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TOPIC K4
NATIONAL
TRANSPORT MODELS

THE ITALIAN DECISION SUPPORT SYSTEM FOR TRANSPORTATION POLICIES AND INVESTMENTS: GENERAL ARCHITECTURE AND DEVELOPMENT STATUS

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Abstract

In this paper SISD, a decision support system at the national level covering both passenger and freight transportation systems is presented. The main role of the SISD is to provide a set of tools aiming at the monitoring of the transport system, the evaluation of medium and long term strategic policy options and the provision of information to authorities and operators of the sector.

INTRODUCTION

The Italian Ministry of Transportation and the National Research Council (CNR) are financing two integrated projects aimed to set up a Decision Support System (S.I.S.D.) for the monitoring of the Italian transport system and the evaluation of alternative policies. The overall project is relative to both passengers and freight systems and is expected to be completed by 1996.

At the time of writing the architecture of the system and all its modelling components are fully specified, surveys are being carried out, some models have been calibrated and parts of the software have been developed and tested.

Although parts of the modelling structure are similar to systems developed in other countries (eg the Netherlands for passengers, Rijkswaterstaat 1992), the SISD has many original features. It includes a number of originally developed models and, above all, the range of components of the transport system and its related impacts being taken into account in an integrated and consistent way is uncommon to other applications at the best of this author's knowledge.

In this paper the general architecture of the system will be described, giving some general information on models and data-bases currently under development.

Further elements on various components of the modelling system and the DSS can be found in a number of other papers referred to in the following.

FUNCTIONS AND ARCHITECTURE OF THE SYSTEM

The DSS has been designed to support three basic activities:

- monitoring of the transport system
- assessment of policies and support to the transportation Master Plan of Italy
- supply of information services

The monitoring of the transport system is carried out by surveying, calculating and analyzing a number of demand and supply variables. The values of these variables, providing an indication of the consolidated state of the system, are obtained by filtering and elaborating statistical data as well as through a system of mathematical models simulating various aspects of the national transportation system.

The assessment of policies is based on the simulation of a number of impacts, both internal and external to the transportation sector, associated to alternative policies and background scenarios. Policies include new infrastructures at the national level, changes in transport services, pricing and regulatory measures.

Information supply services essentially consist in the production of periodical reports on the state of the transport system and in allowing external operators, organizations and authorities, restricted access to the data base of the system.

The schematic representation of the system functional architecture is shown in Figure 1.

The main inputs are relative to transport supply, macro-economic and socio-demographic scenarios, the last two being significant only for long-term forecasting. The main outputs are national and international travel demand (both passengers and freight) for different time periods, traffic flows on infrastructures and services, operating and investment costs, traffic returns and impacts on users, territorial accessibility, pollutant emissions, safety and energy consumptions.

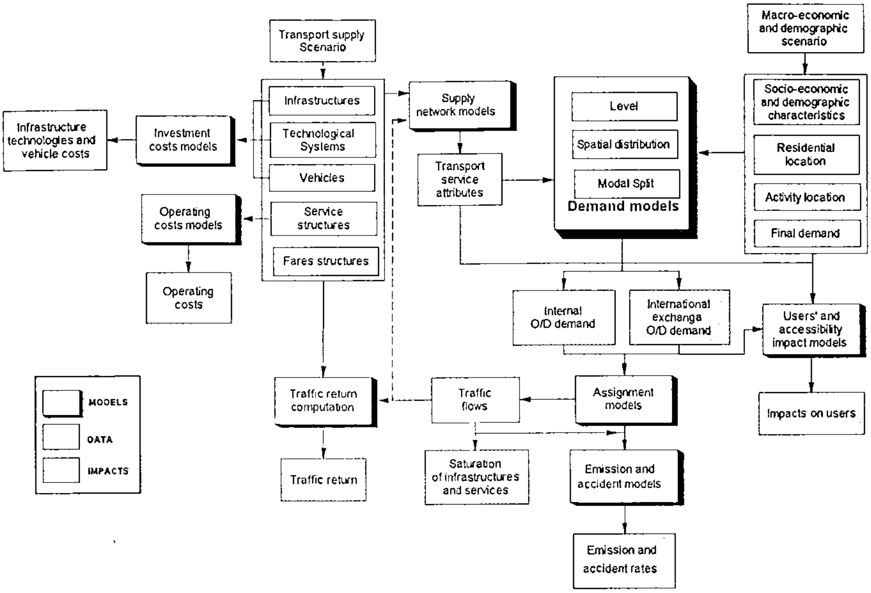


Figure 1 **Overall structure of the SISD**

Computed outputs are such as to match present available statistical information and allow economic and financial analysis of major projects and policies. The main modelling components are relative to internal demand models, international demand models, supply (infrastructure and services) models, assignment models to road and transit services networks, impact models relative to the different impacts taken into account. All models are duplicated for passengers and freight.

