Modelling Transport Corridors

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Synopsis

The paper deals with transport demand modelling and provides an overview of common methodological approaches to the estimation of traffic demand within the strategic analysis of transportation corridors.
Economic evaluation of transport systems is built on consolidated modeling approaches. Within this framework, demand estimation and forecasting are essential tasks, which are performed through the definition of suitable models able to predict users' behaviour and response to changes in transport services and/or infrastructures.
The most common model for travel demand forecasting is the so called "four-stage model", which divides the multidimensional choice into four levels: choice of travelling for a stated purpose (emission or frequency models), choice of destination (distribution models), choice of mode (modal split models) and choice of route (path choice models).
In the paper an example of a "four-stages model" is presented and discussed with reference to a transport corridor planning study: the estimation of freight and passengers' flows in the case of the realization of a new high-capacity railway between Venice and Ljubljana, which should perform the necessary connection between the E.U. Corridor n°6 (Lyon, Torino, Venezia, Trieste), identified by the Essen Conference, and the 5th Pan European priority Corridor (Trieste, Ljubljana, Budapest, Kiev) as defined in the Crete Conference.
In order to carry out the evaluation of this new transalpine rail crossing, a transportation study has been carried out which included the estimation and prediction of traffic flows on rail and road networks. A demand and supply analysis has been carried out; Origin/Destination matrices have been provided both for passengers and freight transportation and different graphs have been realised for rail and road networks. Then generation, distribution, modal choice and assignment models have been calibrated.
In the paper some important modelling issues are discussed, which are relevant in corridor planning processes, and finally some remarks are presented about the coherence between predicted traffic flows and the transport system capacity in the design scenario.

Modelling Transport Corridors

Demand forecasting is an essential task in the transportation systems analysis and planning: it is concerned with the behaviour of users of transportation facilities and services, and in its modeling to predict users' response to changes brought about by investments in infrastructures.
Within this framework, this paper focuses on strategic planning of transport corridors seen as privileged multi-modal links. An efficient planning approach, based on scientific and consolidated quantitative methods for the definition and the evaluation of alternative projects, may help in designing functional transport facilities and services, in order to minimize the risk of waste of economic resources.
In the present work these issues are analysed with reference to strategic transport corridor planning studies.
The paper is organized as follows. The first part is concerned with an overview of common methodological approaches to transport demand estimation and forecasting, then giving some details in the case of corridor studies. Within a real transport corridor planning process, some models are provided and discussed; they have been developed for the strategic estimation of passengers and freight flows in the case of the realization of a new high-capacity railway between Venice and Ljubljana. Finally some applicative issues, conclusions and further developments of the work are drawn.

MODELLING TRANSPORTATION SYSTEMS

Any transportation system can be spilt into two main components: *demand*, as the result of users travel choices, and *supply*, given by the characteristics of transportation services. The relevant interactions among the elements of the system can be simulated with consolidated mathematical models (Cascetta, 1998).
Supply models simulate the performances of infrastructures and services for the users, by means of flow network models. Infrastructures and services may relate to several modes, as in the case of transport corridors, which are a typical example of multi-modal systems, simulated through multimodal transport networks.
Demand models simulate the relevant aspects of travel demand as a function of the activity system and the supply performances. They are known as *descriptive* if they describe the relationship between travel demand and socio-economic and level-of service attributes without making specific assumptions about decision makers' behaviour, or *behavioural* if they derive from explicit assumptions about users' choice behaviour.
Models based on the second approach are able to make a stochastic simulation of the choice, which can be viewed as an outcome of a sequential decision-making process, including the definition of the choice problem, the generation of alternatives, the evaluation of alternatives' attributes and the choice itself. Any single decision maker considers a subset of the universal set, the *choice set*, which includes the alternatives that are both feasible to the decision maker and known during the decision process. The common assumption is that the decision maker is assumed to have a rational behaviour, meaning that he is a "maximizator" of utility and, under identical circumstances, will repeat the same choice. The attractiveness of an alternative is evaluated in terms of a vector of attribute values, which may be reducible to a scalar, thus defining a single objective function expressing the utility of an alternative, a measure that the decision maker attempts to maximize through his choice (Ben Akiva and Lerman, 1986).
A common model used in travel demand forecasting is the *four-stages model* (see Figure 1), which divides the multidimensional choice into four levels: the choice of travelling for a stated purpose (*emission* or *generation model*), the choice of destination (*distribution model*), the choice of mode (*modal split model*) and the choice of route (*path choice model*).

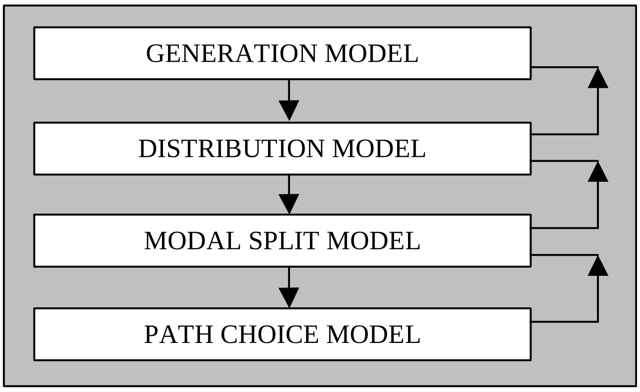

Figure 1: The four-stages model factorization

The transport demand is factorized into four sub-models linked to different choice dimensions:

$$d_{OD}(s,m,k) = d_O(s) \cdot p(d/os) \cdot p(m/ods) \cdot p(k/\text{mod}\, s)$$

where the demand flow between the origin *O* and the destination *D* is expressed through the product of the following factors:
- the fraction of travellers who decide to travel for purpose *s*;
- the fraction of users undertaking a trip from *o* for purpose *s* travelling to destination zone *d*;
- the fraction of users who, travelling between *o* and *d* for purpose *s*, use transport mode *m*;
- the fraction of users who, travelling between *o* and *d* for purpose *s* by mode *m*, use route *k*.

The expression for d_{OD} may be seen as the result of real observed choices but also as the estimate provided of choice models.

In case of estimation for aggregate demand within planning processes, descriptive models are often adopted within the first two stages (i.e. emission and distribution), while mode and route choice are generally handled using behavioural models.

