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COUNTRY STUDIES

NETWORK AND ASSIGNMENT MODELS FOR THE ITALIAN NATIONAL TRANSPORTATION SYSTEMS

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Abstract

In this work the problem of supply and assignment models for national transportation networks is studied. The system in the infrastructural network and in the service networks is analysed. The assignment problem for private and public mode is tackled. For the first system the structure of path choice model is specified and calibrated.

INTRODUCTION

The study of passenger and freight models at national level is a recent development, especially with the intensification of cultural and economic exchange between different regional areas. The scientific literature report various models of transportation on a national scale. They adequately describe demand models but supply models and interaction models are not generally studied in depth. Existing demand models can be divided into two classes: models oriented to the study of particular aspects of phenomena and models oriented to global planning. The main demand models on a national scale are: the Dutch model (Bovy et al. 1992), the Egyptian model (Moavezandeh et al. 1983), the French model (Lopez Pita et al. 1990), the German model (Ashley and Baanders 1990) and the Italian model (Cascetta et al. 1994). The utilised supply model is broadly described in Moavezandeh et al. (1983). In this model different cost functions are presented in relation to the mode considered (highway, rail, water transportation). Moreover these functions are different in relation to three categories of actors: owners of infrastructures; owners, public or private, of vehicle to transport passenger or freight; users. The link cost functions compute the costs and the impacts of four types of transport policies: investments, maintenance, operations (eg scheduling) and pricing.

An important element of national scale models is the analysis of interaction between demand and supply, which is translated into the formulation of assignment models. In the literature the assignment is widely treated in relation to the urban case, studying the conditions of congestion and the dynamic effects for private transport (Sheffy 1985; Cascetta 1990; Cascetta and Cantarella 1993) and the formation of hyperpaths for public transport (Nguyen and Pallottino 1986; Spiess and Florian 1989; Cascetta and Nuzzolo 1988). Few studies have been carried out for national transport, especially as regard behavioural models; behavioural path choice models for private route transport have been proposed (Ben Akiva et al. 1984) and recently for public transport (Nuzzolo and Russo 1993).

In this work the problem of supply and assignment models at a national level is studied. The Italian transportation system is analysed through the definition of the multimodal network and with the study of the service network. The infrastructure network includes the road network with connections with the terminal infrastructures (railway stations, airports, ports, interports) and the railway network; the supply networks of services considerate are: railway passenger (intercity, express and night), extraprovincial buses, airlines. In the second part the road assignment problem for the different modes of transport (public or private) is described. The path choice models and the assignment models for private and public transport systems are then treated. For the first system the choice model structure with the specification of criteria of choice set generation and the specification and calibration of the choice model is defined. For the second system the approach for evaluating flows with frequency models is described in relation to the network model utilised for the representation of supply.

THE SUPPLY MODEL

The zoning model

Italy is zoned according to the administrative subdivision through the following criteria:

- the necessity to refer to the local administrative units, on average homogeneous in terms of mobility: province and, in the case of further, the town or, in the metropolitan area, the quarter;
- The homogeneity of the zone size, in relation to population, obtaining zones with about 200,000 inhabitants;
- the homogeneity of zones in term of accessibility to the national transportation network;
- the compatibility of the General Transportation Plan with zoning.

The resulting zoning includes 270 internal zones, distributed as follows: 25 zones belonging to six metropolitan areas (Turin, Milan, Genoa, Rome, Neaples and Palermo); 97 provincial capitals; 148 sub-provincial zones.

The zoning for freight transport is not as dense as that for private transport, with 103 zones coinciding with the Italian provinces.

The zoning used for foreign countries follows similar criteria, with a greater aggregation of countries as distances from Italy increase. The total number of foreign zones is 62.

The infrastructure supply network

The multimodal infrastructure supply graph includes the road graph, with the connection with the terminal infrastructures (railway stations, airports, ports, interports) and with the zone's centroids, the railway graph with the connection with the terminal infrastructures and the terminal links of railway services and those of other modes (airports, ports and interports). For further information see Nuzzolo et al. (1993, 1995).

The road network consists of all the motorways and of the main national roads. The graph includes about 2,000 nodes and 5,000 links. The data acquired for the links concern physical characteristics (length, average width of carriageway and shoulders and total number of lanes in both directions), functional characteristics (link type, passing visibility factor, altimetrical trend, flow limit, section type, user type, capacity) and data of vehicle passenger and freight traffic on an average working day.

The railway network includes the commercial network of "Ferrovie dello Stato" (FS), for a total of about 8,000 km, the part of the secondary national network, for a total of 3,500 km, the inter-provincial railways in concession. The graph includes all major railway stations, the chief national ports, border crossing, place where there are junctions or forks and the points of discontinuity of traction characteristics and the number of track lines for a total of about 750 links and 300 nodes. The link is defined as a railway stretch homogeneous by traction type and number of track lines. The acquired data for links concern the physical and technical characteristics (station type, number of running track lines, number of stations included between the limits of the link).

The terminal links of services are associated to the multimodal national graph. Thirty-one airports are considered: the information regarding each airport concerns essentially the infrastructural and functional characteristics necessary for the definition of the operative capacity and the mode of access to the airport as well as its distance from the town centre and parking spaces. Overall, thirty-three seaports were considered with the characteristics appropriate to defining operative capacity. For the freight inter-ports the information concerning the dimension of fixed plant and connections with other types of transport were considered.

The passenger and freight service networks

The network model used was obtained from the infrastructure network used by each transport services considered and from access and egress systems. It is similar to the public transport system network model commonly used for urban areas.