The main modelling components and relative data-bases are briefly described in subsequent sections.

Information about the functional and informatic architecture of the system can be found in Conigliaro and Stefani (1995).

SUPPLY MODELS AND DATA

Zoning system

For passenger models the national territory has been divided in to 267 internal zones with the following characteristics:

- 25 zones belonging to 6 metropolitan areas or large urban areas (Turin, Milan, Genoa, Rome, Neaples, Palermo)
- 97 are provincial capitals
- 148 sub-provincial zones

The average number of inhabitants in each zone is approximately 200,000.

For freight models 103 internal zones were considered corresponding to provinces.

Other countries were subdivided in 62 "foreign" zones progressively more aggregated as distance from Italy increases and consistent with the official European zoning system (NUTS).

For zones not corresponding to single cities or towns, centroid nodes were located baricentrically with respect to the population distribution of the zone.

Multimodal graph of physical infrastructures

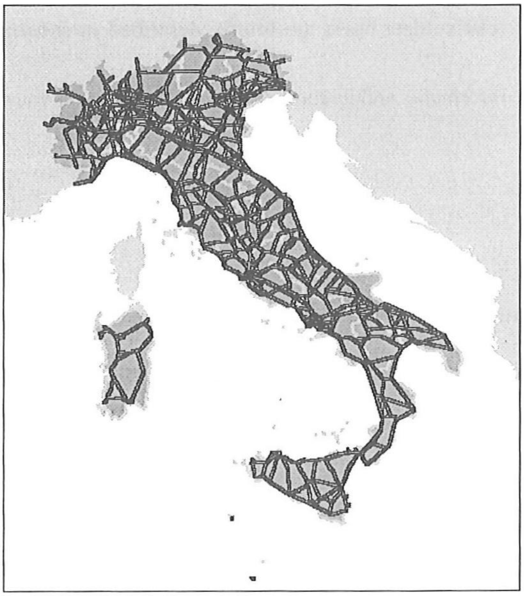
The graph of physical infrastructures at the national level comprises:

- the road graph, with all motorways, main roads and highways, the links between centroids and service terminals (railway stations, airports, ports, interports and freight centres). The road graph has about 2,000 nodes and 5,000 links; the data base contains information on the physical and functional parameters of each link
- the railway graph, including both the State Railway (FS) and local railway infrastructures; the railway graph has about 300 nodes and 750 links; for each link, information about its technical, functional and operating parameters are provided
- service terminal links. All major railway stations, airports, ports and multimodal freight centres are represented by links with a number of associated physical and functional characteristics

The physical dimensions of the infrastructures included in the network are summarized in Table 1. As an example, information associated to the road network links is reported in Figure 2.

Table 1 Infrastructural network dimensional aspects

Motorways	6,500 Km
Roads	24,500 Km
Urban streets	443 Km
Railways	12,225 Km
Railway stations	339
Airports	31
Seaports	33
F Freight centres	29



☐ Nodes *(1559)*
. geographical localization
. municipal code

☐ Links *(4430)*
Identification parameters
- Initial node
- Final node
- Denomination

phisical characteristics
- Lenght of section in km
- Average width of roadway in m
- Average width of shoulders in m
- Total numbers of lanes in both directions

Functional characteristics
- Toll code
- Link type
- Altimetrical trend
- Passing visibility factor
- Basic average speed in km/h
- Flow coefficient
- Maximum acceptable capacity in vehicle/h
- Section type
- User type (regular/nonregular)
- Capacity

Traffic data (average daily flow)

Figure 2 Road and motorway network

The multimodal infrastructures graph in other countries territory also includes the road and rail links connecting Italy with the centroid nodes and service terminals located in "foreign" zones. Physical and functional characteristics at a coarser level are associated to links and terminals.

The nodes of all graphs are geo-coded.

Link and node capacity functions

Transport capacity in relevant units is computed for links and nodes (or their associated links) of the infrastructural network with different methods according to the type of infrastructure and of control technology:

- for roads, following the HCM method and that given by European manuals for motorways, four-lane roads and two-lane roads
- for railways, using the FS method
- for airports, separately for runways, aircraft aprons, passenger and freight terminals. For runways maximum hourly and yearly volumes are computed following the FAA method. For aircraft aprons and passenger and freight terminals STBA methods were adapted to Italian airports.
- for ports, taking into account the following terminals: non-unitized freight, containers, bulk materials, liquids
- for intermodal centers, taking into account the capacity of the rail connections and of warehouses.