Descriptive *emission models* are based on linear regression statistical models, providing the average number of trips for each zone through typically linear function of zonal socio-economic attributes such as population, income, number of cars owned or zonal accessibility.

Descriptive *distribution models* have a functional form that is similar to the Multinomial Logit structure. The variable included can be divided into two groups: attributes of the activity system located in destination zone (or *attractivity attributes*) and *cost* (or *separation attributes*) between origin and destination zones, which are variables measuring the *generalized cost* of a trip. Several cost attributes can be considered: the simple crow-flight distances between centroids or generalized cost variables including various components for the different available transport modes (on board, terminal, on foot times, monetary costs, etc.). In applications, special forms as the *simply* or *double constrained gravitational model* are used, which derive their name from their formal similarity with the Newton’s law of universal gravitation.

Mode choice is a typical example of travel choice that can be modified for different journeys, in which performance and level-of-service attributes have strong influence. The identification of the choice set depends on the transport system under study and parameters characterizing modal choice models are heavily influenced by the study typology and scale. Attributes in the systematic utility function are usually travel attributes (e.g. purpose, time and day), level-of-service attributes related to mode characteristics (e.g. travel time, monetary cost, frequency, transfers), and socioeconomic attributes linked to the decision maker’s characteristics (e.g. age, income, profession). In addition, it is possible to include *Alternative Specific Attributes* (ASA) or *modal preference*, accounting for qualitative characteristics of each mode (e.g. comfort, privacy) or those not explicitly included in the attributes (e.g. service regularity).

Finally, path choice used in practice are all behavioural and the relevant attributes are performances attributes, such as travel times or distances, obtained from the network supply models.

Forecasting Issues

The described methods can be used to estimate present demand or demand variations corresponding to hypothetical scenarios implying modifications of the transportation system and/or of the activity system.

In the case of short-term projects, it is assumed that the socio-economic variables of the activity system do not vary, while the transportation performance variables are modified by the project. These variations may impact travel choices on several dimensions (path, mode, destination, frequency).

Medium-long terms projects usually require the simulation of their effects over a sufficiently long period and in this case it is also necessary to estimate the evolution of socio-economic variables. In general it is very difficult to obtain a reliable forecasting about the main variables of the activity system (e.g. resident population, income levels and economic production organization) in the medium-long term. In practice, for long-term applications, different *scenarios* for the evolution of the socio-economic variables are used (being a scenario a set of internally consistent assumptions on the exogenous variables generally obtained with macro-economic models). Demand models are then applied to each scenario and variations range of the key variables can be used for the design of alternative projects.

Some forecasting techniques are based on the *pivoting method* in which models are used as simulators of the variations with respect to present demand, rather than directly future demand, by means of a double application of the model to present and future scenarios (Cascetta, 1998). This approach assumes that, if many information sources on present demand are available, it is possible to obtain estimates of the present demand better than those obtained by using only demand models, since modelling errors may be reduced.

CORRIDOR MODELS

Conventional modelling approaches require large amounts of resources, especially as regards data, computing time and technical expertise. Moreover they may not be sensitive to some of the policy options needing analysis. The basic idea is to adopt an approach which uses simpler models to provide a planning background and selectively applies classical models to the most relevant decision elements of the problem.

A typical opportunity for simplifying modelling tasks without compromising realism too much is provided in *corridor studies*. Transport corridors are privileged multi-modal and multi-commodity links, comprising strong,

basically linear, transport facilities; their linear nature may help to simplify both the data collection and the modelling task (Ortuzar and Willumsen, 1994).
The basic information needed are the current flow levels by mode for the different sections of the corridor, data on level of service variables for each mode and section, focusing in particular on data referred to the main branch of the corridor and neglecting crosswise traffic flows.
Within the modelling tasks, sometimes it may be sufficient to model the linear corridor and consider only the points of entry and exit to it as origins and destinations. There may be a major destination at one end of the corridor or they may be distributed throughout its length. In any case, assignment problems are often minimal and the modelling effort is focused on issues such as destination and mode choice.
Direct demand models, such as the *SARC Model* or the *Quandt and Baumol Model*, appear as suitable choices, in particular in areas with large zones, such as inter-urban and corridor studies (Ortuzar and Willumsen, 1994). Direct demand models can be of two types: purely *direct*, which use a single estimated equation to relate travel demand directly to mode, journey and traveller attributes (Safwat and Magnanti, 1990); and a *quasi direct-approach* which employs a form of separation between mode split and total Origin-Destination travel demand.
In most cases a multimode trip matrix is assumed in these studies. If the study covers several years in the future, it may be necessary to use some matrix updating techniques based on suitable models.
Corridor modelling with severe capacity constraints requires some care; bottleneck effects in the corridor should be treated specifically and sometimes micro-assignment models may be applied to them. Moreover, in some cases, mixed modes or combinations of different modes such as car plus train, or different services of the same transport mode (e.g. High-Speed, Intercity or Regional for the railway mode) are included as choice alternative, thus needing suitable micro-modal choice models to simulate such alternatives.
Such considerations provide a scientific basis for the methodological approach which has been adopted in the case study discussed in the present work.

THE PROPOSED APPROACH

Strategic transport corridor planning studies generally aims at performance evaluation of infrastructures during the period for which the system has been designed, as regards network and traffics. Thus much attention has to be paid to demand estimation and forecasting over long periods, at strategic level and wide geographic scale, taking onto account the specific features of the studied corridor and involved zones.
As regards data collection, it is worth considering that the knowledge on passengers and freights flows by mode in interregional transport is generally limited since data of the number of O/D flows are generally not easily available. Moreover the usual international framework of these studies further increases the difficulty of this task, because of discrepancies and inconsistencies among data achieved by sources coming from different countries, for different purposes and with different modalities, especially as regards border crossing flows data.
The lack of suitable and reliable data often leads to important consequences in modelling approaches to be adopted as regards both emission/distribution stages and modal split one, since route choice is generally less important in the evaluation of flows in multi-modal corridors, due to the reduced number of alternatives. Moreover some problems caused by zoning also influence the modal split model specification and calibration, leading to some important deepening.
Next section refers to the approach which has been proposed for strategic forecasting purpose and then applied to a specific case study.