In general, for the public transportation system on a national scale, two different representative methodologies are possible, according to whether the basic reference element of the graph, the link ij between two service nodes, represents only a spatial relation between nodes i and j, or whether it also has a temporal connotation given by the schedule in which the service is operated. In the scientific literature, the term "line" is used to indicate the spatial path followed by a vehicle given by a sequence of stops, while the term "run" is used to refer to a space-temporal path with certain pre-fixed departure times or arrive time at the stops. It thus follows that the generic link representing the service, in the first case, will have associated the line characteristics, while in the second case it will have the characteristics of the individual run.

In this work the passengers services scheduled on different modes (railway, bus, airline) are represented with an approach for "lines". The network model for each service derives from two models, the first concerning access-egress network (A/E) from the public transportation system and the second individual service network supplied by the mode considered by the user.

The A/E graph for each A/E mode consists of a set of infrastructural network nodes and links which allows spatial centroids to be connected to the terminals of the various service networks which are operated on the national network. The service graph for line derives directly from the graph for A/E from the service, to which nodes and links are added, that are representative of public transport lines, as well as nodes and links connecting the A/E graph with that of lines. The nodes and links used are those which are commonly defined for representing transport network by means of graph. In the case of low frequency systems, such as those defined by public transport network on a national scale, it is necessary to insert a further set of connections identified by the transport links which represent connection for transit passengers at a stop (Figure 1).

The network of freight services includes: rail lines, air lines, sea lines. This network also include the access/egress links to the terminal of services.

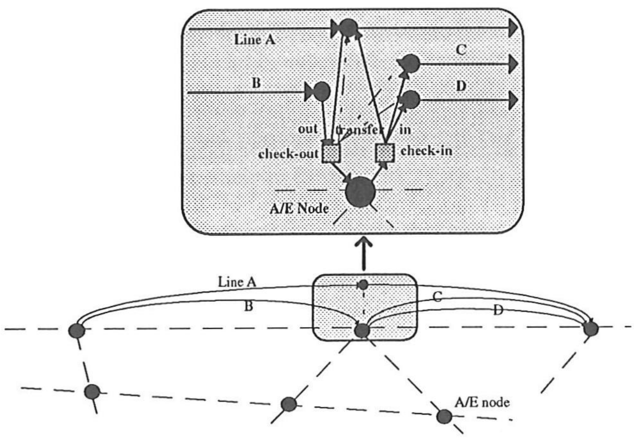

Figure 1 Network example and particular of stop node

The cost functions for users

In the transportation networks different cost functions were used, in relation to passenger or freight transport. The cost functions utilised for passenger transport are considered in a different way in relation to the type of link (motorway, extraurban or urban) and in relation to the type of transport (private or public). The function utilised for freight transport are different depending on whether transport is on wheels or on rails.

Cost functions for passenger transport

The calculation of cost functions are different for private road and public systems.

Private road transport

The calculation of cost for the road passenger transportation network, is made in relation to the following classification of roads: motorway, extraurban roads and urban roads.

- For the motorway private transport unit running time is evaluated according to the Italian CNR (1983) relation:

$$T_{MP} = T_{MP}(\theta, q, Q, p)$$

where:
θ = % overtaking visibility;
p = average slope;
q = light vehicle flow;
Q = heavy vehicle flow.

For unit monetary cost on the motorway the follow relation is considered:

$$C_{MP} = C_{M1} + C_{M2} + C_{M3}$$

where:
$C_{M1} = C_{M1}(v,p)$ =cost for fuel as a function of slope of road p and running speed v;
C_{M2} = cost for lubrificant, tyre consumption and vehicle maintenance;
C_{M3} = toll cost defined according to the Italian fare in force from 1992.

- For the extraurban private transport running time is calculated as a function of the average road speed v obtained with the Nuzzolo-Russo model (1992):

$$T_{EP} = L / v$$

where:
L = length of considered link;
$v = v(l_o, l_s, t_o, p)$;
l_o = shoulder width;
l_s = carriageway width;
t_o = tortuosity;
p = average slope.

The unit cost is assumed as:

$$C_{EP} = C_{MP} \cdot \gamma$$

where: $\gamma = 1.1$ considering a 10% average increase, due to the less uniform movement.

- In the urban private transport running time and monetary cost are evaluated as equal to the motorway in the link with platform and access characteristics of a motorway type. In the link with urban characteristics, for evaluation of the time, the Nuzzolo-Festa (1990) model is used:

$$T_{UP} = L / v$$

where:
L = length of considered link;
$v = v(l_u, p, t_o, q, Q)$;
l_u = width;
p = average slope;
t_o = tortuosity;
q = light vehicle flow;
Q = heavy vehicle flow.

The monetary cost is calculated as in the previous case.

Public passenger service

In the public passenger service networks the running time is calculated in three different ways (see Figure 1): in the links representing the lines, the scheduled running time is considered for railway and airline services, a time proportional to that of private road network is considered for bus services as explained following; in the links representing connection between the check-in node and the line node the time is evaluated in relation to the frequency of the considered line; in the transfer link between check-out node and following line, the time is calculated in relation to the frequency of line and in relation to the importance of station.

The cost for users in railway and airline services is calculated using the FS and Alitalia fares. In bus service the disutility is calculated in relation to the different road utilised.

