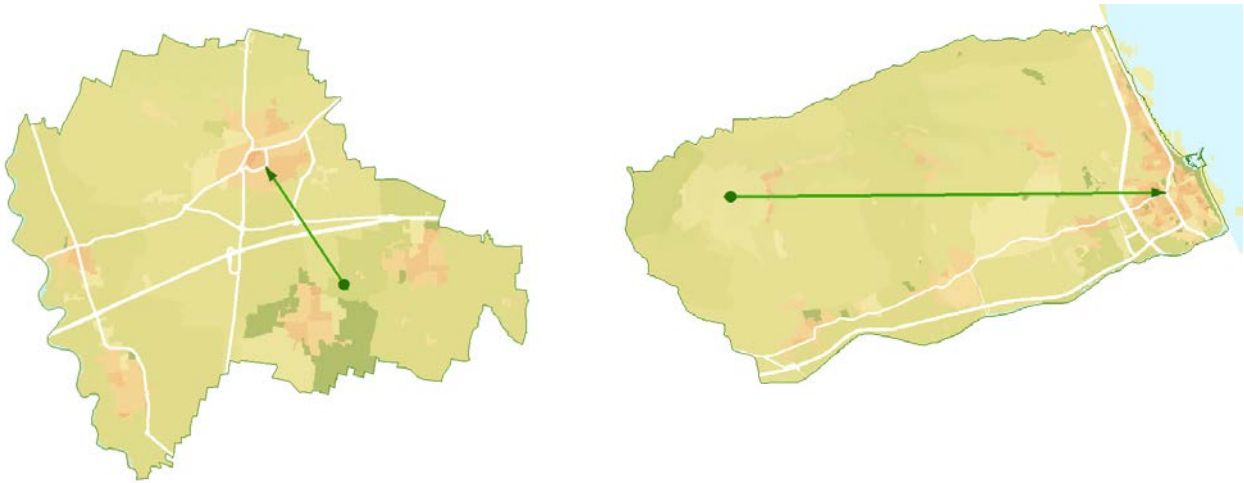
### 3.3 Connectors

**Zonal connectors** connect the centroids – and consequently the OD matrix – with one node of the road network or the public transport network. The choice of such node (i.e. the point of entry of flows on the networks) is a delicate operation, which has been performed manually according to specific criteria.

Firstly, the position of the connector must be barycentrical with respect to the corresponding zone, in particular with respect to its urban pattern. Generally, the centroid is connected with the core of urban areas, where most of activities and roads concentrate and/or in correspondence with access points to other networks

(e.g. the station's square), as in Figure 37. Connectors of each class should be placed on corresponding network classes. For example, NUTS-4 zones are usually connected with class 4 roads.

Figure 37. Example of connectors.



In few cases, it is not possible to recognise one main centre of a zone. In this case, the connector has been placed in the geometric barycentre of urbanised areas. In other cases, when a zone is characterised by large flows and heavily interconnected networks (e.g. a city district), more than one connector has been modelled and connected to different nodes, in order to prevent unrealistic overloads of the road network.

Public transport connectors go from a service node inside the zone (or the nearest service node if no lines have stop in the zone) to the centroid. One node for each transit mode is evaluated, so one zone could have one or more connectors depending on transit structure.

Another type of connector is that of **intermodal connectors**. Their purpose is to allow the interchange from one transport mode to another (e.g. from road to rail network). Also in this case, the selection of which interconnections are possible and where, is done case by case.

In terms of **costs**, zonal connectors are associated to a fixed cost, representing the cost of leaving each one's origin and reach the modelled network (and vice versa at destination). Differently, intermodal connectors are associated to specific interchange costs, depending from modes (e.g. all road-rail connectors depend on walking time) or to control for specific situations (e.g. a rail station particularly badly connected with public transport network). To date we attributed to each intermodal connector a cost corresponding to the walking distance, except air-road and air-air connectors, which are differentiated according to airports' local conditions.

### 3.4 Road Graph

The road graph is made of edges and nodes, but to these geometrical attributes other information were added (see Section 2.3.1 for details). Thanks to these information, some procedures compute:

- a. Using **TipoArco** and **Lunghurb**, and based on pre-defined parameters, each link is associated to performance indicators such as a capacity, a free flow speed, and two parameters  $\alpha$  and  $\beta$  ruling the speed(flow) function. More precisely, every **TipoArco** has a family of speed(flow) functions, which are selected on the basis of how much the link is urbanised.

- b. Selecting one specific simulation year (e.g. 2015), links are filtered with **Anno\_ini** and **Anno\_fin**, obtaining the network actually in operation. This is valid also for future links (e.g. a future scenario includes also link existing at that year according to current programming).

### 3.5 BDO procedures and public transport graph

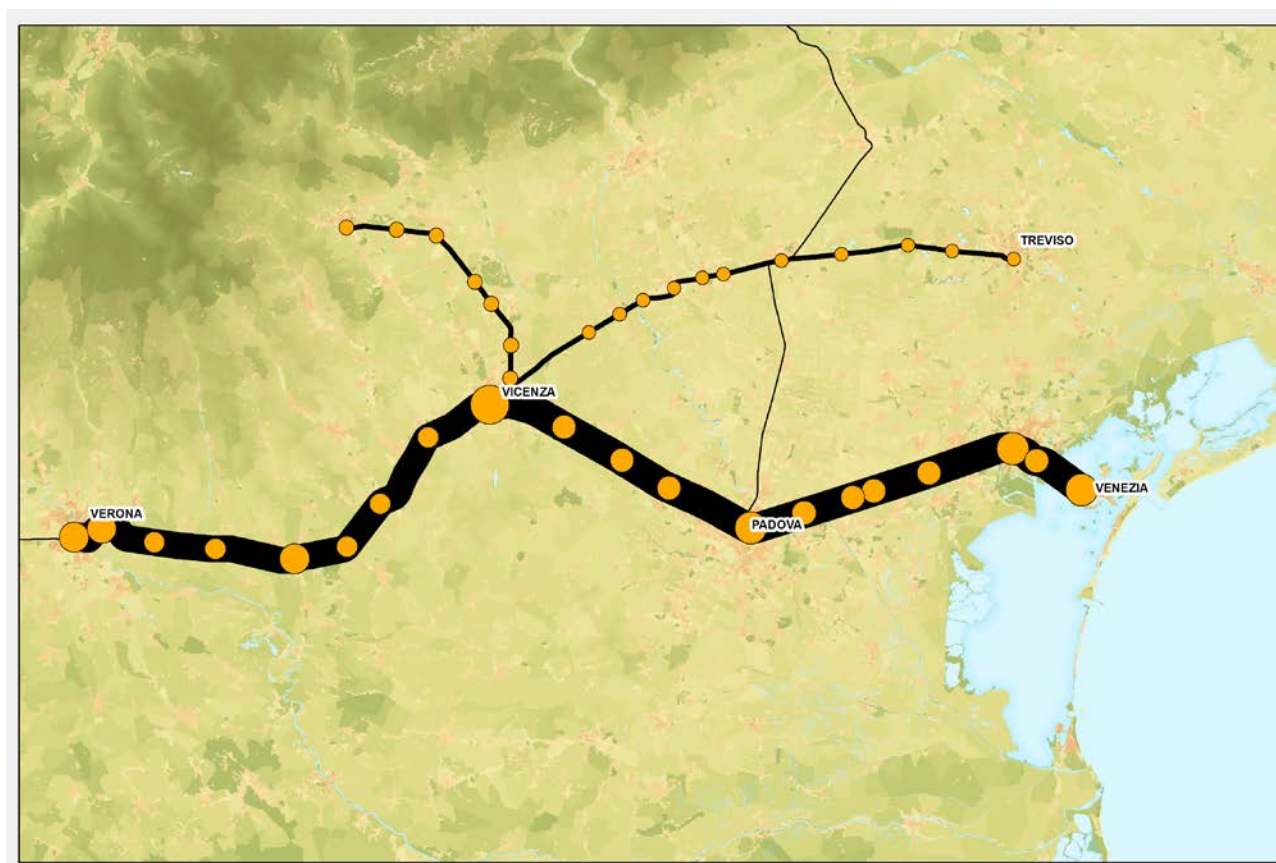
The contents of the **BDO** and of its structure have already been described in Section 2.5. The core of the BDO is the **ride**, which is characterised by:

- One timetable and one yearly calendar
- Stops, georeferenced over the infrastructure graph and associated to zonal objects (municipality, province, zones, etc.)
- Qualitative attributes, such as the name of the line, the mode, the company, etc.

All of these elements can be freely combined to filter rides, lines, stops, etc. For example, it is possible to isolate the *regional trains serving the city of Cosenza, in August*. For these selections it is possible to:

- Visualize them cartographically, thanks to the association between the couples of stops and the graph (see an example in Figure 38).
- Extract statistics, such as speed, vehicles\*km, vehicles\*hour.
- Calculate the number of connections per day towards other territorial contexts. For example, the *number of connections between Cosenza and Basilicata region*.

Figure 38. An example of geographical extraction from BDO: regional rail services passing through Vicenza.



The public transport network is built using specific BDO queries to get all the rides running on a typical business day. Rides and lines are then processed using GIS and database routines that aggregate rides into frequency service lines based on their schedule.

Timetable obviously leans on GIS graph; its structure is very close to the road graph, though it has specific parameters to describe e.g. the rail infrastructure.

### 3.6 Generalised cost calculation

The connection of BDO and of network graphs (see next Section 3.7) is based on the calculation of Generalised Costs (hereinafter “GC”). The GC derives from the usual definitions (Ortuzar and Willumsen, 1990) and takes into account the assumptions made in Table 26.

	Origin zone	Access to the airport / station	On board	Hubbing	On board	Egress from the airport / station	Destination zone
<b>CAR</b>	<i>CAR</i>						
<b>COACH SERVICES</b>	<i>car passenger</i>		<i>COACH</i>	if possible	<i>COACH</i>	<i>public transport</i>	
<b>TRAIN SERVICES</b>	<i>public transport</i>		<i>TRAIN</i>	if possible	<i>TRAIN</i>	<i>public transport</i>	
<b>AIR SERVICES</b>	<i>car passenger</i>		<i>PLANE</i>	if possible	<i>PLANE</i>	<i>public transport</i>	

Table 26. Assumptions for the calculation of the generalized cost

GC is differentiated among private (car) and public transport modes. The private car GC is:

$$GC_{car} = [t^{car} VOT + cD + \gamma P_{toll}^{car}] \quad [1]$$

Where:

D is the distance [km]

$t^{car}$  is the travel time by car [h]

$P_{toll}^{car}$  is the toll [€]

c is the vehicle operating cost (0.25 €/km);

$\gamma$  is a parameter describing the toll perception (60%)<sup>6</sup>

Public transport options include more components of GC<sup>7</sup>:

$$GC_{coach} = [\gamma t^{accCAR\_pax} VOT + \gamma P_{toll}^{car} + cD] + [\sum_{i=1}^N (\gamma t_i^{co} VOT + P_i^{co})] + [\gamma t_w^{hub} VOT_w + I_w^{hub}] + [\gamma t^{egrPT} VOT + P^{PT}] \quad [2]$$

$$GC_{train} = [\gamma t^{accPT} VOT + P^{PT}] + [\sum_{i=1}^N (\gamma t_i^{tr} VOT + P_i^{tr})] + [\gamma t_w^{hub} VOT_w + I_w^{hub}] + [\gamma t^{egrPT} VOT + P^{PT}] \quad [3]$$

$$GC_{air} = [\gamma t^{accCAR\_pax} VOT + \gamma P_{toll}^{car} + cD] + [\sum_{i=1}^N (\gamma t_i^{air} VOT + P_i^{air})] + [\gamma t_w^{hub} VOT_w + I_w^{hub}] + [\gamma t^{egrPT} VOT + P^{PT}] \quad [4]$$

Travel time and fares components are:

---

<sup>6</sup> It considers how tolls differently impact on the total GC among user categories, providing a weight. In general, business users have a lower perception being more time sensitive while economy users may opt for a non tolled alternative, if present, thus using a tolled infrastructure has a higher weight.

<sup>7</sup> A simplified version includes only access and egress equivalent time, without specifying other monetary costs:

$$GC_{coach} = [\gamma t^{acc\_pax} VOT] + [\sum_{i=1}^N (\gamma t_i^{co} VOT + P_i^{co})] + [\gamma t_w^{hub} VOT_w + I_w^{hub}] + [\gamma t^{egrPT} VOT] \quad [2]$$

$$GC_{train} = [\gamma t^{accPT} VOT] + [\sum_{i=1}^N (\gamma t_i^{tr} VOT + P_i^{tr})] + [\gamma t_w^{hub} VOT_w + I_w^{hub}] + [\gamma t^{egrPT} VOT] \quad [3]$$

$$GC_{air} = [\gamma t^{accCAR\_pax} VOT] + [\sum_{i=1}^N (\gamma t_i^{air} VOT + P_i^{air})] + [\gamma t_w^{hub} VOT_w + I_w^{hub}] + [\gamma t^{egrPT} VOT] + \quad [4]$$

$t_i^{co}$  travel time on coach transport [h]

$t_i^{air}$  travel time on air services [h]

$t_i^{tr}$  travel time on train services [h]

VOT value of time [€/h]

$P_i^{co}$  tariff on coach services [€]

$P_i^{tr}$  tariff on train services [€]

$P_i^{air}$  tariff on air services [€]

In addition, the model considers access and egress time and cost:

$t^{accPT}$  access time to the railway station from the origin zone using public transport [h]

$t^{egrPT}$  egress time from the railway station, airport, coach stop/station to the destination zone using public transport [h]

$t^{accCAR_{pax}}$  access time by car as a passenger from the origin zone to the airport or the coach stop/station, [h]

$P_i^{PT}$  public transport tariff [€]

And, where applicable, also interchange components:

$t_w^{hub}$  waiting time between two connecting services [h]

$VOT_w$  value of waiting time [€/h]

$I_w^{hub}$  interchange penalty [€]

$\gamma$  is a parameter describing the time perception, that represent the perceived discomfort of travel and waiting time for each mode of public transport.

The value of time has been defined starting from the national guidelines of the Ministry of Transport which provides different values distinguishing between classes of distances (short and long) and reasons for traveling (business, commuting and other reasons). For example, for long distances trips and the category “other reasons for traveling”, the guidelines suggest values of time between 10 and 25 €/h (MIT, 2016). For example, the value now used in the model for air transport is 20€/h.