Emission And Distribution

The first task refers to the development of mathematical forecasting models, calibrated on the present socio-economic situation and traffic data, which would be able to project the total O/D matrices (road + rail traffic flows in the reference scenario) to different time horizons.
As previously seen, an alternative approach to the classical four-stages model in the case of transport corridors is to develop directly a model subsuming trip generation and distribution. A simultaneous emission and distribution model may be defined to estimate future demand among different O/D pairs by means of one single step, aiming at minimizing the disturbance effect due to the lack of data for some O/D pairs. Such model also tries to overcome some problems arising from the high data aggregation level, as commonly happens for corridor studies (e.g. presence of different Countries with different economic levels, freight demand data which are aggregate as for goods typology and economic activity sectors).
The structure of the proposed model is derived from the classical gravitational model (Morlok, 1976) which must be modified slightly so that the desired conditions on total production equal the estimated trips generated in a zone and total terminations equal the number of trip attracted. These modifications, firstly developed by A. Voorhees, are here summarized.
The basic formulation is the following:

$$d_{ij} = \alpha \frac{G_i \, A_j}{(c_{ij})^b}$$

where d_{ij} denotes the total number of trips (rail + road) from zone *i* to zone *j*, G_i and A_j are respectively the emission potential of zone *i* and the attraction potential of zone *j* (both function of socio-economic variables), while c_{ij} is the travel cost from zone *i* to zone *j* and *b* is the cost exponent which is generally linked to travel purpose. The factor α must be evaluated: this is done in such a way that the constraint on trip originations holds:

$$\sum_{j=1}^{N} d_{ij} = \sum_{j=1}^{N} \alpha \frac{G_i \, A_j}{(c_{ij})^b} = G_i$$

Solving for α, the relation becomes:

$$d_{ij} = G_i \frac{\dfrac{A_j}{(c_{ij})^b}}{\displaystyle\sum_{k=1}^{N} \frac{A_k}{(c_{ik})^b}}$$

The specification task needs to be differed for passengers and freights demand, for inner and external zones and for different countries, by considering suitable socio-economic variables and accounting for specific features of the zones. Available statistics socio-economic variables usually refer to population, employment for different economic field and total income, thus emission and attraction potentials of each zone could be expressed as a function of these few variables.

In the passengers' model, trips can be considered symmetrically distributed between each O/D pair if data are referred to annual trips. Stating that each element of the O/D matrix referred to both journey there and back between each pair, total trips among the *N* zones are provided by the following:

$$d_{ij} + d_{ji} = G_i \frac{\dfrac{A_j}{(c_{ij})^b}}{\displaystyle\sum_{k=1}^{N} \frac{A_k}{(c_{ik})^b}} + G_j \frac{\dfrac{A_i}{(c_{ji})^b}}{\displaystyle\sum_{k=1}^{N} \frac{A_k}{(c_{jk})^b}}$$

As regards freight transport, the hypothesis of symmetric distribution of trips does not hold, being goods carried from production to consumption zone. Moreover consumers may be either intermediate (production companies) or final (families, public administration). Demand flows d_{ij} and d_{ji} for each O/D pairs are therefore simulated separately.

Since the evolution of the exogenous variables over long time periods depends on complex phenomena related to demographic and socio-economic evolution of the study area, the usual practice is to consider different scenarios to estimate the range of variation of the simulated effects and to check the robustness of the alternative projects with respect to the possible future scenarios.

Mode Choice

In zoning, it is assumed that the departure and arrival points of all the trips related to a zone are concentrated in a single arbitrary point, known as *zone centroid*, which is generally located baricentrically with respect to zone itself. This simplification sometimes implies some difficulties when models are calibrated in order to reproduce the real situation, mainly whereas considered zones are quite large as in the case of corridors.

If zones are quite large, trips performed between points which are located close to the boundary are not adequately described and this may severely affects modal choice. To give an example, in an extra-urban context, road traffic is present both across and near to the boundary. In a multi-modal system the train mode can be rejected because it often implies a trip by car to the station, which may be comparable to the length of the whole trip. In this case, it is difficult to describe the modal choice behaviour using only typical attributes, such as distance between centroids or average travel time, and some specific attributes are needed.

Furthermore, it is useful to underline that it is not possible in general to disaggregate zones in such a way as to reproduce these movements, since in case of corridor strategic planning studies within international frameworks data are generally unreliable and too much aggregate.

The problem explained above suggests the introduction of new attributes in the usual theoretic Logit approach (Cascetta, 1998), to minimize the effects of boundaries between adjacent zones within the modal split model.

Where choices are made among two alternatives, as in the case where rail and road are considered as competing modes, a binary Logit model is usually adopted. The general functional form, which gives the choice probability of the train alternative, is assumed to be the following:

$$P(t) = e^{\overline{\beta}\,\overline{X}_t} \Big/ \left(e^{\overline{\beta}\,\overline{X}_r} + e^{\overline{\beta}\,\overline{X}_t} \right)$$

where *t* denotes the train mode and *r* the road mode; β represents the parameters' vector and *X* is the independent variables' vector (i.e. modal attributes).

Modal attributes choice may be classified into three groups: characteristics of the trip maker, characteristics of the journey and characteristics of the transport facility. Regarding the first group, features such as car availability and/or ownership, possession of a driving licence, household structure, income and residential density are generally believed to be important. If the characteristics of the journey are considered, mode choice is strongly influenced by the trip purpose and time of the day when the journey is undertaken. As regards the characteristics of the transport facility, they can be divided into two categories: firstly, quantitative factors such as relative travel time (in-vehicle, out-of-vehicle, waiting and walking times) and relative monetary cost (fares, fuel and direct costs); secondly, qualitative factors which are less easy to measure, such as comfort and convenience, reliability and regularity, protection and security.

In order to describe in better way trips between points close to the boundary, a dummy binary variable is introduced into the cost function, taking the values of 1 for adjacent zones or 0 otherwise. The new attribute is called ADJACENCY and allows avoiding the boundary problem. Adjacency may be considered as an "internal" variable, strongly linked to zoning, which does not belong to any of the classical categories of modal attributes already mentioned and cannot be changed by any modal improvement.

Since a binary variable could cause a too drastic division, a further improvement is obtained by analyzing the boundary influence in greater detail. Thus, Adjacency is redefined as a product of another two coefficients (Bernetti, Camus, Longo, 1999):

- the *Osmosis coefficient*, indicating the permeability of boundaries for short range movements;
- the *Shape coefficient*, explaining the influence of shape on the permeability of boundaries.