- For public transport on motorway running time is assumed proportional to that of private transport, with an average increase of 10%. The unit monetary cost for ticket is considered as 64 £/Km.
- In the case of public transport on extraurban road, for the evaluation of running time, a speed equal to private case reduced by an aliquot function of slope is used, in according with the TRRL (1980a, b, c) indications and considering the stops of vehicles in stations with acceleration and deceleration time, boarding and alighting of users:

$$T_{EC}=L/v_p + T_s$$

where:
$v_p = v-a*p$
v = speed calculated as for private transport;
p = average slope;
a = parameter greater than 0;
T_S = rate of increase due to stopping time.

Unit monetary cost is evaluated as in the motorway situation.

- For urban public transport time and cost are calculated as in extraurban roads. In the links connecting roads, railways, airports, ports and interports, a parking time and parking price are introduced.

Cost functions for freight transport

Cost functions for the freight network are calculated differently for on road or on rail transportation.

Road transport

To calculate attributes, vehicles were classified according to maximum load and number of axles as follows:

- light, two-axle vehicles, with a net maximum load of 3.5 t;
- medium, three-axle vehicles, with a net load between 3.6 and 20 t;
- heavy, four- and five-axle vehicles, with a net maximum load exceeding 20 t.

Evaluation of average travel time on each O/D pair was carried out by using functions reported in the literature. The functions proposed by the CNR (1983) were used for motorways, while TRRL functions (1980a, b, c) were used for extraurban roads.

- For motorways the travel time on the generic link is determined as follows:

$$T_{GM} = \max(t_a, t_b) . L$$

where:
t_a = time per unit of distance, for cars, calculated by the previous relation;
t_b = time per unit of distance, for heavy vehicles, function of slope and speed on the motorway;
L = length of link considered

- For extraurban roads, the travel time of the generic link is determined as follows:

$$T_{GE} = L / v$$

where:
L = length of considered link;
$v = v(lu,p,to,q,Q)$;
lu = width;
p = average slope;
to = tortuosity;

q = light vehicle flow;
Q = heavy vehicle flow.

- For the other link types, it is supposed that:

  for motorway barrier links, the travel time is evaluated in 5 minutes;

  for urban links the time is calculated with an average speed of 20 km/h;

  for connector links the time is calculated with an average speed of 40 km/h.

In the analysis of road haulage production costs, specific costs were analysed which may be related to the various links. The global path costs consist of an additive aliquot obtained from the sum of each link cost comprising the path and from a non-additive aliquot given by the path costs function of total travel times inclusive of stops.

Motorway network links are considered as reference links for the complete specification of the various costs making up the additional aliquot. Specific costs of links relative to extraurban and urban networks are inferred from those of motorway links, eliminating non-existent costs and expressing the others as linear functions.

Overall path cost defined by the set of links I is given by:

$$C_G = {}_{i \in I} C_i + C_{Gd}$$

where:
C_i = cost of the generic link i with $C_i = C_{G1i} + C_{G2i} + C_{G3i}$;
C_{G1i} = is the link cost arising from fuel consumption: $C_{G1i}=C_{Gl}(v,p,m,L,Cg)$;
v = travel speed;
p = slope of link;
m = minimum unit consumption estimated from real consumption;
L = length of link;
Cg = diesel fuel cost by the litre, VAT-exempt;
C_{G2i} = sum of costs not correlated to service level attributes of the path used which may be summarised into:

- technical running costs (lubrificant, tyres, maintenance, taxes, insurance);
- driver extras (overtime and travel allowances);
- depreciation;
- brokerage;

C_{G3i} = monetary costs of motorway pay tolls;
C_{Gd} = driver cost for the whole trip. Such a cost is not included in the cost specification under Own Account insofar as it is supposed that the staff at origin and destination chiefly undertake other tasks. It is supposed that $C_{Gd}=C_{Gd}(T)$;
T = travel time on path.

Railway transport

As with road haulage, a statistical model was also used for rail transport which allows us to obtain the time perceived T_F directly according to distance with a constant which considers average access time. The relation used is thus:

$$T_F = a\,L + b$$

where:
L is the distance on the O/D relation;
a is a parameter greater than zero;
b is the access/egress time.

Specification of the prices perceived for the railway carrier is a process which produces great variability. The relation used holds for shipments effected with quantities less than 3 tons, the cost being sustained by the sender firm and capital goods shipments. The railway price is calculated with the following formula:

$$P_F/Q_F = C_F(L,Q_F)$$

where:
P_F = shipment price;
Q_F = quantity despatched, in weight;
L = distance on the O/D relation.

GENERAL ASSIGNMENT MODEL STRUCTURE FOR ROAD NETWORKS

The components of transport demands, which generate a vehicle flow on the national road network, are:

1. transport demand on the bus service network which uses the road infrastructure;
2. access/egress to the multimodal service network which uses the national road infrastructure;
3. freight road transport demand;
4. passenger road transport demand.

The last two components are further subdivided into long- and medium-distance trips, depending on whether the linear distance between the O/D nodes is greater, equal or less than 150 km.

The average day is subdivided into time slices. Demand components are thus identified initially for each time slice, giving rise, on assignment, to flows in several transit slices following that of departure until the end of the trip.

The assignment model structure is reported in Figure 2. Initially, extraurban scheduled buses are pre-loaded in relation to the time slices in which services are operated for the average day.

For passenger and freight demand for long distance, the same general system base module is used, referring to the assignment of a demand component which originates in time slice t. Each demand segment which originates in a generic time slice and arrives at destination in a subsequent time slice, is loaded in all the slices concerned in the network links in question. Long distance freight demand considers three different weight classes of vehicles. Long distance passenger and freight transport demand are assigned by means of a pseudo-dynamic (within-day) model with explicit path enumeration. In the next section, a detailed examination will be made of the generation and choice of alternative paths for passengers, presenting results obtained by calibrations.