To date, the only interchange component modelled is that of air transport. It is made of two elements: a penalty equal to 25€ which takes into account the inconvenience suffered by the passenger and a component depending on time, valued 5€/h<sup>8</sup>. In terms of connecting time between domestic flights, the model excludes short interchanges below 60 minutes. Frequencies are modelled according to real services timetables. More specifically, the algorithm calculates the average daily waiting time running

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<sup>8</sup> This value takes into account that, once at the hub point (airport, station, bus terminal), users weight less the time since they are aware of the interchange.

24 iterations (one per hour) between all the origin/destination pairs. The GC is computed both for those relationships with direct services and for those where “hubbing” is possible<sup>9</sup>.

Finally, the price/tariff component  $P$  for the collective modes is further defined, for every route, as:

$$P = p_0 + \rho D \quad [5]$$

Where:

$D$  is the distance

$\rho$  is the fare component proportional to distance,

$p_0$  is a fixed component.

The parameters  $p_0$  and  $\rho$  are calculated on the basis of real tariffs extrapolated from transport operator websites; they vary according to the type of service, purchasing period and presence of competition. In the last months of the project the information collected for rail and coach transport (Section 2.8) will flow into the model correctly defining this function.

### 3.7 Frequency-based graph and Hypergraph

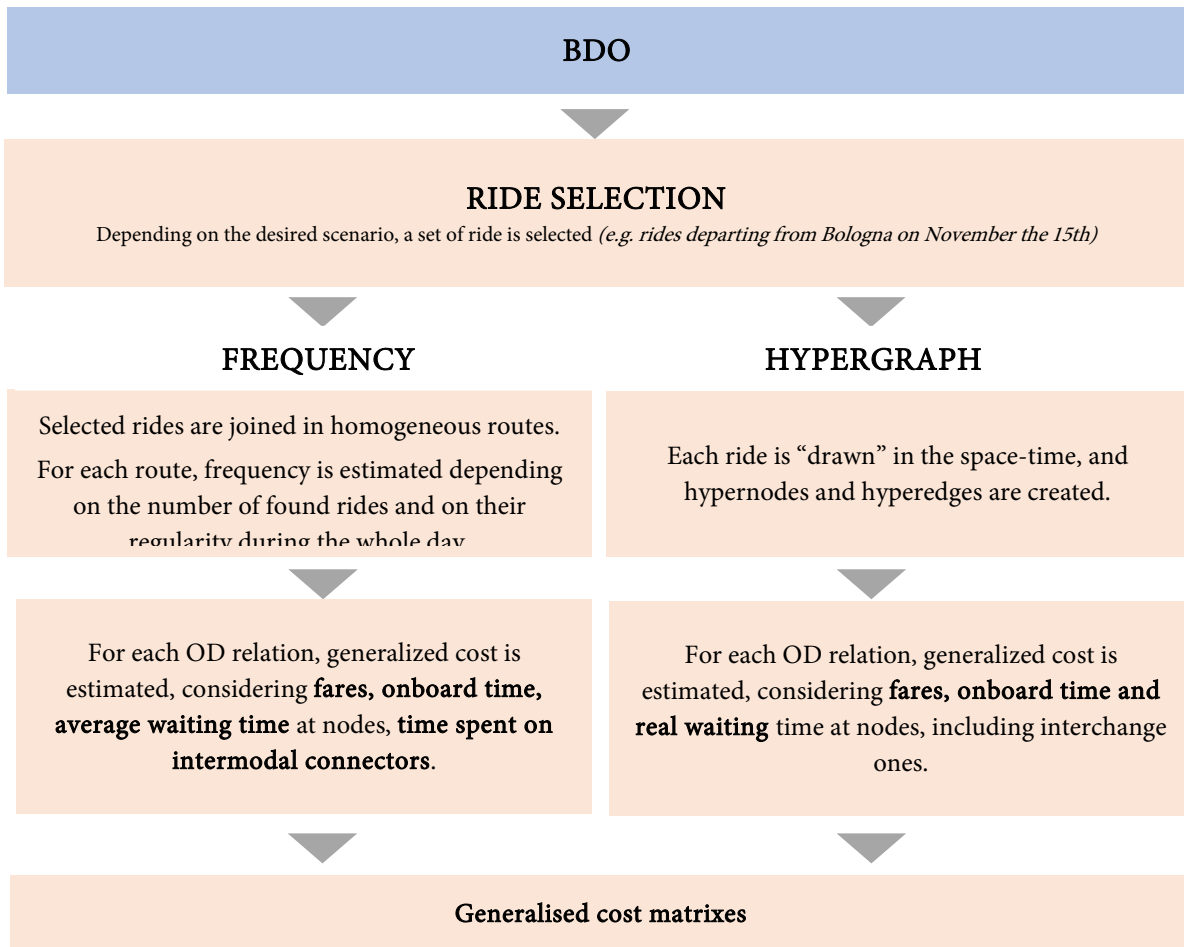
The calculus of generalised cost matrixes as seen in the previous paragraph, is based on two alternative tools: a **frequency-based graph** and a **hypergraph**. The choice between the two depends on the desired outcome: the frequency algorithm allows a quicker estimate of daily average costs, while the hypergraph leads to a very accurate result starting from a specific time of the day.

As shown in Figure 39, both tools require a selection of rides, operated within the BDO, and leads to the generalized cost matrixes as an output.

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<sup>9</sup> This is true for air service but also for coach and train services whereas respectively interchanges at the station or at the bus stops allow reaching indirectly other destinations. Intermodal interchanges are not included in this phase

Figure 39. Frequency graph and hypergraph tool comparison



The **frequency-based graph** depends on the join of similar rides according to the kind of service offered and the route (sequence of stops) followed. In this option, the following cost factors are considered:

- *Fare*, depending on the service type and composed by a fixed component and a variable component dependent on the travelled distance;
- *Travel time*, calculated as the sum of average travel times for each segment between two stops (“*tratta interfermata*”);
- *Waiting time at stops*, calculated on the average number of daily rides of a specific route.
- *Time spent* at the transfer node (walk time).

There are also **penalties** to simulate discomfort or time lost at the initial, transfer and alighting node.

Trips extracted from BDO are grouped into service lines taking into account their:

- *service category*: only trips with the same “mode” attribute are allowed to be joined: for example a rail AV trip must not be grouped with a conventional long haul train. Likewise a regional train is not similar to a metropolitan or suburban trip;
- *stop sequence*: trips with a “similar” stop sequence are grouped. This task is semi-automatic: a procedure compute a “similarity score” based on Levenshtein distance verified manually in a iterative process;
- *trip speed*: lines group trips only if their commercial speed is close enough.

Every line is then identified by one “master” trip that defines the typical stop sequence and its mean travel time. Headway for each line is estimated counting trips (including both master and child) and evaluating their temporal distribution in daily service.

Figure 40. Frequency service lines from BDO rides aggregation: similar routing

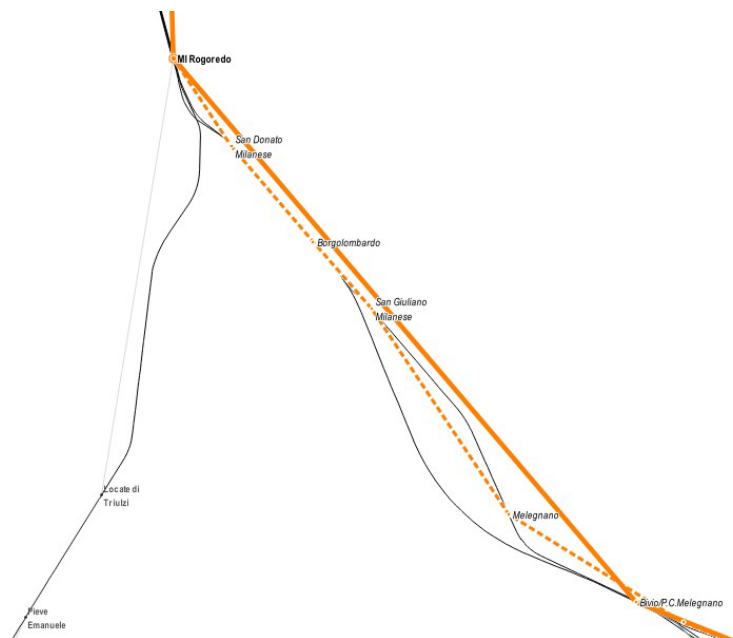
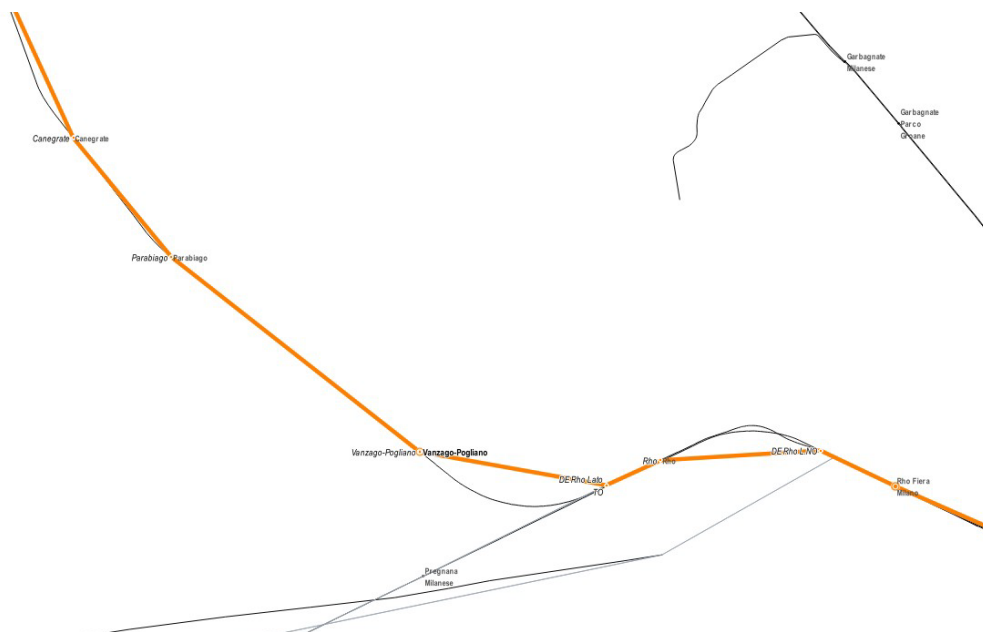


Figure 41. Frequency service lines from BDO rides aggregation: similar stop sequence



The public transport graph, which represent the infrastructure, and the frequency service graph are then combined together to create the network: an automated procedure generates a “virtual graph” for each transit mode where services run. Non-transit links are also created to allow users transfer from a mode to another in the same physical node (e.g. a railway station) and similarly intermodal connectors are “exploded” to represent a transfer from a line to another line that has a different mode attribute (e. g. passenger passing from a metro to a AV railway line).

Figure 42. Public transport modes

grafo		corsa (linea)		id modo
sorgente	descr	tipo	descr	arco
NTL	connettori	-	pedonali	-
		-	motorizzati	-
		-	interscambio tra nodi	-
		-	interscambio tra corse, stesso nodo	-
		-	non assegnato	-
GRAFO FERROVIARIO	ferrovia, LP	A	Alta velocità	11
		C	IC, EC, LP convenzionale in genere	12
		L	ICN, EN, notturni in genere	13
		...	non assegnato	14
		...	non assegnato	15
	ferrovia, SFR/M	D	RV, RE, ex IR/D	21
		R	R	22
		S	S, MET	23
		...	non assegnato	24
	altri imp.fissi, TPL	M	metropolitane	31
		T	tranvie, metrotranvie (U+E)	32
		F	funicolari, altri imp.fissi	33
	non assegnato	...	non assegnato	41
		...	non assegnato	42
		...	non assegnato	43
BUS	autolinee, LP	X	autolinee interregionali	51
		...	non assegnato	52
	autolinee, TPL	E	autolinee extraurbane	61
		U	autolinee urbane	62
NAUTICA	nautica	O	traghetti, navigazione marittima	71
		N	resto navigazione marittima	72
		Q	traghetti, navigazione lacuale	73
		P	resto navigazione lacuale	74
N.AEREA	navigazione aerea	Y	navigazione aerea, legacy	81
		V	navigazione aerea, low cost	82
		...	non assegnato	83
N.A.	non assegnato	...	non assegnato	91
		...	non assegnato	92
		...	non assegnato	93

Figure 43. Frequency graph, AV railway services (A)



Figure 44. Frequency graph, conv. LH railway services (C)



Figure 45. Frequency graph, RegioExpress railway services (D)



Figure 46. Frequency graph, regional railway services (R)



Figure 47. Frequency graph, LH coaches and airport bus (X)



Figure 48. Frequency graph, domestic flights (V + Y)



Figure 49. Frequency graph, ferries and navigation (O + N)