The following formula is proposed for the Osmosis coefficient:

$$K_{osmosis} = L_B / (P_1 + P_2 - L_{NC})$$

where P_1 and P_2 are the lengths of the perimeters of the two adjacent zones, L_B is the length of the common boundary and L_{NC} is the sum of the lengths of not crossable boundaries (e.g. it may be the length of coastal boundaries in the case of land transport modes).

The Shape coefficient, based on a similar concept to that of the hydraulic range (area/perimeter), is defined as:

$$K_{shape} = R_{H1}/P_1 + R_{H2}/P_2 = A_1 \Big/ P_1^2 + A_2 \Big/ P_2^2$$

where R_H denotes the hydraulic range.

Adjacency is not expected to eliminate completely the approximations introduced by zoning in corridor studies, however it may reduce its effects.

THE CASE STUDY

The methodology described in the previous section has been adopted in a real case study: the estimation of passengers and freight flows in the case of the realization of a new high-capacity railway between Venice and Ljubljana, which should perform the necessary connection between the E.U. Corridor n°6 and the 5th Pan European Corridor.

The priority Project n° 6 of the TEN (*Trans European Network*), identified by the Essen Conference, focuses on the Lyon-Torino-Milano-Venezia-Trieste axis, as a vital link connecting the French and Italian High-Speed Train/Combined Transport networks. It would permit the construction of an Atlantic-Adriatic route with possible eastward developments towards central and eastern European countries. Its main advantages are an increase in capacity to overcome the congestion of the existing rail and road Alpine crossings, environmental savings and substantial travel time savings.

The V Corridor, identified by the Crete conference, is a rail and road corridor along the Trieste-Ljubljana-Budapest-Kiev axis, connecting Italy and the Adriatic ports with Slovenia, Hungary and Ukraine. The improvement of the infrastructure and removal of bottlenecks will facilitate commercial relations within the regions and trade with the E.U. Potential distance savings for international transport, increase of capacity, reduction in travelling times, improvements in reliability and safety are further benefits to be gained from the specific projects of upgrading or construction of road and rail infrastructures.

In order to perform the connection between these two corridors, a new or modernized link is planned between the Italian and the Slovenian railway network. This new link may consider different alternative paths with reference to its portion Venezia-Trieste-Ljubljana.

In order to perform the evaluation procedure and to select the best alternative to be realized, a transportation study has been carried out by the authors, including the estimation and prediction of passenger and freight traffic flows on the links of the rail and road networks. The study has been carried out according to the classical steps of transportation systems engineering for planning and evaluation, first referring to the base year (*present system*) and then considering different scenarios for transport demand and supply (*project system*).

Study Area And Zoning

The first step is the definition of the geographical area including the transportation system under analysis and most of the project effects (*study area*). Its limit is usually known as the *area boundary*; outside is the *external area*, which is considered only through its relationship with the analyzed system.
This task is obviously strictly related to the objective of the study. Since the goal is a strategic evaluation of the effects of the realization of a new high-capacity railway between Venice and Ljubljana, the study area is an international wider one comprising Italy, Slovenia, Croatia, Austria and Hungary.
The physical area is usually subdivided into discrete sub-areas or traffic zones (*zoning*). Traffic zones should aggregate parts of the study area which are homogeneous with respect to their land-use and socioeconomic characteristics, accessibility to transportation facilities and services. Due to data availability, traffic zones are often obtained as aggregations of administrative areas, in order to associate to each zone the relevant statistical data, which are usually available for such areas. It is assumed that the departure and arrival points of all the trips related to a zone are concentrated in a single point, known as *zone centroid*.
In this case the study area has been divided into 24 internal zones (including the north-eastern regions of Italy, Slovenia and southern Austria), linked to 8 external zones (south Italy, north-west Italy, north-west and north-east Austria, Hungary, Croatia, Dalmatia and Istria), as is shown in Figure 2.

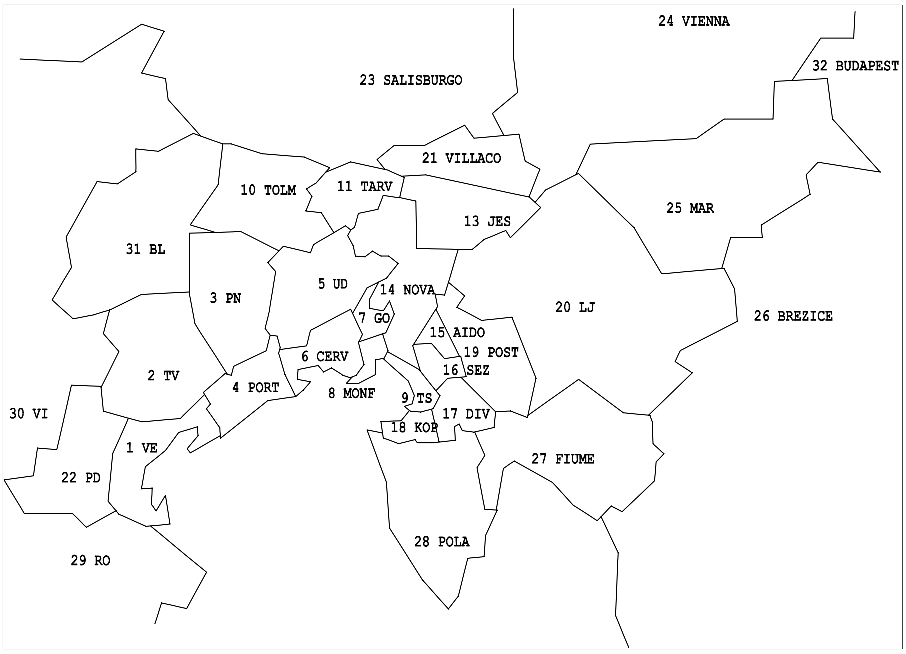

Figure 2: Studied area and zoning

A different level of zoning detail can be usually used for different portions of the study area, depending on the level of precision needed. For example, smaller zones may be used in the neighbourhood of a specific element for which traffic flows and their impacts must be simulated more precisely.
Zoning has been performed to estimate in particular traffic flows for the Venezia-Ljubljana link according to different paths, thus smaller zones have been used in the neighbourhood of the new transalpine crossing between Italy and Slovenia.