Another load, with the same base module, is given by the access/egress components of passengers and freight for average day and the short distance freight component for average day. The access/egress components include the private vehicles for access to national public transport services (airline, train and bus) and different capacity freight vehicles, for access to traditional railway services and for the rate of combined road transport. Each demand is assigned by a stochastic network loading procedure.

Finally, passenger transport demand for short distance by car is assigned by means of equilibrium models which consider congestion and hence, for each slice, the reciprocal influence of flows and costs.

THE PASSENGERS PATH CHOICE MODEL FOR ROAD NETWORK

General definitions

The developed model allows us to analyse user path choice on a road network for intercity and extraurban trips. The study was carried out by model calibrations using random sample of users of the Italian national road transportation system. The main hypothesis for the behavioural model specification (Ben-Akiva et al. 1984) are: user network information and knowledge, decision processes and road attributes considered for the choice.

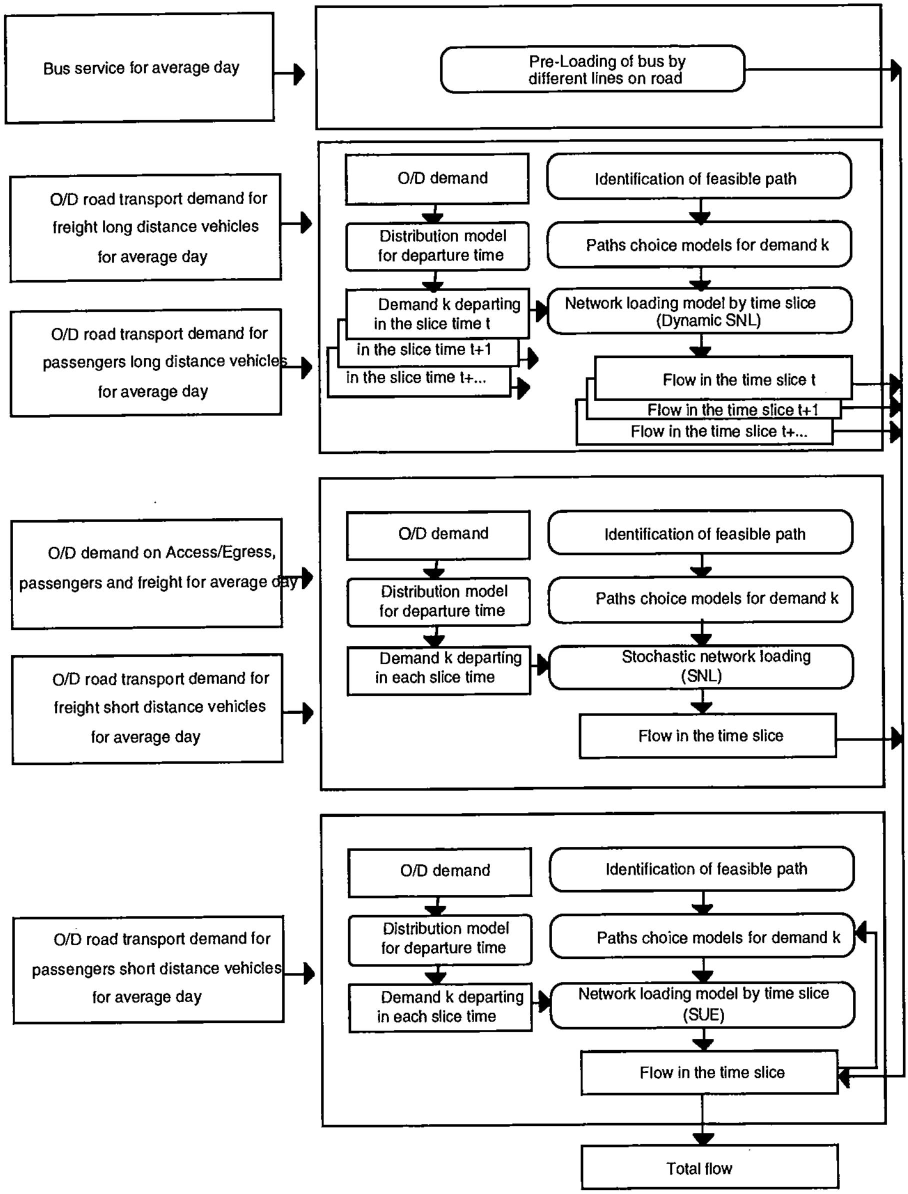

Figure 2 General structure of the national road assignment

User network information and knowledge are summarised in the following hypothesis:

- users on long distance trips tend to restrict their route to the principal network (Tagliacozzo et al. 1973);
- users consider simple path characteristics, such as time and distance (Burrel 1968; Dial 1970);
- user travel on the network in a hierarchical fashion (Cascetta et al. 1992).

The decision process may be of three type (Ben Akiva et al. 1984):

- pre-trip decision (consumptive);
- while-trip decision at some main point of the network (adaptive);
- intermediate choice mechanism decision.

The attributes used for the route choice are:

- travel time (on the primary network and on the secondary network, eventually broken down into different levels);
- distance;
- path capacity (number of lanes, motorway links, number of signalised and not signalised junctions, etc);
- congestion;
- other criteria like road quality, commercial development along the route, safety, scenic, etc.