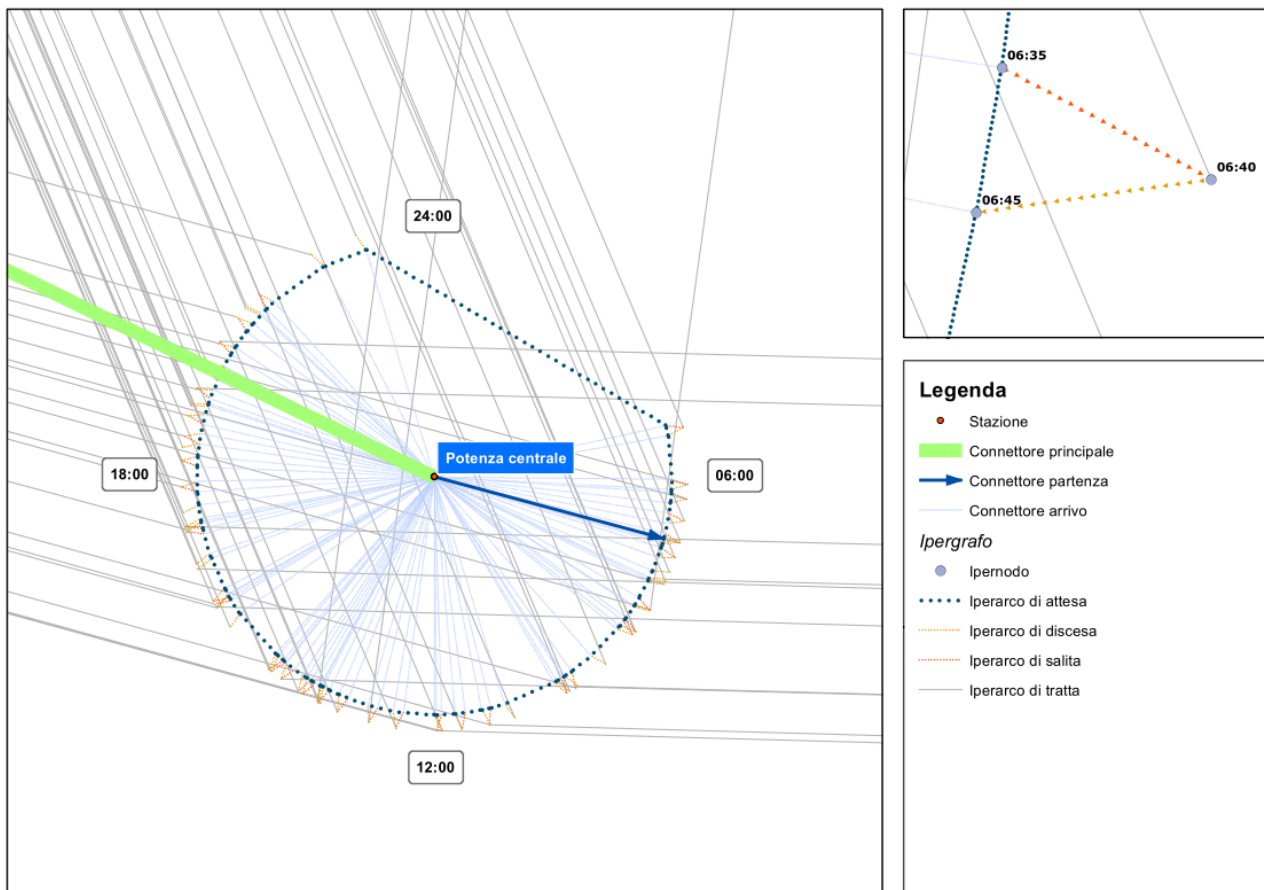
The **hypergraph** tools, instead, considers the real timetable of every single ride, and hence allows a higher accuracy in the generalized cost matrixes, at the expense of a much higher calculus time:

- *Fare* are estimated according to previous methodology;
- *Travel time* is ride-specific, and depends on the timetable stored in BDO;
- *Waiting time* at starting and intermediate nodes also depends on real scheduled times for all the rides stopping at a specific nodes, thus allowing a more accurate estimate of interchange penalty.

Figure 50 includes an example of hypergraph for one train station. It is clear how every node (called *hypernode*) represents a specific moment of the day (e.g. 6:14 am). Similarly, every edge is a connection between two nodes, and can represent:

- The time spent to get on/of a ride;
- The time spent to travel from two different nodes (e.g. from Potenza to Matera);
- The time spent in a station waiting for the next ride.

Figure 50. An example of hypernode



### 3.8 Mobility demand modelling

#### 3.8.1 General structure of the model

The demand-side is developed at two different levels of detail. The passenger mobility uses the highest detail, and is fully described by a 4-step model running on a 1764x1764 matrix established at the level of NUTS-5 zones. A simplified methodology is adopted for freight demand modelling, aiming mainly to describe likely level of congestion on the private transport (road).

#### PASSENGER DEMAND

Passenger mobility is described by a set of matrices, established at NUTS-5 level (1764 zones) and split in main trip purposes and basic transport mode. The time unit is a typical workday.

The estimate is based on 5 main travel purposes, two systematic (Home-to-School and Home-to-Work) and three occasional (business, personal, free time). There will be no distinction between “short-” and “long-distance”, but trips will be characterised by being done during the day or involving a sleepover. Table 27 contains such classification.

<i>Group</i>	<i>Travel purpose</i>	<i>Sub-group daily trips</i>	<i>Sub-group sleepover trips</i>
1	<b>STUDY</b>	Home-to-School	/
2	<b>WORK</b>	Home-to-Work	/
3	<b>BUSINESS</b>	Business	Business
4	<b>PERSONAL TRIPS</b>	Personal	Personal
5	<b>FREE TIME</b>	Leisure	Holidays
6	<b>FREIGHT</b>		

Table 27. OD Matrix final structure

Each demand component is described by different socio-economic parameters (i.e. value of time) and uses specific supply attributes (i.e. transport services fare).

Each demand component can be described by specific datasets, with different levels of precision and likelihood. An extended work of collecting datasets useful to describe passenger mobility has been developed within WP5 activities. In particular, we collected the following:

- i. ISTAT census matrix (home-to-work and home-to-school trips);
- ii. ISFORT national surveys;
- iii. Health and University movements between Regions;
- iv. ISTAT tourism statistics (arrivals and nights spent);
- v. ISTAT sample survey on business and holiday travels of italians;
- vi. ONT – Bankitalia international tourism matrices (Italian going abroad and strangers coming in Italy);
- vii. Regional/local surveys (Lombardia, Piemonte)
- viii. Assoaeroporti matrix (passengers per route)
- ix. BlaBlaCar travels

Since each demand component can be described by different statistical datasets, the estimation methodology is based on three approaches:

- **Systematic daily trips** are mainly modelled on the basis of Census O/D matrix describing home-to-school and home-to-work mobility, updated and adapted to the 1764 zone structure (which required several split for main urban areas;
- **Occasional daily trips** are estimated through a 3 step demand model (generation → distribution → modal split) based both on ISFORT survey parameters and on the description of the structure of mobility attractors at NUTS-5 level for 30 different “micropurpose” layers;
- **Occasional sleepover trips** are mainly modelled on the basis of ISTAT and ONT-Bankitalia tourism statistics.

Each component has been estimated at generation, distribution and modal split (public/private) level, using generalised cost matrices adapted to the socio-economic groups interested to single purposes.

## FREIGHT DEMAND

Freight demand is not of direct interest of QUAINT. However, to perform a correct road assignment, the freight flows are needed to calculate the congestion and assign passengers' private cars. A preliminary matrix has been estimated starting from ETIS-Plus freight matrix, available at NUTS-3 level, disaggregated at NUTS-4 and NUTS-5 zoning by means of electric consumptions and ISTAT census of industrial activities. Then, freight flows are transformed into trucks flows by means of load factors.

## GENERAL OVERVIEW OF THE DEMAND ESTIMATION / ASSIGNMENT PROCESS

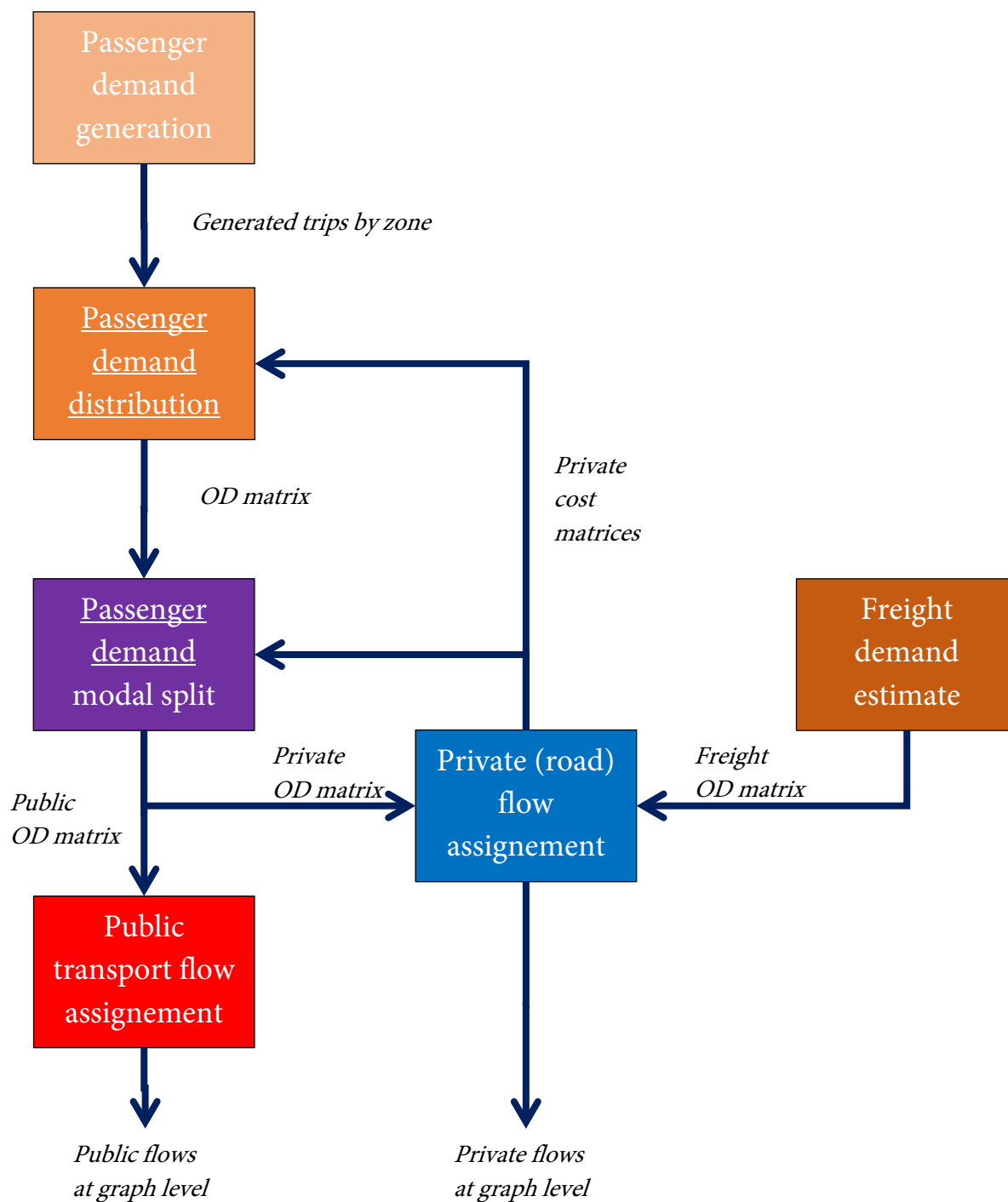
During the last months of activity, the “beta” version of the demand, defined at NUTS-4 level, has been fully developed at NUTS-5 level, allowing for a first full modelling of the generation, distribution, modal split and route choice process at national level.

In this model, freight matrix and the generation of passenger demand are rigid, that is they are not affected by any change of private cost transport. On the other hand, the distribution and modal split of passenger demand are elastic, and they vary depending on the structure of private and public transport costs.

The matrix of private transport cost is in turn estimated on the basis of the assignment of passenger and freight demand to the road graphs. This determines an iterative process in which the estimate of passenger demand and the calculation of road flows are linked together, allowing the model to deal with congestion in a likelihood way.

The general structure of the demand estimation / assignment process is shown in Figure 51.

Figure 51. General overview of demand estimation / assignment process



Further details on the methods and parameters which has been used in each step are illustrated in next paragraphs.

### 3.8.2 Passenger demand step 1: generation

Demand estimation is based on a simple generation model using expressions as:

$$F(i, n) = P(i, s) \cdot k(s, m)$$

where

$F(i, m)$  are the trips generated by zone  $i$  for the purpose  $m$ ;

$P(i, s)$  is the population of the zone  $i$ , belonging to socio-economic group  $s$ ;

$k(s, m)$  is the generation factor for socio-economic group  $s$  and purpose  $m$

Demand is therefore considered completely rigid, without any dependence from accessibility factors or generalised cost of transport.

Generation parameters are derived from different sources.

**Systematic trips** (home-to-work and home-school) are known from ISTAT matrix, as number of people moving daily to a fixed place for study or job purposes. The number of generated trips is calculated in two steps:

- breakdown of trips generated by main urban areas into traffic zones at NUTS-5 level;
- expansion of results by a coefficient taking into account the percentage of workers travelling twice a day from home to Work and vice versa.

Occasional daily trips are estimated using ISFORT mobility coefficient for personal and leisure purposes. These coefficients are used to calculate the other generated short-range trips from each zone; the “business” component, which is unknown, is derived subtracting the ISTAT generation and the back-to-home trips from the “work” purpose.

**Occasional overnight trips** (business/personal travels and holidays) generation coefficients are calculated from ISTAT survey on holidays and the ONT-Bankitalia survey.

### 3.8.3 Passenger demand step 2: distribution

Similarly to generation, also distribution matches existing sources. The distribution of **systematic daily trips** simply recalls the one of the ISTAT matrix. The distribution of the **occasional trips**, both short and long-range, is based on a semi-conventional exponential accessibility model.

$$F(i, j, m) = F(i, m) \frac{A(j, m) \{ \mu + (1 - \mu) \cdot \exp[(-\beta g_{ij})^\omega] \}}{\sum_j A(j, m) \{ \mu + (1 - \mu) \cdot \exp[(-\beta g_{ij})^\omega] \}}$$

where

$F(i, j, m)$  are the trips from zone  $i$  to zone  $j$  for the purpose  $m$ ;

$F(i, m)$  is the demand generated by the zone  $i$  for the purpose  $m$ ;

$A(j, m)$  is the attraction factor of the zone  $j$  for the purpose  $m$ ;

$g_{ij}$  is the generalised cost of the trip from zone  $i$  to zone  $j$  (calculated as composite public/private cost depending on modal split)

$\beta, \mu, \omega$  are validation parameters of the model.

This model is applied iteratively for each travel purposes, following a specific breakdown in 30 “micro-purposes” of travel (i.e., shopping, health cares, visit to relatives...), each of which has a specific set of attraction parameters.

These parameters can be of three different kind:

- a) 0/1 parameters with constrained basins (for example, in legal affairs people can't decide to what court go);
- b) weight parameters without constrained basins (for example, hospitals can be present or absent in a zone, but people can decide to move to different ones)
- c) statistic parameters modelling widespread activities.

In the last case, the attraction factors for a specific purpose are estimated with the model:

$$A(j) = [\sum_e c_e \cdot L_e(j)]^\alpha$$

Where:

$L_e(j)$  is the number of working places in the  $j$  for the economic activity  $e$  (services<sup>10</sup>)

$C_e$  coefficient depending from the economic activity (from 0 to 1)

$\alpha$  is a calibration parameter.

This preliminary weighting is based on easily accessible census data, but the attraction factor could be more appropriately calculated using specific datasets, such as the OSM-Bankitalia database for tourism or other data.

#### 3.8.4 Passenger demand step 3: modal split

Modal split module recall totally the methodology already used for the NUTS-4 level model.