Demand And Supply Analysis

In order to include as much information as possible about rail and rod freight transportation demand along the corridor and among the different traffic zones, a considerable number of Italian and foreign sources have been used, including, for example, railways and road statistics, time-series data on flows through border-crossings, traffic counts. Afterward data, sometimes referred to different time periods and provided by different data sources, have been appropriately elaborated and converted according to the adopted zoning. The analysis has been finalized to the definition of four Origin/Destination (O/D) matrices, related to the annual number of passengers and freight tons on the rail and road network respectively, all made of 32x32 cells. The 1999 has been selected as base year for the analysis, mainly due to the availability of data.

Then a supply analysis has been carried out and two graphs have been defined, referred to rail and road network in the reference scenario. As an example, Figure 3 shows the graph representing the rail network.

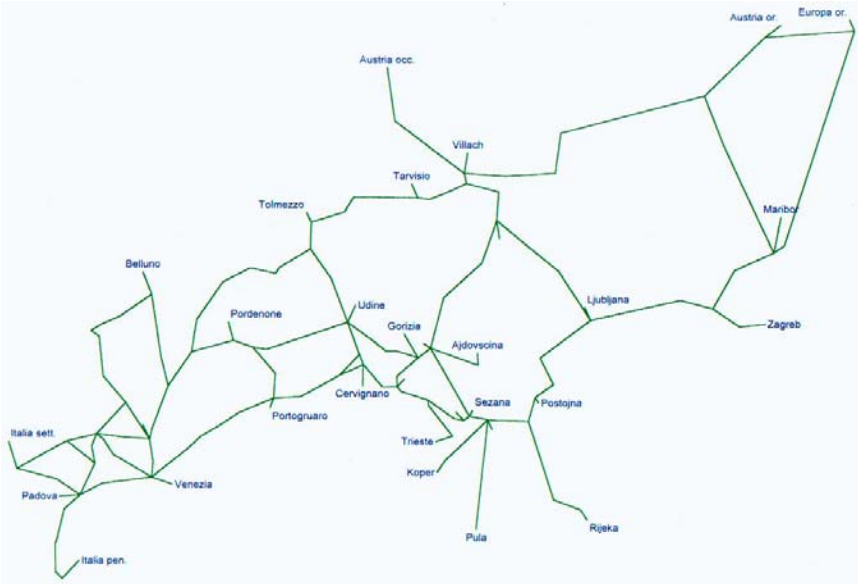

Figure 3: Rail network modeling

Link performance attributes generally depend on the physical and functional characteristics of the facility and/or the service. Thus the operational characteristics of each link are needed. As regards the specification of cost functions, the travel time, given by the ratio between arc length and commercial speed from origin to destination, has been assumed as the arc cost for each link of both graphs.
The O/D matrices referred to the base year have been assigned to the rail and road graphs in order to calibrate the graphs and to estimate the traffic flows on the links of the networks, both as regards passengers and freight. The Dial algorithm, which is associated to a particular specification of the Logit path choice model, has been adopted for the assignment to networks, which have been supposed as uncongested (i.e. link and path cost are independent of flows).
Flows achieved by the assignment of the O/D matrices to monomodal networks have been compared to flows circulating on the real networks and really low differences have been observed. Thus flows computed between the different zones can be used for estimating the impact of the variations in the transport supply on the modal share of traffic.

Forecasting Models

The next task refers to the development of mathematical forecasting models, calibrated on the present socio-economic situation and traffic data, which would be able to project the total O/D matrices (road + rail traffic flows in the reference scenario) to different time horizons. In particular two years will be been considered for the analysis and simulation of alternative systems project (2015 and 2025) and for each year two different hypotheses of economic development will be analysed.
A data-base of socio-economic variables has been defined for all the studied zones, comprising population, demographic density, employment for different economic field and total income (in terms of GDP, Gross Domestic Product) referred to 1999.
Simultaneous emission and distribution models have been defined and calibrated, to estimate future demand among O/D pairs by means of one single step. Different models have been defined for passengers and freight flows, obviously influenced by the high data aggregation level (e.g. freight demand data are aggregate as for goods typology, economic activity sectors and industrial logistic characteristics). A different approach has been adopted for zones included within the study area (for which more accurate data may be achieved especially as regards future scenarios) and external zones. Moreover these models aim at minimizing the disturbance effect due to the lack of data for some O/D pairs.

The Passengers Model

In the passengers' model, trips have been considered symmetrically distributed between each O/D pair, which is a reasonable assumption for annual trips. Each element of the O/D matrix referred to both journey there and back between each pair and these components cannot be divisible with available data. Thus total trips among the *N* zones have been provided by the formula giving $d_{ij} + d_{ji}$ (see section about the proposed approach). The cost exponent has been assumed equal to *2*, as suggested by literature.

The emission potential (given by the O/D matrix) has been expressed as the population of each zone (*POP*) multiplied by *GDP* per head (i.e. higher income levels generally lead to higher tendency to trips):

$$G_i = n_i \cdot POP_i \cdot GDP_i$$

$$G_j = n_j \cdot POP_j \cdot GDP_j$$

where the parameter *n* is an average trip emission index for unit of GDP, to be calibrated. The presence of much different income level within the study area (GDP per head in Slovenia was about *1/3* of the Italian one in the base year) has led to different models for Italian O/D-pairs, Slovenian O/D-pairs and "mixed" ones. Consequently, different values for n have been provided for Italy and Slovenia, denoted as b_I and b_S respectively (under hypothesis $n_i = n_j = n$ within the same country).

The attraction potential has been computed by considering the total employment (*EMP*) for the different economic sectors (industry, farming and tertiary activities), divided by a suitable function of the area of the zone itself (*AREA*), as follows:

$$A_j = \frac{EMP_j}{\sqrt{AREA_j}}$$

$$A_i = \frac{EMP_i}{\sqrt{AREA_i}}$$

The generalized cost of a trip has been assumed as equal in both directions (i.e. $c_{ij}=c_{ji}$). It has been computed as the sum of two components: the travel time between each zone pairs (given by the ratio between distance and average speed on the link) and an attribute t_{bord} taking into account a further time spent at the border crossing, selectively applied to relations between Italy and Slovenia.

$$c_{ij} = \frac{D_{ij}}{s_{ij}} + t_{bord}$$

Since the model expresses the probability of undertaking journeys external to the zone of residence, during the calibration task a further "auto-attractivity" variable has been included within the attractivity of the origin zones. This variable accounts for the minor need to carry out activities outside the zone for individuals who, everything else being equal, live in areas with more opportunities satisfying their needs.