Users cost-functions

Average user link cost functions relate travel times and variable monetary costs to link flows, and simulate congestion effects on the road network.

Road travel times are computed as a function of flow/capacity ratios for different vehicle types.

The general expression for cars is the following:

$$t_n = t_{oa}(G, F) + t_{ca}(f_a, C_a, G, F) \tag{1}$$

where the free flow travel time of link a, t_{oa}, is a function of geometric (G) and functional (F) characteristics and the extra-time due to congestion t_{ca} is an exponential function of equivalent flow, f_a, and capacity, C_a, of link a with parameters depending on G and F.

Travel times of extra-urban scheduled coaches and trucks are linked to the ones obtained for cars.

Monetary costs associated to links are fixed charges on highways and variable operating costs which are assumed a function of commercial speed. Both costs are differentiated for vehicle type.

Passenger service networks

Scheduled passenger services (both national and international) on different modes (rail, bus, airplane, sea-liners) are represented following a line-based network approach.

The services are described by lines, where a line denotes a set of runs (eg by train) with homogeneous terminal stations and intermediate stops and offering the same kind of service (eg Intercity, first and second class). Each line is represented as a subgraph with nodes corresponding to stopping stations and links connecting subsequent stations.

For each line the data base stores the route and daily frequency and for each line link the average travel time.

Service networks also include links allowing access/egress to the related terminals by road and by collective transport.

The service networks at the national scale have the dimensions reported in Table 2.

Table 2 Dimension of passenger service networks

PASSENGER SERVICE NETWORK	n. Service Lines	n. Nodes	n. Links
Railway (Intercity service)	179	3816	6943
Railway (Express service)	606	5997	14543
Railway (Nightly service)	70	2568	14543
Air-lines	129	310	568
Extraprovincial bus	364	2861	6816

ACCESS+PASSENGER SERVICE NETWORK	n. Nodes	n. Links
Railway (Intercity service)	5514	11571
Railway (Express service)	7965	19151
Railway (Nightly service)	4266	8123
Air lines	2008	5176
Extraprovincial bus	3037	7318

Freight service networks

Networks of freight services at international and national scale are currently being built. They include:

- rail lines (traditional and combined)
- air lines
- sea lines (traditional and combined)

These networks also include the road access links to the terminals of the different services.

DEMAND MODELS

Passenger demand models

A complex and integrated model system has been designed to simulate relevant components of passenger travel demand.

Internal (national) demand is simulated through a system of behavioural models for mobility and travel choices, schematically represented in Figure 3.

Mobility choices models include licence-holding and household car ownership models. Both have a logit structure with systematic utilities depending on individual and household socioeconomic variables and characteristics of the residential zone.

Travel choices are modelled through a sequence of tour frequency, destination and mode choice submodels, integrated in a nested logit structure with inclusive variables (dotted lines) accounting for consistency among them, Ben Akiva and Lerman (1985), Cascetta (1990).

Travel demand of extra-urban trips for purpose s originating in zone o and bound for zone d with mode m by users of class c on an average day of the reference period is obtained by:

$$d_{od}(s,m) = N(o)_c \sum_n \cdot p(n,s/o)_c \cdot p(d/s,o)_c \cdot p(m/s,o,d)_c \qquad (2)$$

where

$N(o)_c$ is the number of users of class c living in zone o

$p(n,s/o)_c$ is the probability of making n tours for trip purpose s in the reference period (tour frequency model) for users' class c

$p(d/s,o)_c$ is the probability of going to destination zone d (destination choice model)

$p(m/s,o,d)_c$ is the probability of using mode m (mode choice model)