The share of public and private trips between an origin  $i$  and a destination  $j$  for a purpose  $m$  is calculated by a logit model

$$q_k = \frac{\exp(-\lambda g_k)}{\sum_k \exp(-\lambda g_k)}$$

where:

$k$  mode (public/private);

$q_k$  market share of mode  $k$ ;

$g_k$  generalised cost of mode  $k$

---

<sup>10</sup> We considered the following categories (sum of for-profit and not-for-profit activities): commerce, hotels and restaurants, professional activities, real estate activities, financial intermediaries, schools, health and social services, public administration.

$\lambda$  statistical dispersion parameter.

This module allows also for the estimate of the composite public/private cost, used by distribution model. This cost is calculated with the formula:

$$g_{BUS} = -\frac{1}{\lambda} \log \sum_k \exp(-\lambda g_k)$$

### 3.8.5 Highway assignment

In the final (4<sup>th</sup>) step of the model, the private/public transport matrices are assigned to their graphs by two separate procedures. For private transport matrices, an incremental multiclass assignment is established in CUBE Voyager 6.4 ©, with the following six classes:

- Home-to-school
- Home-to-work
- Business
- Personal purposes
- Free time
- Freight transport

Each class has its own assignment parameters in term of perceived value of time, operating cost, perception levels of motorway fares; therefore, for each O/D pairs, flows generated by different purposes can choose different routes.

Passenger flows are translated in vehicle movements using average occupancy coefficients by single purposes. Accompanying trips are assigned twice to the graphs, taking into account the need for accompanying people to return home.

In term of congestion, total traffic flows are expressed in equivalent vehicles (motorcar = 1 vehicle, truck = 2 vehicle) and compared with the capacity of the road links to determine travel time on all routes. Since the travel time of private transport affect in turn the distribution and the modal split steps, the calculation of congestion level is a part of an iterative process.

### 3.8.6 Public transport assignment

The public transport matrix is assigned to the graph of services using the corresponding module of CUBE Voyager 6.4 ©. As illustrated in paragraph 3.5, all modes of public transport services (air flights, high-speed, long-haul and regional trains, long-haul and airport buses, sea shipping) are modelled as a part of a unique system, so that any combination of services is allowed with the only limit of a maximum number of interchanges.

Public transport generalised costs don't depend on the results of the assignment of passengers to the graph, because no crowding or capacity analysis of single services is carried on. But the total amount of trips assigned to public transport graph can vary depending on the level of road congestion, which affects modal split module.

Public transport flows are expressed as passengers/workday.

## 4. Results

### 4.1 Current scenario simulation

The key scenario to be simulated is the current scenario. It has a twofold importance. First of all, it is **the basis for the calibration**, as will be described in the following section 4.2. Secondly, **it represents a unique picture of the entire Italian system, including road and public transport and related demand**. All of the results of the following tables and maps are the outcome of all simulation activities and must reasonably match with the observed values collected in the POSTRA database (section 2.6).

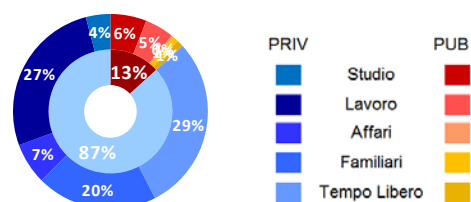
The reference scenario can be used both to draw a general picture of the Italian system and also to focus on some local situations. In the following, we provide examples of both scales.

The Figure 52 includes:

1. A representation of modal shares and travel purposes at the national scale in terms of passengers/year. We can for example appreciate that – excluding trips internal to zones (where probably car and walk predominate) – public transport accounts for 13% of total Italian passengers. Between the systematic trips, commuting is where car has the largest share, while study has the highest public transport share of 60%. Public transport is nearly irrelevant for the remaining occasional trips, around 5%.
2. Detailed indicators for public transport modes, where we can see the relative weights. For example, long distance trains account – despite their actual and perceived importance – for 2-3% of rail passengers, which are obviously concentrated in the local and regional trains. But in terms of paxkm the gap is much less, and long-distance is more than 15%. Interestingly, coaches transport about one third than all long-distance trains in terms of volumes and more than 50% in terms of passengers. Domestic air transport is now comparable to long-distance trains (for the domestic relations only).
3. Average trip length, which are coherent with the typical ranges for each mode.
4. For the private transport, statistics describe volumes, distances and travel times for light and heavy vehicles and for the four types of road. Highway, despite its limited extension, confirms its role as the backbone of the country. Lorries travel proportionally more on main roads than highway, because more sensitive to toll.

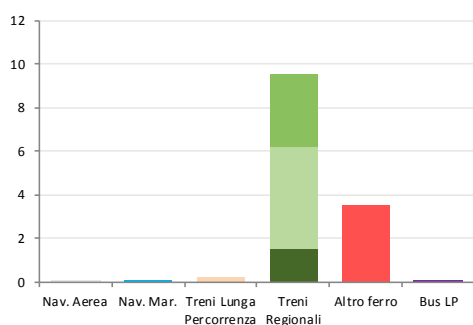
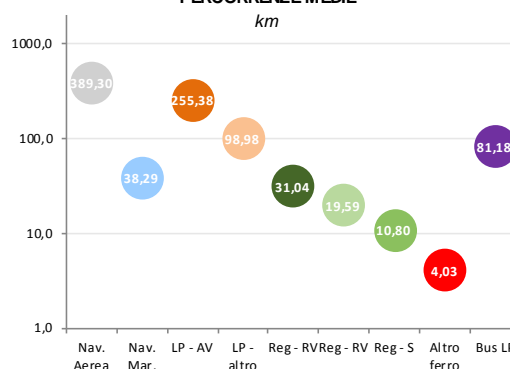
## DOMANDA INTERZONALE GENERATA PER MODO E MOTIVO

	Pubblico	Privato	TOT	% Pubb	% Priv
	<i>mil. spost/giorno</i>				
Studio	3,56	2,41	5,97	60%	40%
Lavoro	2,84	15,74	18,58	15%	85%
Affari	0,20	4,08	4,28	5%	95%
Familiari	0,60	11,90	12,50	5%	95%
Tempo libero	0,67	17,28	17,95	4%	96%
<b>TOT</b>	<b>7,87</b>	<b>51,41</b>	<b>59,28</b>	<b>13,3%</b>	<b>87%</b>



## TRASPORTO PUBBLICO

	corse *km	passaggi	volumi	perc.	tempi	Vel. Comm.	occ. Media
	<i>mkm/giorno</i>	<i>mil/giorno</i>	<i>mil. pax*km</i>	<i>km</i>	<i>pax*h</i>	<i>km/h</i>	<i>pax/corsa</i>
AER Navigazione aerea	0,29	0,08	29,3	389,3	0,1	223,2	101,7
MAR Nav. Marittima ed interna	0,01	0,01	0,2	38,3	0,0	22,6	45,5
LP - Alta Velocità	0,26	0,04	11,4	255,4	0,1	184,8	44,2
LP - Altro	0,22	0,19	18,7	99,0	0,2	102,7	86,2
FER Regionali - RV	0,38	1,53	47,6	31,0	0,6	83,1	125,2
Regionali - R	0,71	4,71	92,2	19,6	1,5	62,7	129,1
Regionali - S	0,30	3,29	35,5	10,8	0,7	47,5	120,0
Altro ferro (metro, tram.)	0,18	3,50	14,1	4,0	0,7	20,8	79,9
BUS Bus lunga percorrenza	0,12	0,11	4,1	81,2	0,1	54,1	33,5
<b>TOTALE</b>	<b>2,46</b>	<b>13,5</b>	<b>253,2</b>	<b>18,8</b>	<b>3,9</b>	<b>64,4</b>	<b>103,0</b>

RIEPILOGO PERCORRENZE  
milioni passeggeri\*km/giornoPERCORRENZE MEDIE  
km

## TRASPORTO PRIVATO

	volumi (mil. vkm/giorno)			tempi (mil. vh/giorno)			velocità (km/h)		
	leggeri	pesanti	totali	leggeri	pesanti	totali	leggeri	pesanti	totali
Rete autostradale	166,9	62,5	229,5	2,73	1,48	4,21	61,2	84,5	66,2
Rete principale	263,7	32,9	296,6	7,76	1,12	8,88	34,0	58,9	35,6
Rete secondaria	176,6	13,6	190,2	9,01	0,64	9,65	19,6	42,5	20,4
Rete interzonale	179,6	9,2	188,8	7,10	0,40	7,50	25,3	46,5	25,9
<b>TOTALE</b>	<b>786,9</b>	<b>118,2</b>	<b>905,1</b>	<b>26,61</b>	<b>3,63</b>	<b>30,24</b>	<b>29,6</b>	<b>32,5</b>	<b>26,7</b>

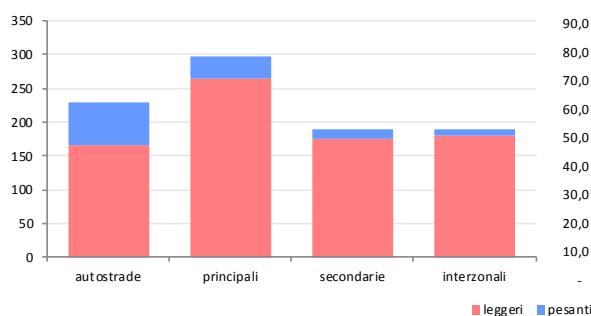
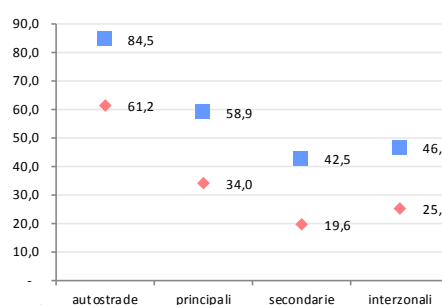
RIEPILOGO PERCORRENZE  
milioni vkm/giornoVELOCITA' MEDIE  
km/h

Figure 52. General results of the Current Scenario

Maps in Figure 53 and Figure 54 depict the current flows in the two subsystems of private and public transport. Without entering in details, it is well visible the core network, but also the urban areas, where local traffic overlaps to long-distance one. In the Pianura Padana the two layers are not distinguishable and generate a continuum of mobility. It is also well visible the cut represented by the Appennini, where the existing infrastructure is barely used, showing that the two territorial systems of the Tyrrhenian and Adriatic coasts are quite separate.

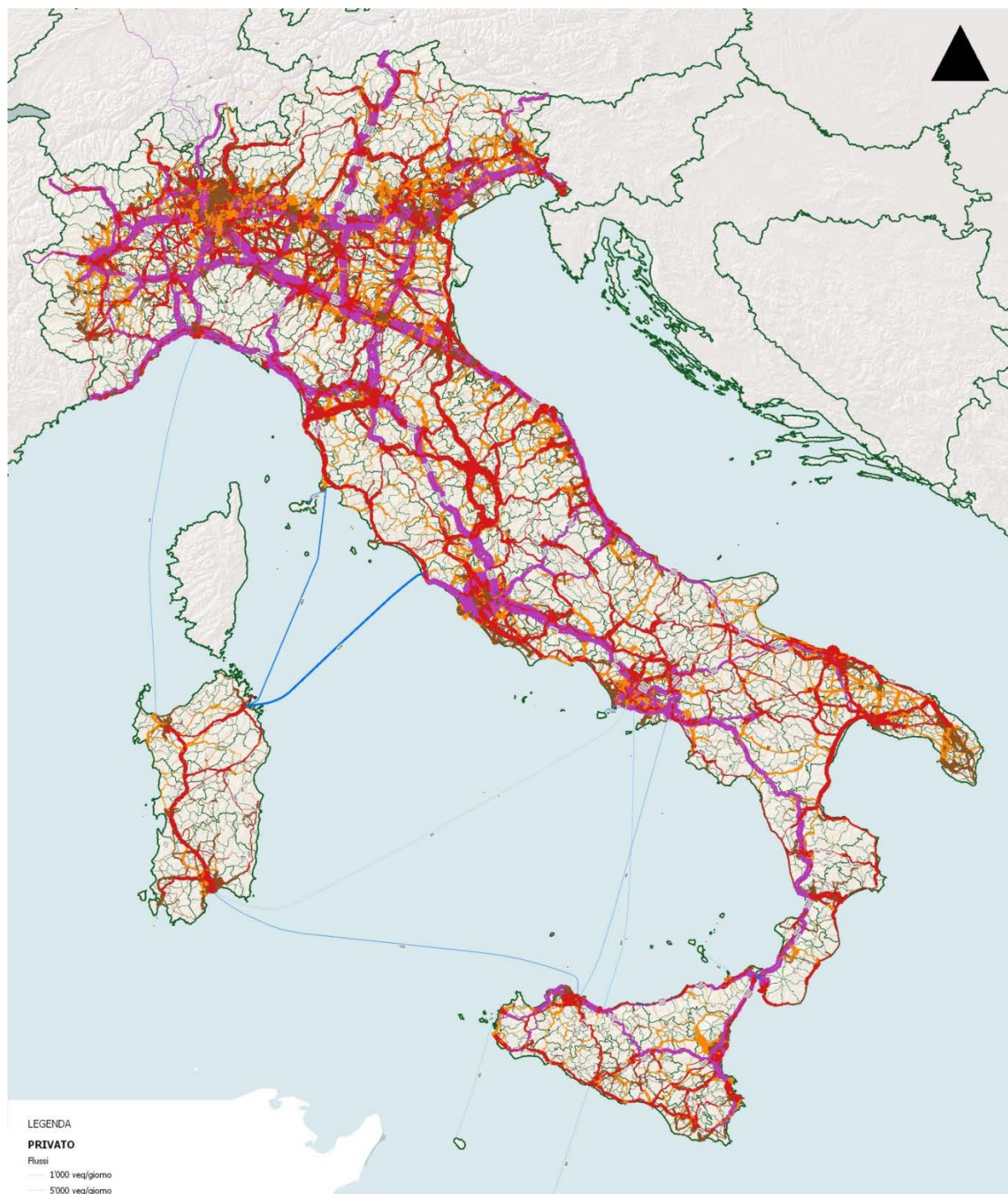


Figure 53. Current scenario - road flows

Public transport map is apparently covered by rail transport only. Regional rail concentrates mainly around cities, but also on some long corridors like the Milan – Venice (where the flow looks continuous, but is actually made of more distinct passengers). The long distance rail, in brown colour, is well evident on the

Torino/Venice – Naples corridor (where most of the supply concentrates). Significant also the share in Puglia and on the Milan – Genova and Milan – Venice. Air transport, with the increasing importance of HS rail, is now relevant especially in the connections with the main islands and much less for the north-south routes (where is present but “visible” only in few cases, such as Milan – Bari). Coaches are often not visible because very sparse on many thin routes (and also for a problem of map transparency). Ferries are visible, at this scale, just around Naples.