Finally, two different models have been calibrated for the different countries (results are: b_I = 1,42 and b_S = 4,12, with both determination coefficients R^2 higher than 90%). Then "mixed" journeys have been also estimated as the sum of two distinct contributions, due to origin and destination zone respectively.

The comparison between predictions gained by the model for the base year and observed data has been provided; total errors were *4,55%* and *6,67%* for Italian and Slovenian trips respectively, and *4,35%* for mixed trips.

The Freight Model

As regards freight transport, the hypothesis of symmetric distribution of trips does not hold and demand flows d_{ij} and d_{ji} for each O/D pairs have been therefore simulated separately.

In this case, emission is linked to goods production and export from each zone, while attraction is expressed as a goods consumption index (import).

The emission potential connecting with goods production has been defined by means of a linear function of the number of people employed in manufacturing concern of each zone [*EMP(ind)*], thus expressing indirectly the consistence of manufactured goods and wholesales, and of the GDP per head (assuming that a richer zone produces more goods on an average), as is shown in the following formula:

$$G_i = n_i \cdot EMP(ind)_i \cdot GDP_i$$

where *n* is an average trip emission index for unit of GDP, to be calibrated for Italy (index b_I) and Slovenia (index b_S), as in the case of passengers.

The attraction potential has been defined by multiplying the population of each zone (seen as final goods consumers) for the GDP per head (indicating the purchasing power):

$$A_j = POP_j \cdot GDP_j$$

Generalized cost has been computed as in the case of passengers, since the high level of data aggregation has not allowed further deepening.

As for passengers, two different models have been calibrated for Italy and Slovenia (results are: b_I = 20,50 and b_S = 13,01, with both determination coefficients R^2 higher than 80%). The comparison between model's predictions and observed data has provided total errors of *2,60%* and *9,18%* for Italian and Slovenian trips respectively.

The Mode Choice Model

The aim is to evaluate the effects on modal split due to the introduction of a new high-capacity railway between Venice and Ljubljana. As previously seen, mode choice is a key element in the evaluation of flows

in this multi-modal network, since, on this scale, route choice is less important due to the reduced number of alternatives.
A binomial Logit model has been specified to simulate the competitiveness between car mode and train mode for passengers. The specification of the model has been divided into several steps with subsequent refinement degree, leading to and subsequent significant improvement of the statistical indicators.
At first (*model 1*) the cost function included the most common variables used in literature has been considered, according to data availability. The main service attributes have been considered: the monetary cost (*COST*), the travel time (*TIME*), the inverse function of the frequency (*PERIOD*) and the number of required transfers from origin to destination (*NTRANS*). The alternative-specific attribute TRAIN was also inserted.
Some variables have been then redefined in order to improve the model. The *NTRANS* attribute was replaced by the *TRANS* attribute (*model 2*), as is shown in the following formula:

$$TRANS = NTRANS / Dist_{OD}$$

where $Dist_{OD}$ denotes the distance between the origin and the destination (the reason is that generally the number of transfers does not have a constant weight, but it depends on the total length of the trip).
A further improvement (*model 3*) has been obtained by considering the natural logarithm of the period *LOGPER*, instead of the period itself, supposing that there is a lower sensitivity to variations at low frequencies.
In order to describe better trips between points close to the boundary, a binary *Adjacency* variable (*ADJAB*) has been introduced into the cost function, taking the values of 1 for adjacent zones and 0 otherwise (*model 4*).
Then Adjacency is redefined by means of the *Osmosis* and *Shape* coefficients (*model 5*). Finally a further improvement has been obtained by giving more weight to the second one (*model 6*), as follows:

$$ADJA = K_{osmosis} \cdot (K_{shape})^2$$

The finale formulation of the cost functions for train and road mode is shown below:

$$V_t = \beta_1 TRAIN + \beta_2 LOGPER + \beta_3 TRANS + \beta_4 TIME + \beta_5 COST + \beta_6 ADJA$$

$$V_r = \beta_4 TIME + \beta_5 COST$$

The introduction of the variable based on the geometry of the zones has been substantially improved the statistics of the calibration. Fiigure 4 shows the progressive improvements obtained after each model, in terms of increase in the value of the statistical indicator adjusted R-squared. The great benefit arising from the introduction of Adjacency is clear in the slope between models 3 and 4.

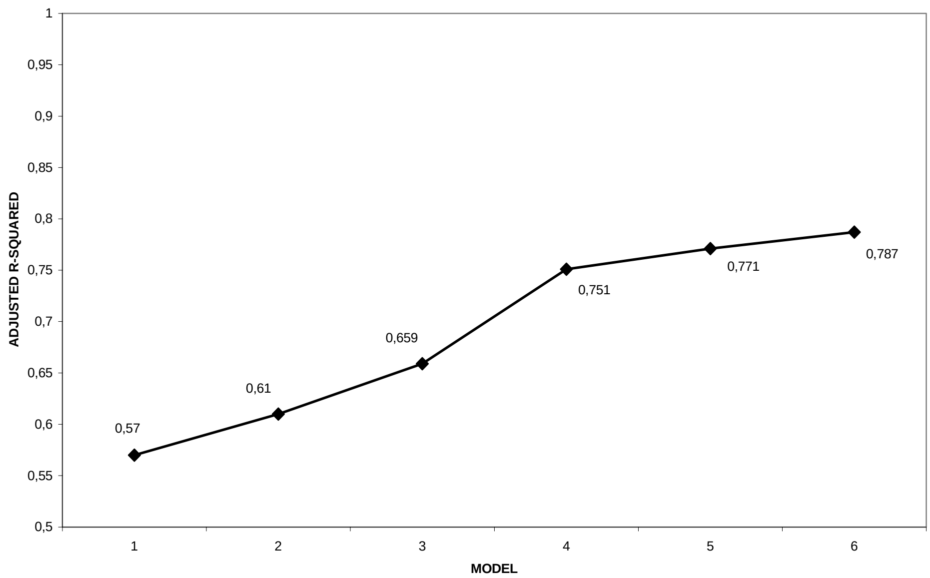

Figure 4: R-squared values for the different models .