The hypothesis on the distribution of random disturbance is represented by the following models: Logit, Nested Logit and Probit. Various studies show the poor significance of models with the presence of correlation between different choices on the extraurban path choice model (Ben Akiva et al. 1984), evidencing the goodness of a multinomial Logit model.

This paper reports a preliminary random utility multinomial Logit model, allowing calculation of the choice probability of each path belonging to the choice set. This set is generated from the use of several labels specified below. The utility function associated to each label consists of a systematic part and a stochastic part. The systematic part is a linear combination of socio-economic attributes, cost and path preference. The latter are defined, in turn, by appropriate combinations of dummy variables directly connected to labels of identical paths.

Set of alternatives

The choice set for trips on the national road transport system between each origin destination pair, generally consists of a few significantly different paths probably belonging to a first level network. For such trips, there is deemed to be only one generating purpose; in other words, secondary purposes and trips are negligible. In this case the trip may be considered direct without deviations as regards the main path. To verify user behaviour in generating the choice set, an analysis was initially carried out of the paths actually chosen by the sample users with regard to a path set generated by the use of the following criteria:

- minimum travel time;
- minimum path length;
- minimum congestion path;
- maximum motorway path;
- maximum path on non-motorway links;
- minimum monetary cost.

The paths which join each O/D pair are represented by a succession of links. To generate paths with regard to the various criteria, impedance functions were introduced on the various links and minimum paths between each O/D pair were generated.

For minimum path generation with regard to travel time, on each link the relation between link length L and relative travel speed v at zero-flow is considered as an impedance function:

$$t_p = L / v$$

For the generation of minimum distance paths, link length is considered as impedance.

To calculate the minimum congestion path, we hypothesise that, on each link, impedance is due to travel time in congestion t_s, which is calculated by:

$$t_s = t_p \, [1+Q_d / (10 \cdot c \,]$$

with Q_d being average daily traffic and C link capacity.

Calculation of the path with the maximum motorway stretch is obtained by supposing that on each network link, impedance is equal to t_p if the link is a motorway one and to $\eta_A * t_p$ otherwise. To calibrate parameter η_A analysis was made of several paths generated on the variation in the same parameter and for different distance classes. It was found that for short distance trips (under 150 km), if the parameter η_A has the value of 1 (minimum time path), the ratio between the distance travelled on the motorway and the total distance travelled (ζ) is approximately 0.65. This ratio stabilises at about 0.9 for parameter η_A values greater than 10. For long distance trips (over 150 km), the ratio ζ, assumes a value of about 0.85 for parameter η_A values equal to 1 and stabilises at about 0.95 for parameter values greater than 8. A parameter η_A value equal to 10 was finally used.

Calculation of minimum travel path on non-motorway links is obtained by hypothesising that, on each network link, impedance is equal to t_p if the link is non-motorway and to $\eta_A * t_p$ otherwise.

The path of minimum monetary cost is obtained by generating minimum path trees using monetary cost as an impedance function on links (see earlier section).

Paths generated by the above-mentioned criteria do not necessarily differ. Indeed, several paths generated with different choice criteria may be identical. Two paths are considered identical if they present a high percentage (λ>80%) of shared links:

$$\lambda = 2L_c / (L_1 + L_2)$$

where
L_c = length of links shared by the two paths;
L_1 = overall length of the first path;
L_2 = overall length of the second path.

In the case where only one path is generated for each criterion, at most a number of paths equal to the number of criteria will be obtained. Alternatively, several paths can be generated for one or more considered criteria. For example, it is possible to generate for the maximum motorway criterion the path which has the minimum impedance and the immediately different successive one with λ less than 0.8.

In constructing the choice set, hypothesising that only one path is generated per criterion, two cases may arise: a first case in which there is a one-to-one correspondence between number of criteria used and number of physically different paths generated, and a second case where different criteria may generate the same physical path. In the first case, the number of alternatives coincides with the number of criteria; in the second, the number of available alternatives is less than the number of criteria. If a path is generated by only one criterion, it is labelled with the name of the criterion used. By contrast, in the second case, the group of physically identical paths is labelled with the name of one of the criteria used to generate the path. The alternative set thus consists in both cases of a number of paths equal to the number of labels. For the purposes of specification and calibration, as will be shown in the following sections, in the second case described above, the sum of the specific variables relative to each criterion may be associated to each criterion group comprising a label. For example, if we use the criteria of minimum travel time, minimum cost, minimum distance and maximum motorway path, and only minimum impedance paths for such criteria are generated, which are indicated respectively by A, B, A, C, the choice set consists of paths A, B and C, labelled respectively time, cost and motorway path. Associated to the time label is a specific variable obtained as the sum of the specific variable relative to the minimum travel time criterion and that relative to the minimum distance path.

Choice model

The choice model used is a multinomial Logit model. For each label, j, the user i associates a utility function $U^i j$ which is assumed as consisting of a systematic part $V^i j$ and of a random part:

$$U^i_j = V^i_j + \varepsilon_j.$$

The systematic part of the utility is assumed subdivided into three parts: an utility linked to service level (V^i_{jA}), an utility linked to socio-economic variables (V^i_{jB}) and a preference utility linked to the label (V^i_{jC}) thereby obtaining:

$$U^i_j=V^i_{jA}+V^i_{jB}+V^i_{jC}+\varepsilon_j.$$

The three utilities may be represented as:

$V^i_j=\beta_A' \, x^i_{jA}$

$V^i_j=\beta_B' \, x^i_{jB}$

$V^i_j=\beta_C' \, x^i_{jC}$

with β_A, β_B, β_C being the parameter vectors to be calibrated;

x^i_{jA} the vector of service level attributes of label j for user i;

x^i_{jB} the vector of socio-economic attributes of user i in label j;

x^i_{jC} a vector of specific variables, which has a number of components equal to all possible alternatives. It consists of unity values in positions corresponding to various alternatives which belong to the same label j, and of a null value in other positions.