Figure 54. Current scenario – public transport flows

Also looking at the details, the simulation shows many interesting facts. Figure 55 for example focus on the Via Emilia area. There we can see that the conventional line Piacenza – Bologna is not “emptied” by the switch to the HS line. Not only many regional passengers move within the cities, but also some long-distance traffic remains on the conventional line. Differently from Milan, the role of the rail is here limited to the main line (and the Venezia one), while secondary lines appear particularly thin, due to the smaller size and catchment power of the cities.

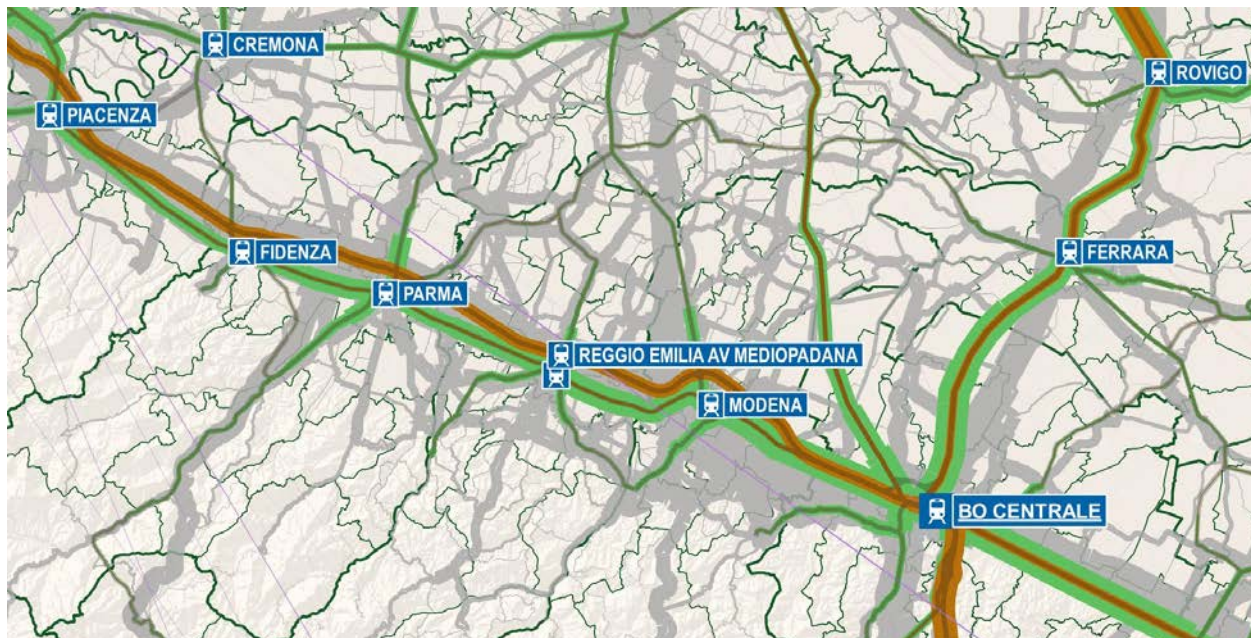


Figure 55. Current scenario – public transport flows. Detail of Via Emilia area.

Looking at the road model, Figure 56 maps the flows east of Milan. Here we can appreciate the difference of scale of the two highways connecting the two main Lombard cities. The A4 is outstandingly more crowded than the new Brebemi. This fact is explainable especially with the different tolls, well described in our model.

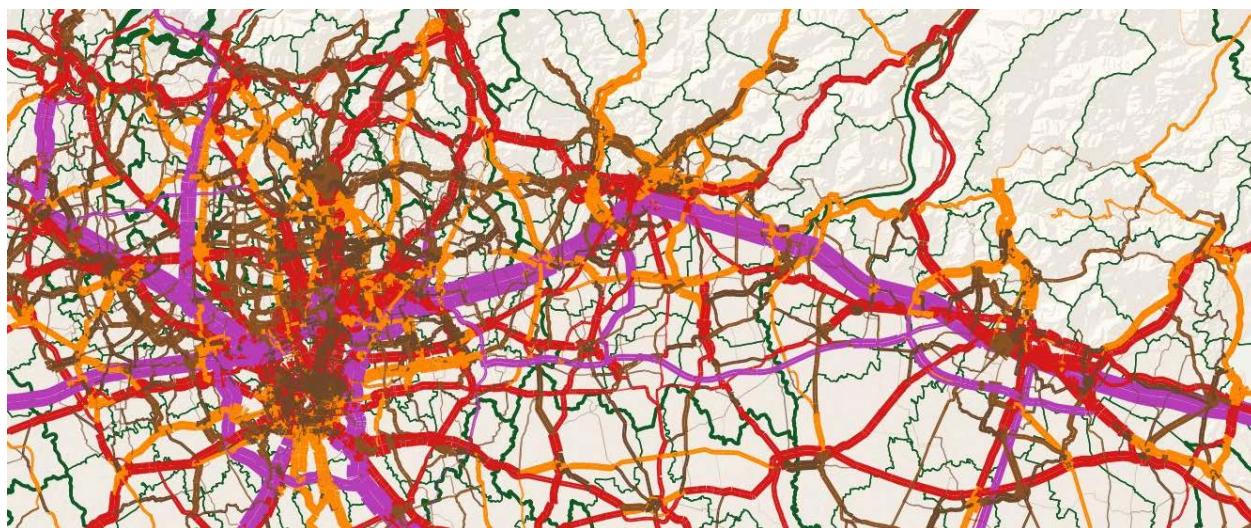


Figure 56. Current scenario – road flows. Detail of Milan-Brescia corridor.

## 4.2 Calibration report

Calibration is an extremely important phase in every modelling exercise. A detailed model is useless if it is not capable to reasonably predict the observed flows. For this reason, we compare the modelled flows with the data collected in the database POSTRA (section 2.6) by means of a scatterplot. A good calibration must fulfil the following conditions:

- The  $R^2$  must be near to 1. A result  $>0,90$  is considered good, moreover in our case where the modelled area is huge.
- The coefficient of the interpolation function must be near to 1. More than 1 means that the model is systematically overestimating flows,  $>1$  means underestimating.

In our case, the fit with the observed highway flows is very good:  $R^2$  is nearly 0,94 and the coefficient is just 3% overestimating (Figure 57).

A calibrated model is not a guarantee of a good job. A model could be perfectly calibrated just because too rigid, for example with the introduction of high modal constants or even local constants. In our case this does not happen as we do not use local modal constants and the model is elastic (as will be shown in the Scenario analysis)

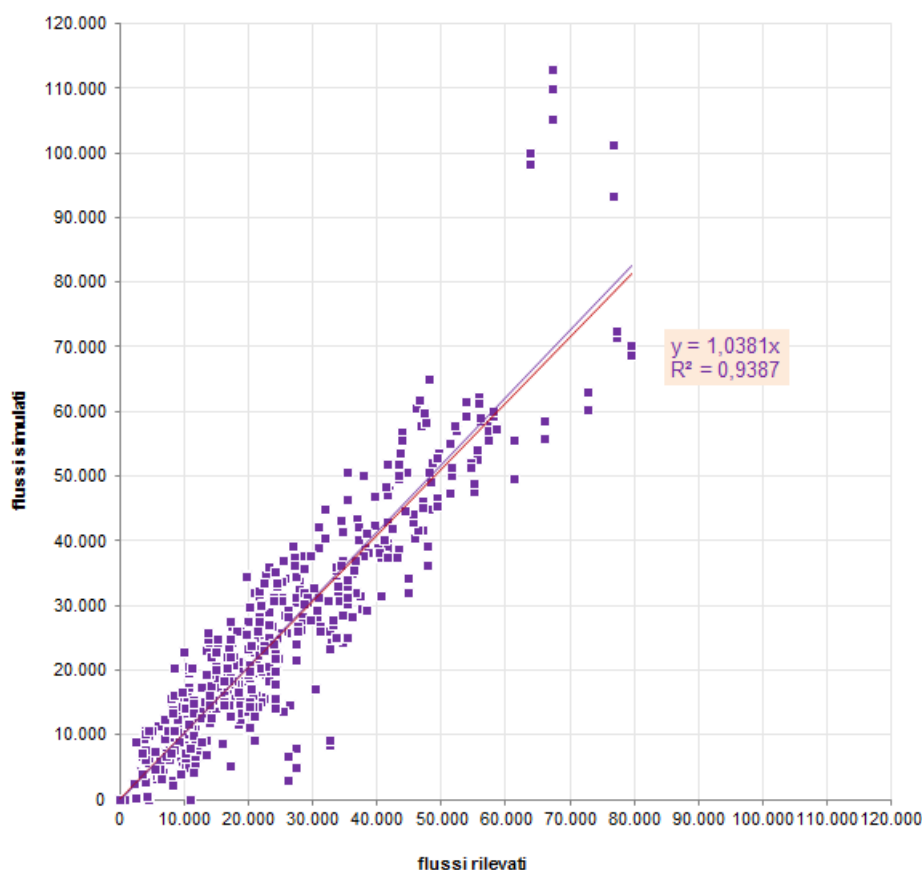


Figure 57. Calibration report for highways, scatterplot.

### 4.3 Accessibility

Long-distance accessibility is a crucial element for economic development and for territorial cohesion. To be revealing, however, a measure of accessibility must not only consider the distance or travel time of a single mode, but should include the fares, the frequency and the interchanges of all available modes.

Thanks to the availability of a detailed description of multimodal costs of the Italian transport system (all modes and different trip purposes), it is possible to draw maps of accessibility. These maps allow to answer the question whether and where there is an accessibility problem between Italian regions, overcoming too simplified approaches such as the one using supply indicators.

The measure used is potential accessibility, with an exponential decay impedance function. Different from similar studies, this one gives a more in-depth definition of impedance parameters due to the availability of a transport model that includes the entire Italian long-distance supply (roads, coaches, long-distance rail services, air services, and ferries). The opportunities at destination are proxied by population, and private and public sector employees.

With respect to similar studies, one of the main novelties of the paper is the level of definition of the impedance function. It is not limited to travel time or distance, but considers all components of generalised cost, including frequency and fare levels depending on competition. Secondly, our accessibility considers all modes (rail, coach, air, car). We pointed out the contributions of each mode in defining the accessibility of one place, by means of single-mode accessibility maps and of multimodal ones.

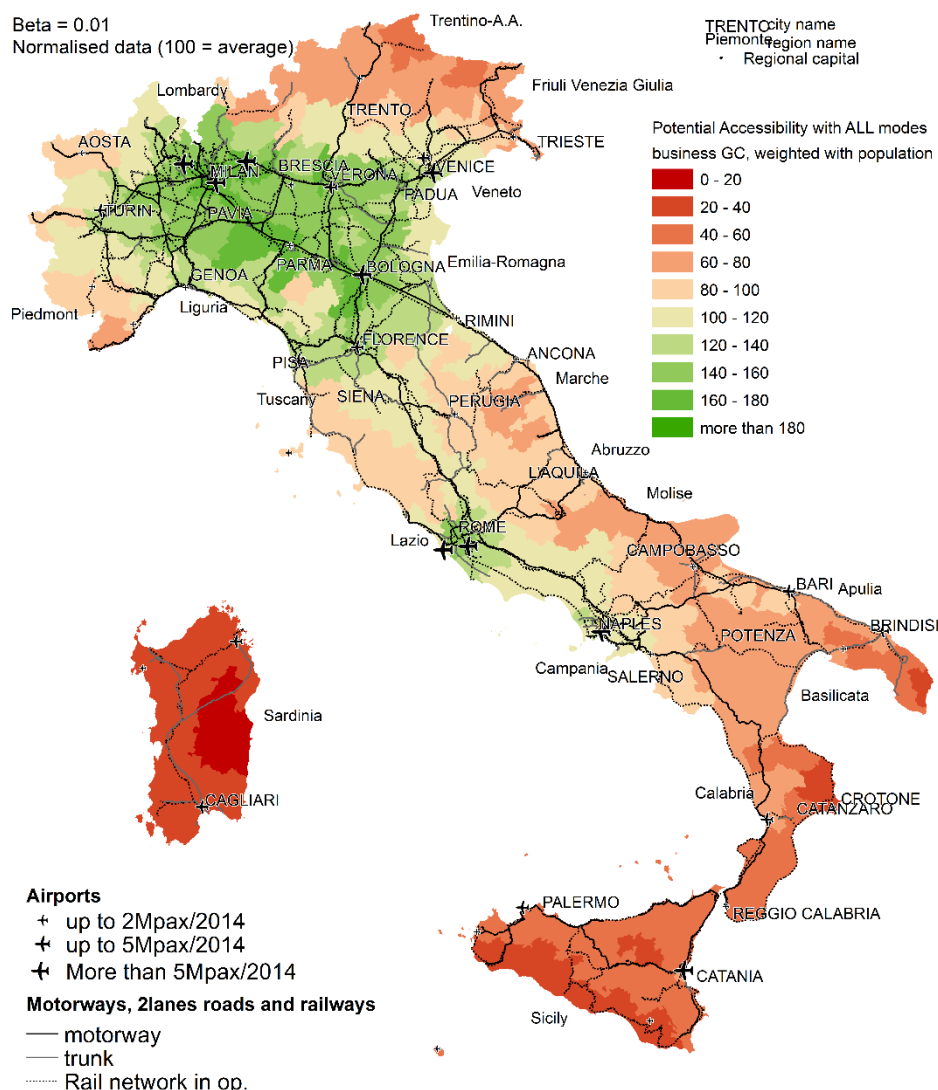


Figure 58. Accessibility map of Italy: all modes, business purpose, weighted with population. Source: Beria, Debernardi, Ferrara (2017).

Findings are quite interesting and clearly show the power of the application, both in describing the complexity of the system and analysing the current and past policies. The complexity of the application involves also some methodological advancements.

It results that Italian geography of accessibility is complex. High accessibility areas are the highly populated north, but also Rome and Naples, forming a sort of dipole. The effect of main infrastructure is well visible, rising the accessibility of the main corridors with respect to peripheral areas. Southern Italy is by far less accessible than the north. The effect is the combination of geographical remoteness, lower population and of underperforming transport networks. However, the condition of inaccessibility is not homogeneous in all Southern Italy, as well as not all North is highly accessible. For example, Naples performs like Northern cities, despite its geographical disadvantage, thanks to excellent road and rail connections.