The final results of the regression analysis have shown that all the estimated parameters are statistically significant. The adjusted multiple determination coefficients R^2_{adj}, indicating the percentage of variance in the dependent variable explained by the selected drivers, was equal to 79%. The Fisher Test value *F*, indicating the overall significance of the regression, was 32,81 thus allowing the rejection of the null hypothesis.

Simulation Of Scenarios

Since the problem was to evaluate how a new railway link would have modified both modal choice and assignment in the design scenario, the first task aimed at performing the estimation of the origin destination matrices referred to different future scenarios, according to the evolution of the socioeconomic parameters.
In particular two years have been considered for the analysis and simulation of alternative systems project: 2015 and 2025. For each year, two different hypothesis of economic development have been considered: a more pessimistic one (*low scenario*) and more optimistic one (*high scenario*), thus defining a kind of "fork" of admissible values for the considered variables.
Different approaches have been followed for zones which are included within the study area and external ones.
The described models allow estimating the growth coefficients for passengers and freights flows among inner zones (i.e. for internal-to-internal trips), to be applied to the reference O/D matrices (year 1999). Data referred to different *scenarios* for the evolution of the socio-economic variables have been used for the considered time horizons, as regards population, employment and GDP per heard.
External-external and external-internal trips have been updated and forecast using an uniform growth factor method based on the annual GDP growth rate for each zone and examined scenarios. Whereas different growth rates have been made available for the origin and destination zone, an average growth factor have been applied in the case of passengers (in accordance with the hypothesis of symmetrical trips), while the growth rate of the origin zone has been considered for freights flows. Since it must be taken into consideration the fact that mobility usually increases more than proportionally to the economic development of a country, we made the hypothesis that the ratio between mobility increase and GDP increase is close to *1,20* (Longo, Padoano, Santorini, 1997).
At the end, four different O/D rail+road matrices have been made available for passengers and four for freights, for the analysed time horizons ad scenarios (i.e. referred to years 2015 and 2025, with reference to the optimistic and pessimistic hypothesis of social-economic development).
As regards supply side, some different scenarios characterized by the introduction of new arcs and nodes referred to alternative paths between the Italian and the Slovenian railway network have been considered see figure 5 for an example), leading to the definition of some alternative network settings, comprising all the functional planned characteristics. Moreover all the planned facilities (either new or upgraded lines) have been inserted into the road and rail freight and passengers graph. As usual, one alternative was the non-intervention option ("do-nothing scenario"), which has been considered as the reference scenario.

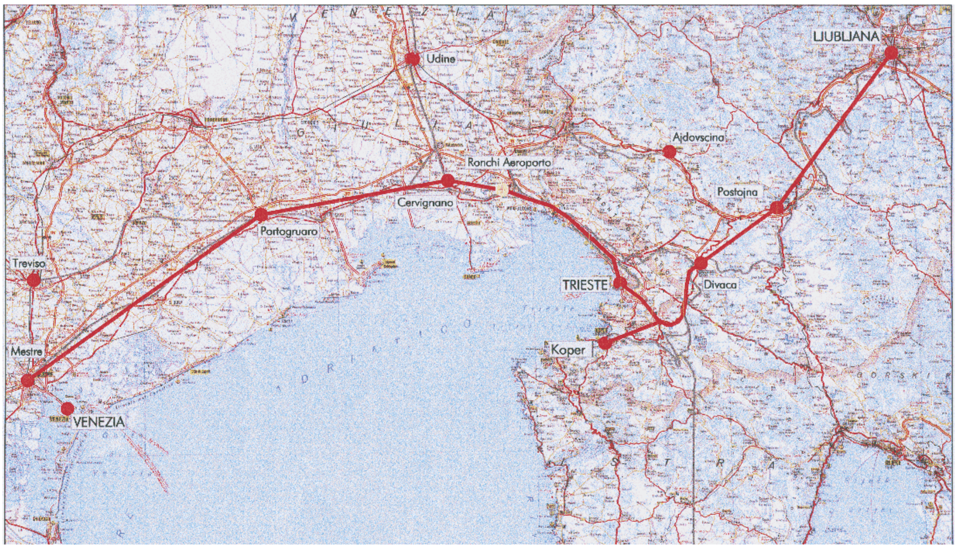

Figure 5: An example of project alternative

Afterwards, starting from the total matrices it was necessary to perform the modal choice task to estimate the split between rail and road, with reference to the different network settings. The modal choice models previously described have been used to simulate variations in rail and road travel demand induced by changes in both transportation supply systems. In order to assess the impact of the new railway link on transport demand, the transportation performance variables which could be modified are mainly rail travel time, service frequency and costs, thus the calibrated model has been applied to the context of reasonable scenarios.
Different matrices have been made available for passengers and freights demand, as regards different road and rail network settings for the considered scenarios and time horizons. Then the assignment procedure

has allowed estimating the traffic flows on each link of the different road and rail networks. An example of traffic flow assignment is shown in figure 6, as regards freights flows on railway network.