Finally, the utility function takes the following form:

$$U^i_j=\beta_A' \, x^i_{jA}+\beta_B' \, x^i_{jB}+\beta_C' \, x^i_{jC}$$

If we suppose that the random terms are distributed independently according to a Weibull Gumbel random variable, the choice model used is a multinomial Logit one. In particular, the probability of user i choosing an alternative represented by label j is equal to:

$$p^i_j = \exp(V^i_j)/\sum_{j'} \exp(V^i_{j'})$$

The database

The database for calibrating the model consists of 406 interviews, carried out by surveying a randomly chosen user sample on a nation wide basis (Nuzzolo et al. 1993, 1995). With a view to identifying the paths chosen by interviewees, the database contains motorway points crossed by users, if there are.

With such a database it was appropriate to carry out two filtration operations in sequence: first, to select the interviews and then to carry them out.

The following interviews were selected:

- interviews in which the declared motorway toll stations of entry and exit from the motorway network are inconsistent with trip origin and/or destination. This is primarily due to statements made by users regarding paths not joining trip origin and destination, or statements regarding the last exit toll station at the Straits of Messina crossing;
- interviews in which the motorway exit toll stations or entry from declared motorway path is not present in the graph.

Subsequent to the above operation 137 interviews were eliminated. Following such elimination, interviews with modifications were filtered. This operation concerns the aggregation within a supernode of several graph nodes which represent various toll stations in the same zone belonging to a metropolitan area. Due to problems connected with the positioning of the centroids, users are indifferent as to the use of such toll stations.

The degree of coverage of declared paths was evaluated with respect to the number of generated paths. After filtration there were 269 useful interviews; in 236 cases, that is 90% of cases, the generated paths coincided on at least one criterion defined by the minimum impedance with the paths chosen.

Among the paths chosen by users and those generated by the model, sensitivity analysis was carried out to verify the possible presence of redundant criteria. Several paths generated with respect to various criteria, between any O/D pair, may be systematically identical. Therefore, to verify possible redundancy of some criteria, a definite concordance matrix was generated (Table 1). In position ij, it contains the path number chosen by users with regard to criterion i and contemporaneously chosen with regard to criterion j. Analysis of the results shows that paths generated relative to minimum time and minimum congestion criteria are to be considered systematically identical, as are non-maximum motorway and minimum cost paths.

The following criteria were thus used for generating the choice set:

- minimum travel time;
- minimum path length;
- maximum motorway path;
- minimum monetary cost.

Table 1 Concordance matrix between criteria

CRITERION	Min Time	Min Distance	Min Congestion	Max Motorway	Min Motorway	Min Cost
Min Time	169	118	162	99	50	49
Min Distance	118	129	114	71	57	57
Min Congestion	162	114	166	103	49	48
Max Motorway	99	71	103	158	40	43
Min Motorway	50	57	49	40	81	58
Min Cost	49	57	48	43	58	65

Model specification and calibration

The attributes used for calibration are:

- service level:
  - travel time for paths with a global distance under 150 km;
  - travel time for paths with a global distance over 150 km;
  - monetary cost (operative cost plus road price);
  - total path length on motorway links;
- socio-economic attributes inserted into the label containing minimum time path:
  - a dummy variable of 1 if the trip is undertaken for commuter work purpose, and 0 otherwise;
  - number of passengers on board the vehicle;
  - a dummy variable of 1 if the vehicle driver is refunded the cost incurred during the trip;
- specific variables described above to insert within the various alternatives identified by the labels; such variables may be inserted into all the paths generated by all the criteria less one, particularly in the path:
  - of minimum distance;
  - of maximum motorway;
  - of minimum cost.

Preliminary calibrations were carried out using the maximum Likelihood method. Table 2 reports calibrated parameters and the relative statistical indicators, considering for the four criteria the variables of specific labels. The various calibrations differ with regard to the socio-economic variables used and in relation to the choice set. For each pair of specification of the model with a set of socio-economic variables, two different models were considered: a model with four labels and one with five labels. In tests A2, A4 and A6, besides the maximum utility paths for each criterion, a second maximum motorway path was considered (for the algorithm used see De La Barra et al. 1993). The latter path was generated by considering the maximum motorway path which differs from the former in at least 20% of its length. Table 3 reports the values obtained in specification that are similar at A2, A4 and A6 without the use of label specific variables.