This fact is important in terms of transport policies. Comparing a distance-based accessibility with the cost-based one, we showed that Italian transport system is effective in reducing the natural geographical differences, making “far” places relatively less inaccessible and at the same time smoothing the relative advantage of core areas. This is the outcome of transport policies of the past which, far from being perfect, aimed at providing a relatively fair level of supply in most of urban areas of the country.

## 4.4 Scenario analysis: the potentialities of the model

The availability of a national-scale transport model, based on the four informative layers:

- a. Infrastructure network and characteristics
- b. Supply of services (frequency, travel time, accessibility)
- c. Supply of services (market structure and fares)
- d. Demand;

allows to simulate a broad range of policies acting on the numerous parameters all of such layers. Just to give an example, the following policies can be analysed:

1. New road infrastructure;
2. Change of road capacity (e.g. more lanes);
3. Introduction/removal/change of road tolls;
4. Introduction of road charging into cities;
5. Change in max speed;
6. Fuel price variations;
7. New rail infrastructure and services;
8. Reorganisation of existing rail service (faster, more/less stops, hierarchisation);
9. Different fare policy;
10. Improvement of interchange nodes, intermodality;
11. Public transport extension;
12. Liberalisation/entry of a new player/exist of a player/mergers;
13. End/change of subsidies;

The model assumes some elements as invariants and consequently cannot simulate the related effect. The main ones are:

- e. Land use structure: generators and attractors do not change;
- f. Mobility rates: changes do not induce more/less mobility.

These two are the typical elements included in a LUTI model, whose scale is however usually local.

In the following, we will describe the test-scenarios simulated.

### 4.1 Description of analysed scenarios

This chapter illustrate the set of policies that has been tested with the aid of the model. The results of three of these scenarios will be presented and commented in the following sections. The evaluated policies and scenarios cover a range of variations in different kind of variables: exogenous or endogenous, evolution of the offer both in term of service and infrastructure changes, regulatory framework.

#### 4.1.1 Fuel price increase

The price of fuel at gas stations is the result of the sum of a number of components. These are: the price of the raw material, the gross margin of the company (that includes the remuneration of all the processing and distributions steps plus company and dealer's profits), and taxes, like excise duty and VAT.

The fuel price component less likely to lead to a significant change of the total price is the gross margin, that accounts for just about the 8%; the price of raw material instead, that accounts for about 1/3 of the total price<sup>11</sup> is subject to variations in international stock exchange quotation and the effects of currency fluctuations, therefore its amount may vary substantially over time, according to economic conditions, leading to a potentially perceivable change in the overall price. The most relevant component, taxes, may be redefined on the basis of policy decisions, leading therefore to a significant change in the total fuel price: in the European countries excise duty and VAT account generally for more than one half of the final price<sup>12</sup>.

The hypothetical situation analysed through the model is **the increase in final fuel price of +50%**. As fuel price is typically highly perceived by users, along with any tolls they may have to pay during the trip, the length of travel with private car (and secondarily the type of road travelled) will become more important both in modal and route choice, leading to an expected decrease in overall vehicle•km for private transport.

The fuel price impact is modelled through an increase in the vehicle operating costs that is the part of Generalised Cost varying with the length of travel, according to the quota of cost associated to fuel consumption.

#### 4.1.2 Highway pricing

In almost all countries the majority of the network has been built and maintained with public funds and managed directly by the State or by means of a national or local road agency.

In Italy, the tool of concession was used since the beginning, often by private or public-private enterprises. The concession model refers to the existence of a subject entitled to manage the infrastructure, the concessionaire, for a given period. In exchange of certain obligations (e.g. network construction or expansion), it is granted with the right to collect fees, typically from the users of the infrastructure, in order to recoup its investment and make some profit. The concession can be given to a private subject (and we will refer as “private concession”), to a state-owned company (“public concession”) or to a mixed ownership company (“mixed concession”). Concerning dynamics of tolling, the more common approach in Italy sees the road left to the concessionaire (usually without any public procedure), in exchange of the extension/upgrade of other infrastructures. This is, in fact, the case of almost all Italian concessions expired in the Nineties<sup>13</sup>. Traffic volume over the entire network reached in 2016 a total of 81.319 Millions of vehicle per km, with 62.889 Mv•km for light vehicles and 18.430 Mv•km for heavy-good vehicles<sup>14</sup>, with an increase of about 3% over the previous year. Revenues from tolling have reached in 2016 the total amount of 5.710 Millions of Euro, with an increase of 4.1% over the previous year. The net profit for the companies was 1.115 M€.

This scenario analyses the effects of the **elimination of tolls for all motorways**. This condition can be reached changing the remunerating system for concessioners from direct or indirect road tolling to a shadow tolling one, in which the company is directly remunerated by the public awarding authority.

The shadow tolling system enables the public authority to delegate the construction, funding and management of a road infrastructure to a concession company. The public authority remunerates the concession company

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<sup>11</sup> [http://www.unionepetrolifera.it/?page\\_id=303](http://www.unionepetrolifera.it/?page_id=303), accessed 18/04/2018

<sup>12</sup> Georgina Santos, Road fuel taxes in Europe: Do they internalize road transport externalities?, Transport Policy, Volume 53, 2017, Pages 120-134

<sup>13</sup> Paolo Beria, Francesco Ramella, Antonio Laurino, Motorways economic regulation: A worldwide survey, Transport Policy, Volume 41, 2015, Pages 23-32.

<sup>14</sup> Italian motorway vehicle classification is based for almost the whole network on number of axles (>2 axles) and height at the front axle (> 1,3 m), where every vehicle reaching one of the requirements is classified as a HGV.

principally based on the degree of utilization of the infrastructure (e.g. number of users) and on the performance of the concession company (e.g. number of lanes closed to traffic, intervention for increasing road safety, etc.). Thus, the concession company collects no toll from the users, for whom the infrastructure is free. In general, the shadow toll practice is used along motorways with few heavy-vehicle traffic.

In case of shadow toll system there is no tendency to shift traffic onto other roads as the users perceive the use of road infrastructure as free. There are no expenses associated with toll collection (in general between 10 and 15% of revenue are absorbed by toll collection costs and approximately 10% of the initial cost of the infrastructure represents construction of the toll stations). The final cost is borne by the tax-payer and not by the road user.

Tolls are taken into account in the model in different ways according with the type of tolling. These can generally be grouped in two categories: the “closed system”, in which a user pays according with the length of travel on the tolled road (plus a fixed fare to enter the system), and the “open system”, in which the user pays at specific points along the route, if passed.

In this scenario, both groups of tolls are set equal to 0, deleting from the Generalised Cost of private mode the component of tolls.

#### 4.1.3 Speed limitations

The current traffic law in Italy has been issued in 1992, and has been integrated and modified many times in the course of years. The 142<sup>nd</sup> article sets the speed limit for each kind of road.

On highways, the general speed limit is 130 km/h, to be considered automatically reduced to 110 km/h in case of adverse weather conditions. Where there are three lanes and the emergency lane for both directions, provided a safe road layout and a low rate of incidents for the previous five years, the administrating company can raise the speed limit to 150 km/h. To date, this has never been the case. Some categories of drivers are entitled to lower speed limits: those who have been having driving licenses for less than three years cannot exceed 100 km/h.

Regarding the implications of speed limit on safety, there is a definite trend of increased fatality risk when speed limits are raised<sup>15</sup>, which can be modelled with an exponential model, known as Power Model. Different studies set a range of values for exponent in the formula that link the percentage of speed change and the variation in fatal accident and fatalities, both for increase and decrease of speed limit, where an interesting finding is that those do not depend upon the initial speed<sup>16</sup>. The speed to be considered is the effective average speed before and after the speed limit change, thus it is not possible to directly evaluate the potential change in safety without considering the actual drivers' speed distribution for the specific road considered.

Environmental impacts of lowering the speed limit show mixed results in literature, as results indicate that emissions of most classic pollutants for the research undertaken do not rise or fall dramatically with speed limit variations<sup>17</sup>.

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<sup>15</sup> Charles M. Farmer (2017) Relationship of traffic fatality rates to maximum state speed limits, *Traffic Injury Prevention*, 18:4, 375-380

<sup>16</sup> Elvik, Rune. The Power Model of the relationship between speed and road safety: update and new analyses. Department of Safety, Security and Environment, Norwegian Centre for Transport Research, No. 1034/2009

<sup>17</sup> Panis, L. I., Beckx, C., Broekx, S., De Vlieger, I., Schrooten, L., Degraeuwe, B., & Pelkmans, L. (2011). PM, NOx and CO2 emission reductions from speed management policies in Europe. *Transport Policy*, 18(1), 32-37.

In the model, variation in the speed limit is taken into account by modifying the flow function. Specifically, the ones associated to highway arcs have been modified according to the **new speed limit of 110 km/h**. The module to estimate the environmental impacts utilize indicators of energy consumption and emissions of air pollutants. Regarding road transport, fuel consumption and consequent emissions per each kind of engine (the share of these is based on the average vehicles fleet) is calculated on each kind of road under different conditions (namely free flow or congestion), according to COPERT 4 methodology; other emission factors are used for public transport modes. Safety is addressed generally considering the amount of km travelled on different roads and the statistical probability of accidents of various severity, according to different speed profiles.

#### 4.1.4 Rail prices

Railway fares are subject to different regimes, according to the scope of the transport. Rail services can be distinguished in three main groups: long-distance market services, long-distance PSO services (subsidized by the State) and regional services (subsidized by the Regions).

Long-distance passenger rail transportation in Italy is subject to an ongoing increase in competition both intra-modal and inter-modal. Inter-modal competition has had a significant increase in 2008 when HSR services started run on the Rome-Milan line, leading to a tough competition between high-speed rail and air transport on the national route with the higher transport demand. On the same route, in 2012 entered in the market a new rail company, *Nuovo Trasporto Viaggiatori*, in competition with the incumbent Trenitalia. This resulted in an even higher pressure on the air companies operating that route, whose market share fell to 26%, about half of the 2008 one<sup>18</sup>. Focusing on intra-modal competition, nowadays it takes place on the entire high-speed network with some extensions to conventional lines in north Italy.

Regional transport is operated under PSO schemes, with each Regional Council deciding whether to give a direct procurement to the rail operator or to issue a call for tender. Only in a few cases though operations have been awarded with a public tender up to now. In both cases anyway, under PSO, the service is subsidized and fares (as well as compensation for operators) are decided by the Region.

In this scenario, **three different variations in fares will be tested: free travel on regional trains, an increase of 30% of regional fares, and the adoption of the price level of market service on the whole long-distance rail network**. The two variations in regional fares are tested in the model by setting the relative fares functions (equal to zero in the first case and with an increase of 20% in the second one) for all travel purpose, while the latter is simulated by substituting the correspondent market fare to the PSO service for each group of travel purpose.

#### 4.1.5 New infrastructure: completion of the A12 Tirrenica highway

The project of a highway between Genova and Roma along the coast dates back to the sixties, when the first parts east of Genova have been built, reaching Livorno during the seventies. Since then, two other main section have been realized, one extending the northern part, and one in the south from Civitavecchia. A final project for the central part was presented in 2011 by SAT<sup>19</sup> but the Government eventually did not finance it. In 2017, a project review by the ministry of transport lead to a different configuration: according to ANAS, the new infrastructure would be limited to a part of the itinerary, while other parts would see a renewal of the Aurelia

<sup>18</sup> Beria, P., Albalade, D., Grimaldi, R., & Bel, G. (2016). Delusions of success: costs and demand of high speed rail in Italy and Spain. In 14th World Conference on Transport Research (pp. 1-20)

<sup>19</sup> "Società Autostrada Tirrenica"

state road, widening it to 2 lanes per direction<sup>20</sup>, but without emergency lane. The proposed itinerary has been modified according to the various reviews during the years, leading to some confusion about the exact path and road layout.

To **simulate the realization of the A12 highway**, the itinerary as presented in 2011 by SAT has been taken into account, considering also the specified portions of Aurelia state road subject to revamping. The whole project has been integrated in the road graph, drawing arcs of the new road where necessary and modifying features of the existing one in case of upgrades of present infrastructure. Links to the ordinary road network have been implemented where hypothesized in the project. Tolling has been implemented using the same values published by SAT concerning the existing parts (no effect of local reduction agreements have been considered).

#### 4.1 Test Scenario 1 – Fuel price increase

The first scenario simulates the effect of an increase of 50% of the fuel price, which corresponds approximately to a +25% of vehicle operating costs. This large but not impossible variation has limited consequences in the modal change and remain limited to different route choice. This result would be impossible to be estimated without an intermodal model.

In Figure 59 we can appreciate the variations of flows in the road system. The map is mostly “red”. This means that the road system has lost traffic in favour of the public transport system. This fact is, in principle, not obvious, as in case of unavailability or ineffectiveness of public transport, any fuel increase would increase private costs but not involve any modal change. In fact, this is what happens: not all road corridors lose traffic. Actually, the main effect is visible only on long-distance relations while traffic on local roads is almost unchanged. This means that alternatives for commuting are not perceived as useful, while the long-distance system yes. Some roads look “blue”, which means that they received traffic from other roads, typically because shorter and allowing a fuel cost saving.