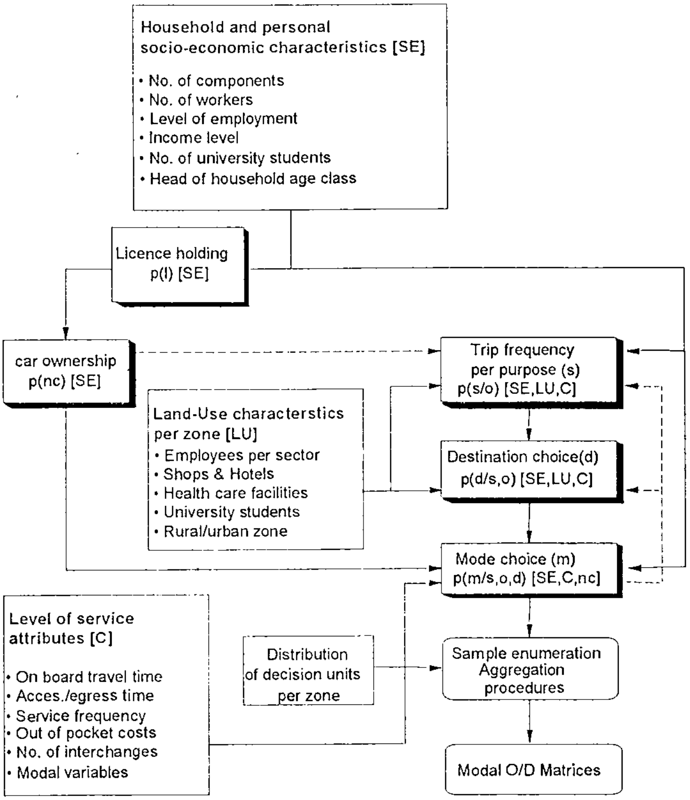


Figure 3 Structure of intercity passenger demand models

A sample enumeration procedure is adopted to aggregate individual choices into Origin-Destination matrices for each travel purpose.

Different model systems are adopted for different travel purposes and reference periods, as indicated in Table 3.

A preliminary version of winter models is described in Cascetta, Nuzzolo, Biggiero and Russo (1995).

As for international mobility, different models are adopted for Italian residents and foreigners as well as for periods of the year (winter/summer).

In all cases, systems of aggregated models including level, distribution and modal split for three basic purposes (work, tourism and vacation, other purposes), have been calibrated on cordon surveys.

Table 3 **Travel demand model systems: internal demand**

Reference Period	Travel purposes
Av. winter work-day	workplace
	education
	professional business
	leisure and tourism
	other purposes
Av. winter weekend	"
Av. summer work-day	workplace
	education
	professional business
	leisure and tourism
	vacation
	other purposes
Av. summer weekend	"

Freight demand models

Freight transport demand is simulated following a "mixed" approach combining a multiregional Input-Output model for level and spatial distribution and a nested-logit random utility model for mode/service choice.

The structure of the model system is represented in Figure 4.

The spatialized I-O model produces region-to-region trade flow matrices for each economic sector using final demand vectors, technical coefficient matrices for regional economies and inter-regional trade coefficients which are elastic with respect to generalized transport costs. These matrices expressed in monetary terms are transformed in to Origin-Destination matrices of freight quantities and split among sub-zones (provinces) belonging to each region following a gravity model. O-D matrices are subsequently disaggregated with respect to freight types and shipment dimensions through fixed (exogenous) coefficients and split among available modes/services by discrete-choice models. Finally, modal O/D matrices are assigned to networks following normative (rail) and random utility (road) path choice models.

Consistency among different models is achieved through aggregation/disaggregation procedures and inclusive variables (dotted lines in Figure 4).

Further details on preliminary specifications on freight demand models can be found in the above quoted paper of Cascetta et al. (1995), and in Nuzzolo and Russo (1995).

Assignment models

Origin-Destination matrices are assigned to infrastructure and service networks following different approaches.

The road network assignment model can be classified as a Multi-User Stochastic Equilibrium with explicit path enumeration and pseudo within-day dynamics, Sheffy (1985), Cascetta (1990).

The last feature is obtained by segmenting O/D matrices, including return trips, in 5 departure time slices h, with constant fractions p(h/s,od) varying for market segments and O/D types.

Users undertaking trips between O/D pairs over 250 km apart, on average need more than are time slice to reach their destination and are loaded to links in the time-slice of arrival.