Table 2 Road path choice: multinomial Logit with label variables

Attributes	Measure unit	A1	A2	A3	A4	A5	A6
Time for distance less than 150 km	h	-2.2	-3.8	-1.8	-3.0	-2.09	-3.7
(t)		(-1.3)	(-2.0)	(-1.0)	(-1.6)	(-1.2)	(-1.9)
Time for distance more than 150 km	h	-1.2	-2.4	-0.3	-1.5	-1.07	-2.3
(t)		(-1.3)	(-2.2)	(-0.2)	(-1.3)	(-1.1)	(-2.0)
Total Cost (operative + road price)	£/1000	-0.10	-0.03	-0.10	-0.03	-0.10	-0.04
(t)		(-2.4)	(-1.0)	(-2.3)	(-1.0)	(-2.5)	(-1.1)
Motorway length	Km	0.031	0.015	0.032	0.016	0.030	0.017
(t)		(2.7)	(1.7)	(2.4)	(1.6)	(2.7)	(1.8)
Commuter (min time)	0/1			4.82	3.66		
(t)				(5.7)	(5.3)		
Number of passengers (min time)	0,1,2..	2.20	1.85	2.50	2.00	2.1	1.84
(t)		(9.2)	(8.7)	(7.6)	(7.6)	(9.0)	(8.5)
Refunded (min time)	0/1					1.25	2.21
(t)						(1.2)	(2.2)
Min distance	0/1	5.3	4.3	6.6	5.3	5.1	4.3
(t)		(8.1)	(7.5)	(6.9)	(7.0)	(8.1)	(7.4)
Max motorway (first path)	0/1	6.7	5.3	8.48	6.8	6.5	5.5
(t)		(9.4)	(8.6)	(8.2)	(8.3)	(9.4)	(8.6)
Max motorway (second path)	0/1	3.9		5.21		3.7	
(t)		(5.3)		(4.7)		(4.9)	
Min cost	0/1	5.8	4.8	7.3	5.9	5.7	4.9
(t)		(6.9)	(6.3)	(6.3)	(6.3)	(6.8)	(6.3)
Observations		236	236	236	236	236	236
"Rho-Squared"		0.73	0.67	0.80	0.73	0.74	0.67

Note:
(t) = Value of the t Student variable

The global indicators of calibrations provide some optimal goodness of fit values for the model, with parameter R^2 between 0.67 and 0.80 if there are specific variables, and between 0.33 and 0.35 if such variables are not present.

It is worth noting that the models reported in Table 2, despite presenting high goodness of fit values, show greater inelasticity as scenarios for attributes (level of service) are modified. On the contrary, the models reported in Table 3, despite having lower goodness of fit, show greater elasticity.

From analysis of the data reported in the tables, it emerges that all the calibrated parameters are correct in the sign. Moreover, all the socio-economic parameters, inserted into the label with the minimum time path, and the parameters of dummy variables are positive.

The last parameters examined must be seen as parameters of the labels and not only parameters of the individual criterion. In this regard, it is worth noting that a path which is optimal with respect to two or more criteria attracts far more than a path which is optimal for only one criterion. The considerable weight assumed by specific parameters requires models to be specified and calibrated without such parameters.

The total trip time attribute was considered differently depending on whether the total trip length was less or greater than 150 km. In all the tests conducted, the parameter relative to the time criterion for distances under 150 km is greater than the parameter relative to the time criterion for distances over 150 km. This means that the monetary value of time for users differs between short distances and long distances. The suitability of segmenting the market by distance classes would thus appear confirmed.

It should be noted that the user considers motorway paths as high attraction links. Indeed, all the parameters relative to the motorway length travelled by users are positive.

The parameters of socio-economic attributes are all positive and do not vary significantly in the various calibrations effected. They were inserted into the label containing minimum time path; it may be observed that such a path is chiefly chosen if a systematic trip is undertaken (commuter work).

The parameters of the dummy variables are all positive and assume values of the same order of magnitude. In particular, the motorway path parameter has greater values than those of other variables. This confirms the attraction of the motorway path. Moreover, if two different paths are generated for the maximum motorway criterion, it is noteworthy that the first path generated is more attractive than the second.

Table 3 Road path choice: multinomial Logit with second motorway path

Attributes	Measure unit	B1	B2	B3
Time for distance less than 150 km	h	-1.76	-1.46	-1.72
(t)		(-1.8)	(-1.5)	(-1.8)
Time for distance more than 150 km	h	-1.07	-0.83	-1.03
(t)		(-1.9)	(-1.5)	(-1.9)
Total Cost (operative + road price)	£/1000	-0.04	-0.04	-0.04
(t)		(-1.5)	(-1.7)	(-1.5)
Motorway length	Km	0.018	0.019	0.018
(t)		(2.7)	(2.8)	(2.7)
Commuter (min time)	0/1		0.89	
(t)			(3.5)	
Number of passengers (min time)	0,1,2..	0.93	0.79	0.9
(t)		(8.8)	(7.6)	(8.3)
Refunded (min time)	0/1			0.62
(t)				(1.2)
Observations		236	236	236
"Rho-Squared"		0.33	0.35	0.34

Note:
(t) = Value of the t Student variable.

PUBLIC TRANSPORT ASSIGNMENT

In the public transport, to calculate flows, congested networks must generally be distinguished from non-congested networks. In the extraurban context, if services tend towards congestion, their operation is not determined by successive positions of flow equilibrium, but by demand control policies such as the most commonly used policy of seat booking. In the case of non-congested networks, the non-additivity of frequencies in the case of series lines and the necessity of path selection, as will be seen below, do not allow the use of algorithms for flow calculation without path enumeration. Hence, a specific stochastic loading procedure was set up which allows us to calculate the probabilities of using individual paths consistent with the hypotheses made up to now (Nuzzolo and Russo 1993).

The procedure involves three main phases:

I Identification of feasible paths for each O/D relation;

II Selection of attractive paths from possible ones;

III Calculation of the probability of using paths included in the attraction set and arc loading.

Research and identification of possible paths is carried out by means of a specific algorithm which defines all possible paths between two centroids i and j with travel times not exceeding $\alpha\%$ of the minimum time (Ceder and Wilson 1986).