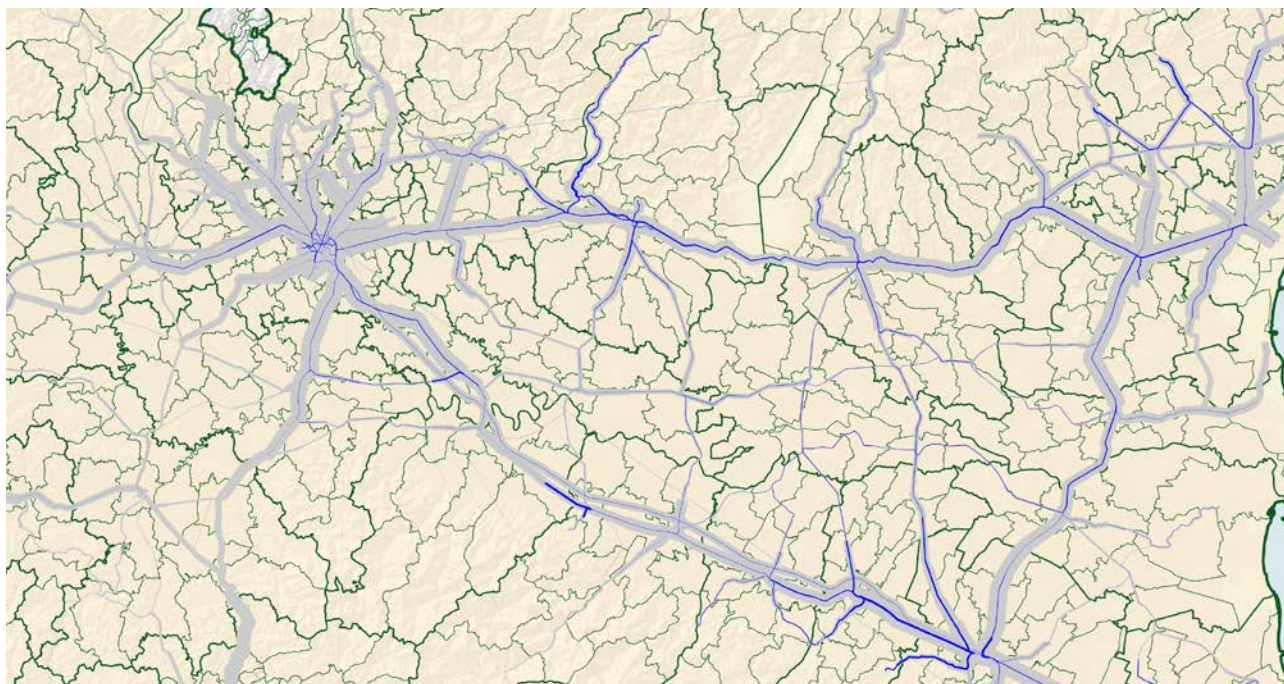
Figure 60 depicts what happens in the public transport system. The small share of users that switched to public transport are unevenly distributed. In some contexts the public transport alternative is more attractive, typically for longer commuting flows (e.g. around Brescia or in northern Puglia). Not all good transport systems attract flows: Milan is almost invisible, sign of the fact that public transport is already used and that those not using it do not have a real alternative, like everywhere else in the country.

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<sup>20</sup> Source: <https://www.stradeeautostrade.it/notizie/2017/autostrada-tirrenica-un-piano-anas-per-adequare-laurelia-a-superstrada/>



Figure 59. Scenario fuel price +50%. Variation of road flows.

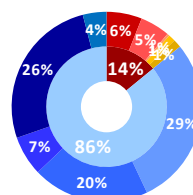


*Figure 60. Scenario fuel price +50%. Variation of public transport flows. Focus: Pianura Padana*

Actually, the overall effect of this scenario is very small, as Figure 61 documents. Public transport share remain almost constant (+0.5%). This is, again, a demonstration that the public alternatives at the local level are more limited (at the national scale) than long-distance ones.

## DOMANDA INTERZONALE GENERATA PER MODO E MOTIVO

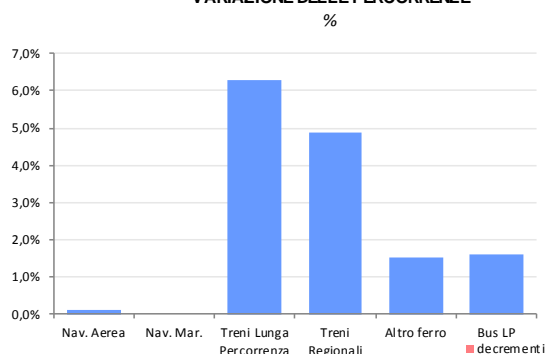
	Pubblico	Privato	TOT	% Pubb	% Priv
	<i>mil. spost/giorno</i>				
Studio	3,58	2,39	5,97	60%	40%
Lavoro	3,00	15,58	18,58	16%	84%
Affari	0,24	4,03	4,28	6%	94%
Familiari	0,71	11,79	12,50	6%	94%
Tempo libero	0,83	17,13	17,95	5%	95%
<b>TOT</b>	<b>8,36</b>	<b>50,93</b>	<b>59,28</b>	<b>14,1%</b>	<b>86%</b>



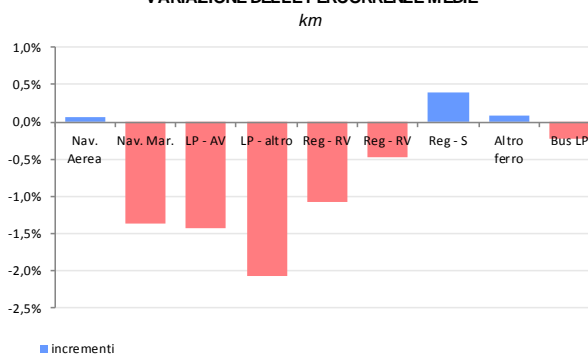
## TRASPORTO PUBBLICO

		corse *km	passenger	volumi	perc.	tempi	Vel. Comm.	occ. Media
		<i>mkm/giorno</i>	<i>mil/giorno</i>	<i>mpax*km/g</i>	<i>km</i>	<i>pax*h</i>	<i>km/h</i>	<i>pax/corsa</i>
AER	Navigazione aerea	0,29	0,08	29,36	389,5	0,1	223,2	101,8
MAR	Nav. Marittima ed interna	0,01	0,01	0,24	37,8	0,0	22,6	44,6
	LP - Alta Velocità	0,26	0,05	11,66	251,7	0,1	184,7	45,2
	LP - Altro	0,22	0,20	19,57	96,9	0,2	102,9	90,2
FER	Regionali - RV	0,38	1,61	49,34	30,7	0,6	83,1	129,9
	Regionali - R	0,71	5,00	97,42	19,5	1,6	62,7	136,4
	Regionali - S	0,30	3,39	36,80	10,8	0,8	47,4	124,3
	Altro ferro (metro, tram...)	0,18	3,55	14,32	4,0	0,7	20,8	81,2
BUS	Bus lunga percorrenza	0,12	0,11	4,12	81,0	0,1	54,1	34,0
<b>TOTALE</b>		<b>2,46</b>	<b>14,0</b>	<b>262,8</b>	<b>18,8</b>	<b>4,1</b>	<b>64,4</b>	<b>107,0</b>

## VARIAZIONE DELLE PERCORRENZE



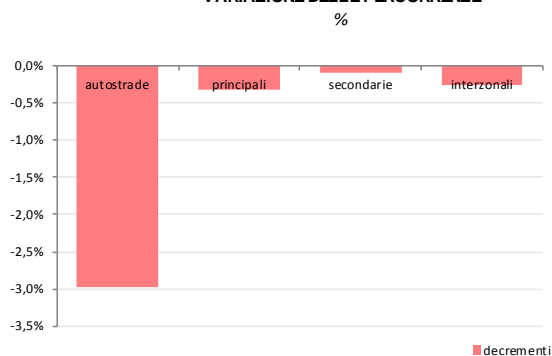
## VARIAZIONE DELLE PERCORRENZE MEDIE



## TRASPORTO PRIVATO

	volumi (mil. vkm/giorno)			tempi (mil. vh/giorno)			velocità (km/h)		
	leggeri	pesanti	totali	leggeri	pesanti	totali	leggeri	pesanti	totali
Rete autostradale	162,6	60,0	222,7	2,64	1,42	4,06	61,6	84,6	66,5
Rete principale	261,8	33,8	295,6	7,77	1,16	8,94	33,7	58,1	35,4
Rete secondaria	175,9	14,2	190,1	9,12	0,67	9,80	19,3	42,2	20,1
Rete interzonale	178,6	9,7	188,3	7,13	0,42	7,55	25,1	46,7	25,7
<b>TOTALE</b>	<b>779,0</b>	<b>117,7</b>	<b>896,7</b>	<b>26,66</b>	<b>3,67</b>	<b>30,34</b>	<b>29,2</b>	<b>32,1</b>	<b>29,6</b>

## VARIAZIONE DELLE PERCORRENZE



## VARIAZIONE DELLE VELOCITA'

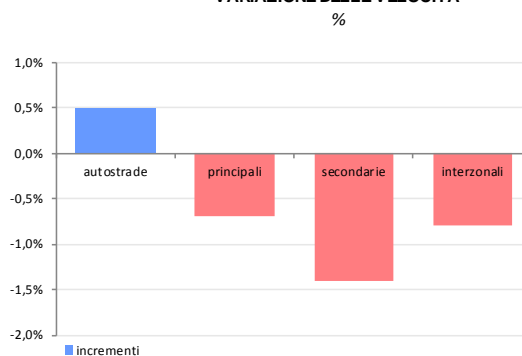


Figure 61. General results of the Scenario fuel price +50%.

## 4.2 Test Scenario 2 – Highway pricing

The scenario represents a case which is not likely to happen, but also not unrealistic. It might be the case of end of concessions and (political) decision to remove tolls (it is what happened in Germany in the past), at least for cars. The obvious effect is an attraction of trips from conventional road network (and public transport network, too) to highways, which are now “capped” by the extra-cost of tolls.

Figure 62 shows the effect in the road system. The larger effects are in the Pianura Padana, and it is due to the importance of short-trips that can be attracted to the main network. In the South the effects are negligible (Puglia excluded) because highways are often already free or traffic is scant.



Figure 62. Scenario free highway. Variation of flows.

Some corridors are particularly interesting. For example, the Roma – Orte freeway (Figure 63), now preferred from Veneto to Central Italy despite its bad geometry, that will lose a lot of traffic in favour of the now free A1. Around Milan (Figure 64) we see sometimes no effect, like along the A4 north of the city, already free. But the Pedemontana and the Brebemi increase significantly their traffic, usually from the conventional network and very limitedly from the *unsubstitutable* A4.



Figure 63. Scenario free highway. Variation of flows. Focus Roma-Orte

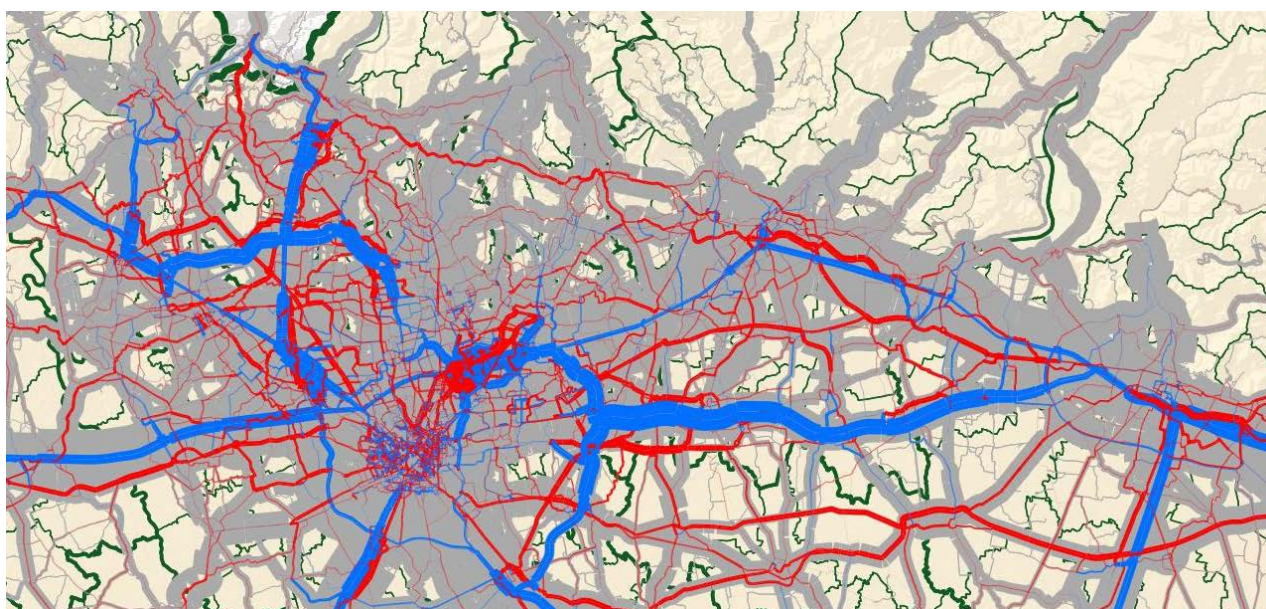
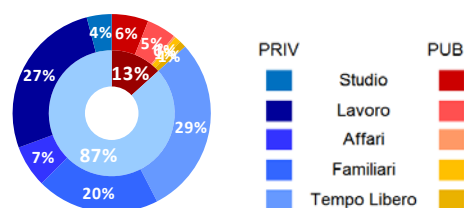


Figure 64. Scenario free highway. Variation of flows. Focus Milan – Brescia corridor.

The overall effects at the national scale are summarised in Figure 65. The policy increases the traffic on the highway network of the 8%. This figure is not a lot, sign of the fact that the highway has a rigid demand which is already present despite the toll.