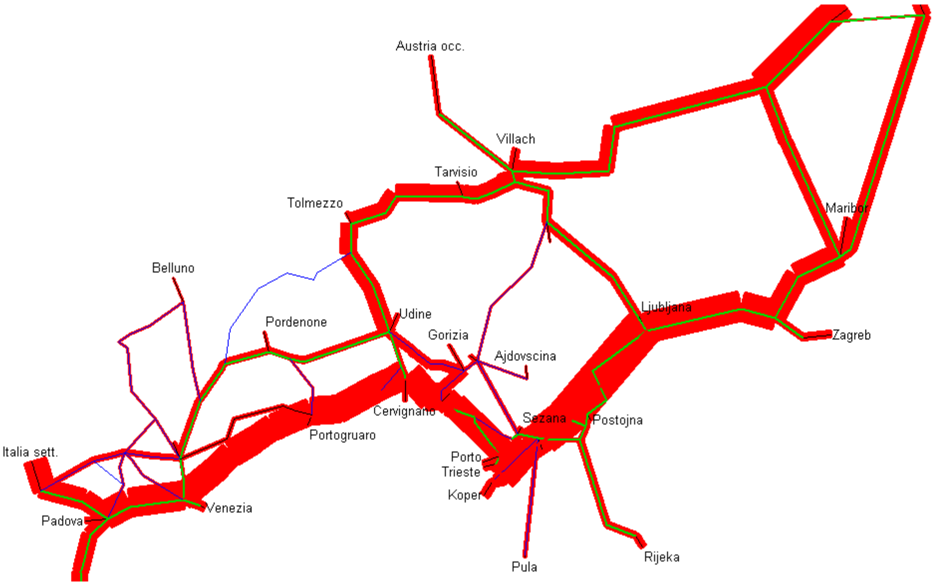

Figure 6: Example of freight traffic flow assignment

APPLICATIVE ISSUES

It is worth underlining that many relevant outputs may be achieved from the performed procedure, which may be really helpful in designing functional transport facilities and services, also as regards choices of investment priorities.

Primary objectives to be pursued by means of planning transport study based on suitable models may be the followings:

- to obtain aggregate network measures, such as total motorway and railway flows;
- to estimate zone-to-zone traffic flows, travel costs and times for a given (or forecast) level of demand;
- to obtain reasonable link flows and to identify heavily congested links;
- to assess the coherence between predicted traffic flows and the transport system capacity, both in actual and in the design scenario;
- to identify possible present and future bottlenecks in road and rail network;
- to evaluate the potential causes and solutions to future capacity constraints.

Secondary objectives may be, for example:

- to estimate the routes used between each O/D pairs;
- to analyse which O/D pairs use a particular link or route;
- to obtain turning movements for the design of future junction at a micro level.

Some important preliminary steps are needed, mostly if the starting point consists of some matrices which are available in terms of person trips, as in the case study.

In the case of road trips, data should be firstly converted into vehicle trips, as capacity and speed flow relationship are described in these terms. Suitable average car occupation coefficients in the long range travels must be considered to obtain an estimation of vehicle trips on the networks; reasonable values may be 1,5 passengers/vehicle for Italian vehicles and 2,6 passengers/vehicle for foreign vehicles, according to road statistics. More attention should be paid for freight transport, due to the wide range of products with different characteristics and nature, influencing the way in which they can be transported and leading to a great variety of vehicle types to match commodity classes.

Then the different classes of vehicles composing traffic flows (cars, buses, coaches and commercial vehicles) must be made homogeneous by converting them into the so called passenger-cars equivalent vehicles, to be compared with the available values for capacity which are usually expressed in terms of passenger-car. Moreover levels of service for the various links of the network may be calculated by means of usual methods (see for example the *Highway Capacity Manual*) to describe qualitatively their operative conditions and identify more congested links and bottlenecks.

The common practice for rail services is much more complex, depending rail capacity upon structural aspects (such as the proposed track layout and the underlying safety system), timing aspects (such as running times and dwelling times of trains as well as the amount of time required for boarding and alighting) timetables and management aspects. Some methods exists which allow estimating the maximum number of trains that can travel on a specific infrastructure in the time unit (see for instance the U.I.C. fiches). Moreover some organizational and management elements may affect the possibility to make optimum use of this

capacity (for example, think about the constraints regarding the train composition, the co-presence of freights and passengers traffic, the empty vehicle management and some legal issues).
Railroad planning is therefore particularly challenging because different improvements can be used to achieve project objectives. Three main categories of improvements can be identified: infrastructure, rolling stock and operations. Improvements in each category need to be evaluated against improvements in other categories to develop the optimal investment plan. In this framework computer simulation may be a particularly important and useful tool for evaluating different improvement strategies for railway networks. An example of efficient and effective railroad simulation program is provide by *OpenTrack* (Huerlimann and Nash, 2003), which has been used successfully in many different planning projects throughout the world.
Finally, some key questions may find a solution starting from the analysis of models' output, such as:
- What is the capacity of rail and road networks to meet present and future freight and passengers needs?
- Is there sufficient capacity to support future developments of specific logistic nodes (e.g. ports)?
- What improvements are needed in road and rail networks to ensure adequate capacity now and in the future?
- What happens if rail and road capacity does not increase?
- Knowing that a series of incremental improvements are foreseen for a network, significantly improving existing transport systems performance, how quickly will the new capacity be used up as freights and passengers demand increases?

Reasonable answers to these key questions may arise only from a rational approach to decision-making based on the evaluation of the various effects of the different possible projects.

CONCLUSION

In the context of strategic transportation planning processes, where consolidate modeling approaches enable demand estimations and forecasting, this paper addresses in particular the issues of transport corridors. Their nature of basically linear strong transport facilities, often comprising more countries, leads to some important consequences in modelling tasks for strategic forecasting purposes, mostly due to the lack of suitable demand data.
In the paper, a simultaneous trip generation and distribution model is proposed to estimate future demand among different O/D pairs by means of one single step, in order to minimize the disturbance effect due to the partial lack of reliable data.
Moreover, starting from the Logit approach to modal split, it is found that the classical modal attributes (e.g. distance, travel time…) seem to be unable to describe some peculiarities of users' behaviour, such as the short range movements across the borders, when zones are quite large and zoning cannot reproduce accurately the real transportation system, as in the case of corridors. Thus some specific attributes have been suggested for the generalized cost functions in order to mitigate the approximations introduced by zoning.
In order to test these improvements, some results are present with reference to a case study. In particular different models have been specified and calibrated to estimate passengers and freights flows in the case of the realization of a new high-capacity railway between Venice and Ljubljana. The conclusions drawn may be useful also in other similar transport studies, in particular at a strategic level when is quite difficult to collect suitable data about transportation system.
Future developments of this work should probably integrate the proposed modeling approach with detailed simulations of some operative issues, both as regards passengers and freights transport. In both cases, the problem of capacity assessment for railway infrastructure plays a key role in the design of layouts of infrastructural elements (e.g. lines, tunnels, bridges, stations) and should be deeply analysed. Moreover, it seems very interesting to develop suitable models able to forecast operators' choices regarding specific types of accompanied combined transport, such as "rolling-road" systems, which concern both rail and road network and may be considered as a possible solution for decongesting some transalpine road axes.

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