A selection procedure is applied to the possible path set, which allows the attraction set to be defined consistently with the formulated behavioural hypotheses. In particular, it is necessary that they are not alternative paths which use the same line but with different boarding and/or alighting nodes. Of these (alternative paths), it is supposed that only the minimum cost one is part of the attraction set. Finally, we proceed to calculate the probability of using paths included in the attraction set by using a Logit formulation, like road path choice.

CONCLUSION

In this work the problem of national-scale transport models was treated. First we described the supply model used, outlining the type of zoning, infrastructural supply, service networks and cost functions. Subsequently, models of path choice and assignment were developed. In particular, path choice models were calibrated for the national road transport system. These calibrations supplied some valid results and provided valid indications on the user choice mechanism in the extraurban context.

Such models will be able to receive more detailed treatment in the future, through the use of a more extensive database both in terms of user sample and in terms of the supply model. Furthermore, the possibility may be verified of using a hierarchized Logit model of path choice and a differentiated model for market segments.

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REFERENCES

Ashley, D.J. and Baanders, A. (1990) International travel and the high speed rail alternative: some issue in travel forecasting, *Developments in Dynamic and Activity Based Approach to Travel Analysis*, Aldershot - England, Gower Publishing Group.

Ben-Akiva, M., Bergman, M.J., Daly, A.J. and Ramaswamy, R. (1984) Modelling inter urban route choice behaviour, *Ninth International Symposium on Transportation and Traffic Theory*, VNU Science Press.

Bovy, P., Jager, J. and Gunn, H. (1992) The Dutch national and regional model systems: principles, scope and applications, Presented at the *6th WCTR*, Lyon.

Burrell, J.E. (1968) Multiple route Assignment and its application to capacity restraint, *Proceedings of Fourth International Symposium on the Theory of Traffic Flow*.

Cascetta, E. (1990) *Metodi quantitativi per la pianificazione dei sistemi di trasporto*, CEDAM, Padova.

Cascetta, E. and Cantarella, G.E. (1993) Modelling dynamics in transportation networks, *Transportation Science*.

Cascetta, E. and Nuzzolo, A. (1988) *Uno schema comportamentale per la modellizzazione delle scelte di percorso nelle reti di trasporto pubblico urbano*, Int. Rep., Dipartimento di trasporti, Università di Napoli.

Cascetta, E., Nuzzolo, A. and Biggiero, L. (1992) Analysis and modelling of commuters' departure time and route choices in urban networks, Presented at the *Second International Seminar on Urban Traffic Network*, Capri, Italy.

Cascetta, E., Nuzzolo, A. and Biggiero, L. (1994) A system of behavioural models for the simulation of inter-city travel demand in Italy, *IATBR-94*, Valle Nevado, Santiago, Cile.

Ceder, A. and Wilson, N.H.L. (1986) Bus network design, *Transportation Research* 20B.

CNR (1983) *Istruzioni per la determinazione della redditività degli investimenti stradali.*

De La Barra, T., Pérez, B. and Anez, J. (1993) Multidimensional path search and assignment, *Proceeding of the 21 PTRC Summer Annual Meeting*.

Dial, R.B. (1970) Probabilistic assignment: a multipath traffic assignment model which obviates path enumeration, Ph.D. dissertation, University of Washington, Seattle.

Lopez Pita, A., Arduin, J.P. and Tardier, P. (1992) Prevision du traffic des voyageurs sur ligne ferroviaires a grande vitesse: experiences avec deux modeles d'analyses sur la relation Barcelone-Fronière Franaise, Presented al *6° WCTR*, Lyon.

Moavezandeh, F., Markow, M.J., Brademeyer, B.D. and Safwat, K.N.A. (1983) A methodology for intercity transportation planning in Egypt, *Transportation Research* 17A (6).

Nguyen S. and Pallottino, S. (1986) Assegnamento dei passeggeri ad un sistema di linee urbane: determinazione degli ipercammini minimi, *Ricerca Operativa n°38*.

Nuzzolo, A. and Festa, C.D. (1990) Analisi sperimentale delle relazioni velocità-flussi per le strade urbane, *Le Strade*.

Nuzzolo, A., Frondaroli, A., Grassi, E., Pirani, G. and Montella, B. (1993) Un modello del sistema di trasporto a scala nazionale, *1° Convegno Nazionale PFT2-CNR*, Roma.

Nuzzolo, A., Frondaroli, A., Grassi, E. and Montella, B. (1995) Un sistema di modelli di domanda e di offerta a scala nazionale, *2° Convegno Nazionale PFT2-CNR*, Genova.

Nuzzolo, A. and Russo, F. (1992) Un modello statistico di calcolo delle velocità per le strade extraurbane, *Trasporti e trazione*.

Nuzzolo, A. and Russo, F. (1993) I modelli di assegnazione alle reti di trasporto collettivo extraurbano, *1° Convegno Nazionale PFT2-CNR*, Roma.

Sheffy, Y. (1985) *Urban Transportation Networks*, Prentice Hall, England.

Spiess, H. and Florian, M. (1989) Optimal strategies: A new assignment model for transit networks, *Transportation Research* 23B.

Tagliacozzo, F. and Pirzio, F. (1973) Assignment models and urban path selection criteria: Results of a study of the behaviour of road users, *Transportation Research* 7, 313-329.

TRRL (1980a) *A study of speed/flow/geometry relations on rural single carriageway*, LF 923.

TRRL (1980b) *Speed/flow/geometry formulae for rural single carriageway*, LF 924.

TRRL (1980c) *Change in speed on rural roads*, LF 925.