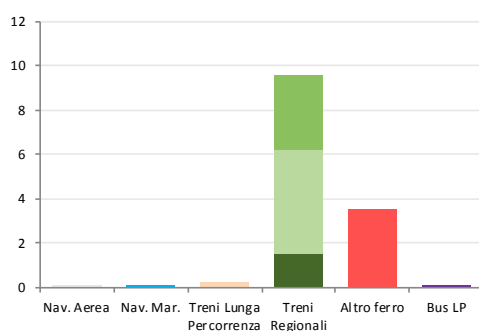
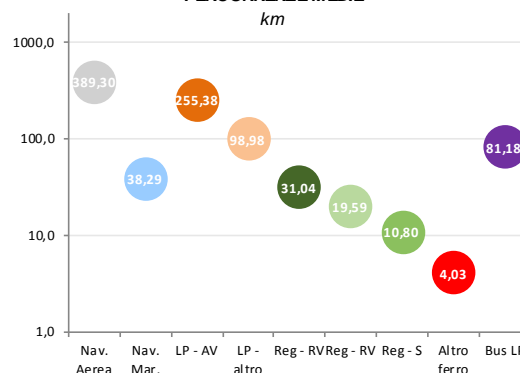
## DOMANDA INTERZONALE GENERATA PER MODO E MOTIVO

	Pubblico	Privato	TOT	% Pubb	% Priv
	mil. spost/giorno				
Studio	3,56	2,41	5,97	60%	40%
Lavoro	2,84	15,74	18,58	15%	85%
Affari	0,20	4,08	4,28	5%	95%
Familiari	0,60	11,90	12,50	5%	95%
Tempo libero	0,67	17,28	17,95	4%	96%
<b>TOT</b>	<b>7,87</b>	<b>51,41</b>	<b>59,28</b>	<b>13%</b>	<b>87%</b>



## TRASPORTO PUBBLICO

		corse *km	passegge	volumi	perc.	tempi	Vel. Comm.	occ. Media
		mkm/giorno	mil/giorno	mpax*km/g	km	pax*h	km/h	pax/corsa
AER	Navigazione aerea	0,29	0,08	29,31	389,3	0,1	223,2	101,7
MAR	Nav. Marittima ed interna	0,01	0,01	0,25	38,3	0,0	22,6	45,5
	LP - Alta Velocità	0,26	0,04	11,40	255,4	0,1	184,8	44,2
	LP - Altro	0,22	0,19	18,70	99,0	0,2	102,7	86,2
FER	Regionali - RV	0,38	1,53	47,59	31,0	0,6	83,1	125,2
	Regionali - R	0,71	4,71	92,25	19,6	1,5	62,7	129,1
	Regionali - S	0,30	3,29	35,51	10,8	0,7	47,5	120,0
	Altro ferro (metro, tram.)	0,18	3,50	14,10	4,0	0,7	20,8	79,9
BUS	Bus lunga percorrenza	0,12	0,11	4,06	81,2	0,1	54,1	33,5
<b>TOTALE</b>		<b>2,46</b>	<b>13,5</b>	<b>253,2</b>	<b>18,8</b>	<b>3,9</b>	<b>64,4</b>	<b>103,0</b>

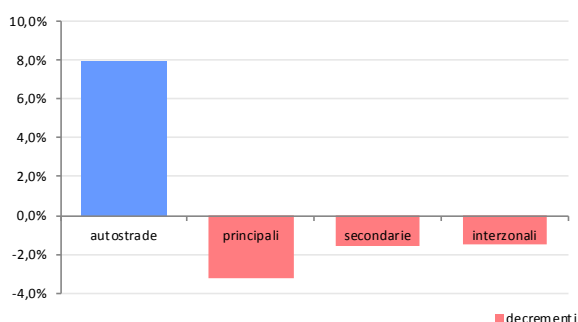
RIEPILOGO PERCORRENZE  
milioni passeggeri\*km/giornoPERCORRENZE MEDIE  
km

## TRASPORTO PRIVATO

	volumi (mil. vkm/giorno)			tempi (mil. vh/giorno)			velocità (km/h)		
	leggeri	pesanti	totali	leggeri	pesanti	totali	leggeri	pesanti	totali
Rete autostradale	180,7	67,0	247,8	2,90	1,60	4,50	62,2	84,0	66,9
Rete principale	256,7	30,3	287,0	7,54	1,02	8,56	34,0	59,5	35,7
Rete secondaria	174,6	12,7	187,3	8,93	0,61	9,53	19,6	42,0	20,3
Rete interzonale	177,4	8,6	186,0	7,11	0,38	7,49	25,0	45,5	25,5
<b>TOTALE</b>	<b>789,5</b>	<b>118,7</b>	<b>908,2</b>	<b>26,48</b>	<b>3,60</b>	<b>30,08</b>	<b>29,8</b>	<b>33,0</b>	<b>30,2</b>

VARIAZIONE DELLE PERCORRENZE

%



VARIAZIONE DELLE VELOCITA'

%

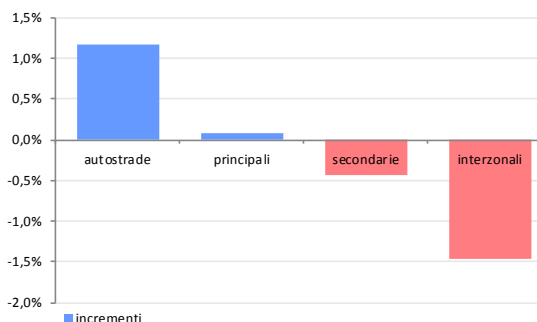


Figure 65. General results of the Scenario Free highway.

### 4.3 Test Scenario 3 – Speed limitations for environmental policies

The scenario tests the effect of a decrease in max speed on Italian highways. This kind of policy may have interesting impacts in terms of safety and environment, but involves an increase in travel time, which is a surplus loss for users. Actually, the effects of such variation are not limited to highways. In fact, on some relations users will probably change just marginally their behaviour, because highway remains the best option. They will just “pay” more travel time. In other situations, the toll saving and the availability of not much worse alternative routes may push vehicles to ordinary roads.

Figure 66 depicts the results at the national scale. Effects are visible, even if softer with respect to the previous case and to current flows (in grey). Interestingly, the effect is not particularly concentrated in some areas/contexts, but involve all the network. Figure 67 clearly shows a typical case: in Puglia, the availability of a parallel freeway with good geometrical and speed characteristics, shifts a lot of users from the tolled highway. In other areas, like Milan metropolitan area, the shift is not on a specific corridor, but spreads all over the network.

The overall effects of this shift can be appreciated in Figure 68. Highway system loses a small share of users, about 4%. However, not only the total travel time increases, but also speed on the entire network decreases: the shifted users, especially around cities, increase the congestion and this causes a decrease of the speed on most of network.

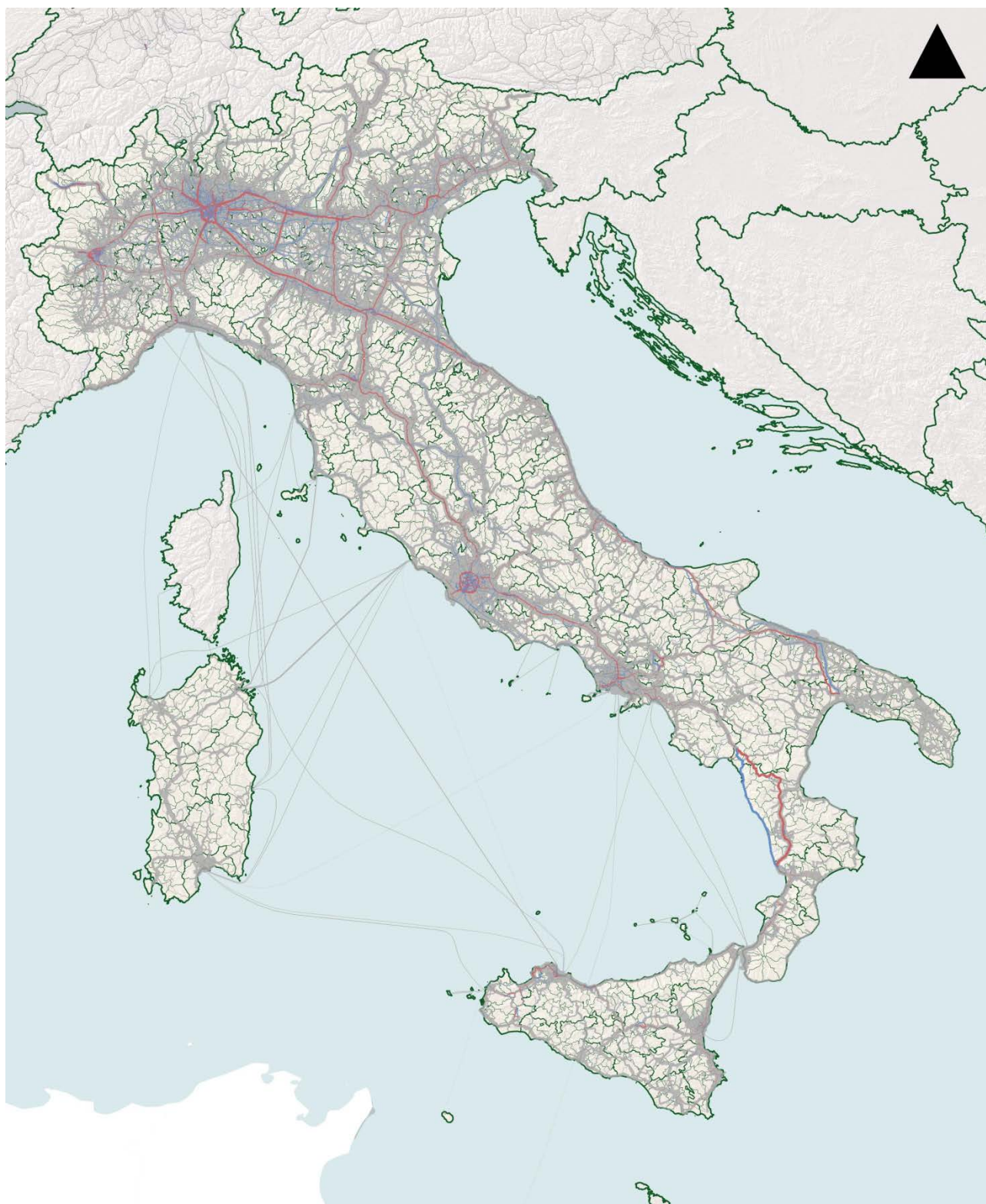


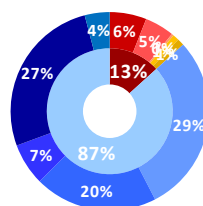
Figure 66. Scenario highway speed 110km/h. Variation of flows.



*Figure 67. Scenario highway speed 110km/h. Variation of flows. Focus Northern Puglia.*

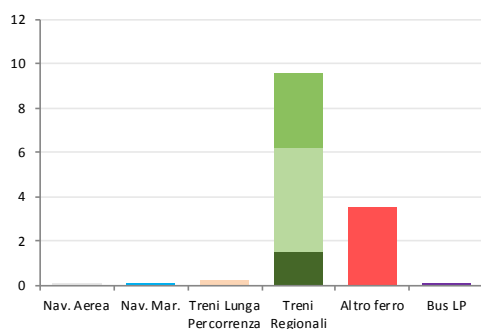
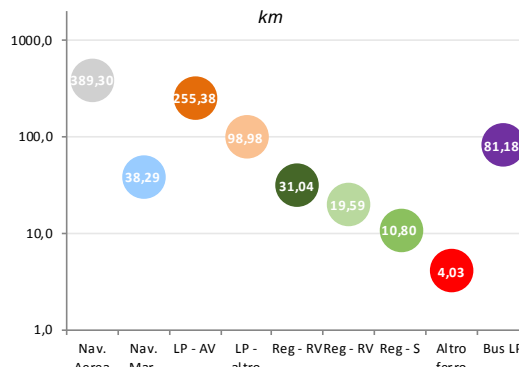
## DOMANDA GENERATA PER MODO E MOTIVO

	Pubblico mil. spost/giorno	Privato mil. spost/giorno	TOT	% Pubb	% Priv
Studio	3,56	2,41	5,97	60%	40%
Lavoro	2,84	15,74	18,58	15%	85%
Affari	0,20	4,08	4,28	5%	95%
Familiari	0,60	11,90	12,50	5%	95%
Tempo libero	0,67	17,28	17,95	4%	96%
<b>TOT</b>	<b>7,87</b>	<b>51,41</b>	<b>59,28</b>	<b>13%</b>	<b>87%</b>



## TRASPORTO PUBBLICO

		corse *km mkm/giorno	passegge mil/giorno	volumi mpax*km/g	perc. km	tempi pax*h	Vel. Comm. km/h	occ. Media pax/corsa
AER	Navigazione aerea	0,29	0,08	29,31	389,3	0,1	223,2	101,7
MAR	Nav. Marittima ed interna	0,01	0,01	0,25	38,3	0,0	22,6	45,5
	LP - Alta Velocità	0,26	0,04	11,40	255,4	0,1	184,8	44,2
	LP - Altro	0,22	0,19	18,70	99,0	0,2	102,7	86,2
FER	Regionali - RV	0,38	1,53	47,59	31,0	0,6	83,1	125,2
	Regionali - R	0,71	4,71	92,25	19,6	1,5	62,7	129,1
	Regionali - S	0,30	3,29	35,51	10,8	0,7	47,5	120,0
	Altro ferro (metro, tram.)	0,18	3,50	14,10	4,0	0,7	20,8	79,9
BUS	Bus lunga percorrenza	0,12	0,11	4,06	81,2	0,1	54,1	33,5
<b>TOTALE</b>		<b>2,46</b>	<b>13,5</b>	<b>253,2</b>	<b>18,8</b>	<b>3,9</b>	<b>64,4</b>	<b>103,0</b>

RIEPILOGO PERCORRENZE  
milioni passeggeri\*km/giornoPERCORRENZE MEDIE  
km

## TRASPORTO PRIVATO

	volumi (mil. vkm/giorno)			tempi (mil. vh/giorno)			velocità (km/h)		
	leggeri	pesanti	totali	leggeri	pesanti	totali	leggeri	pesanti	totali
Rete autostradale	160,7	60,1	220,8	2,80	1,43	4,23	57,4	84,2	62,8
Rete principale	266,7	34,3	301,0	7,89	1,17	9,06	33,8	58,5	35,5
Rete secondaria	177,9	14,0	191,9	9,19	0,66	9,85	19,4	42,6	20,2
Rete interzonale	180,8	9,5	190,4	7,15	0,41	7,55	25,3	46,8	25,9
<b>TOTALE</b>	<b>786,0</b>	<b>118,0</b>	<b>904,0</b>	<b>27,02</b>	<b>3,67</b>	<b>30,69</b>	<b>29,1</b>	<b>32,2</b>	<b>29,5</b>

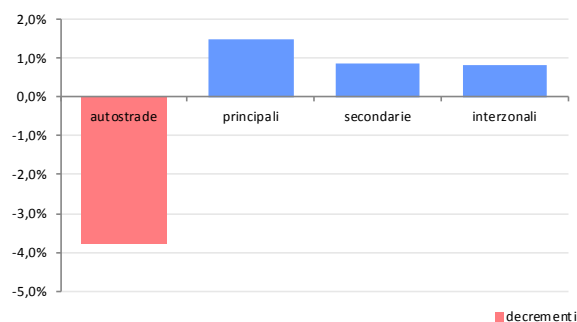
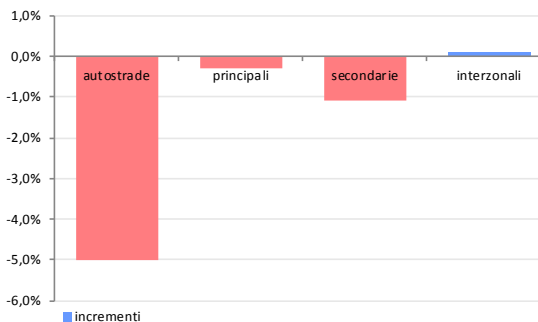
VARIAZIONE DELLE PERCORRENZE  
%VARIAZIONE DELLE VELOCITA'  
%

Figure 68. General results of the Scenario highway speed 110km/h.

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