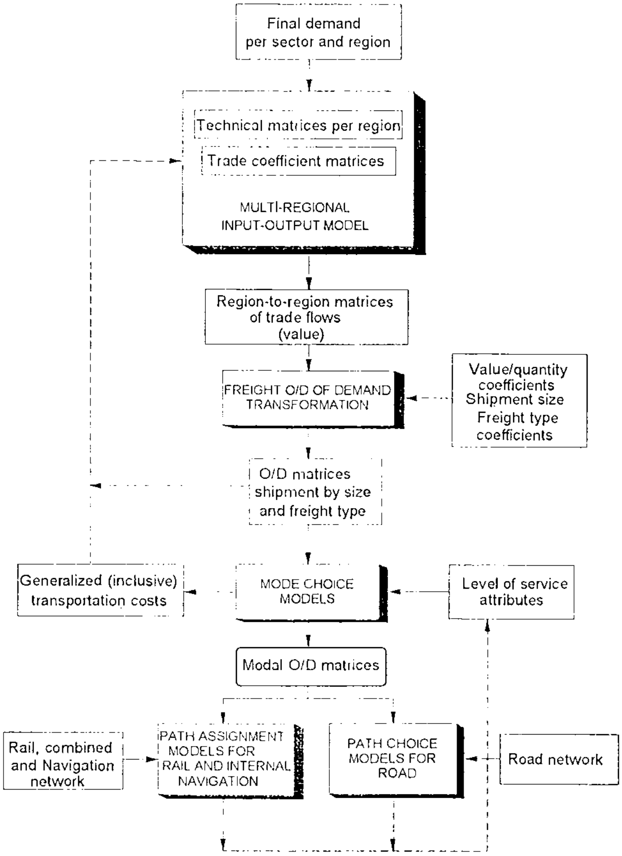


Figure 4 **Freight demand model system**

The general architecture of the road assignment model is represented in Figure 5.

For each O/D pair a number of "feasible" paths are explicitly generated through a set of criteria.

Different path choice models for passenger and freight segments are used to split O/D flows among feasible paths.

It is also assumed that short and long range trips have different levels of network knowledge; this is dealt with by assuming free-flow attributes and different path choice models for long-range trips.

Network loading models produce link flows in the current and subsequent time slice.

In each time slice short-range O/D demand is equilibrated over feasible paths taking into account congestion effects on path attributes.

Further details on path and assignment models can be found in Russo and Videtta (1995).

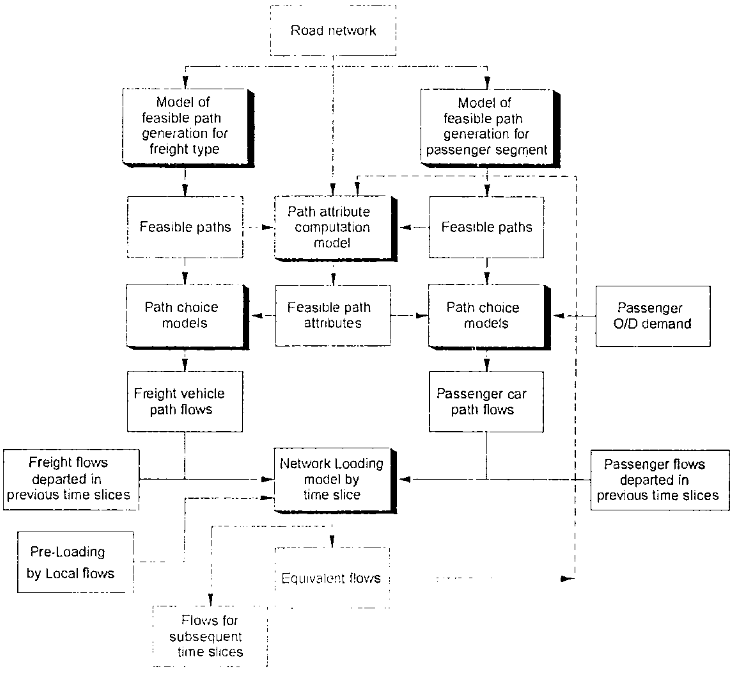


Figure 5 Structure of road assignment model

O/D demand estimation and prediction

Systems of demand models described so far, when applied to present-day conditions, provide estimates of zone-to-zone Origin/Destination matrices for each market segment, eg by travel purpose for passengers and industrial sector for freight.

Such matrices have to be made consistent with other information sources, collected both routinely and ad hoc. Available information includes partial terminal-to-terminal O/D matrices and flow counts:

- railway station-to station O/D matrices
- airport-to-airport O/D matrices
- motorway tollgate-to-tollgate O/D matrices
- ad hoc flow counts (see surveys)
- operators: flow counts

The "corrected" estimate will be obtained with a Generalized Least Square (GLS) estimator (Cascetta 1984), combining "a priori" model estimates with all other available information:

$$d^{*} = \underset{d \geq 0}{\arg\min}\ D(d) = (d-d')^{T}V^{-1}(d-d')+(f'-Hd)^{T}W^{-1}(f'-Hd) \qquad (3)$$

where

- **d*** is the final "correct" estimated for the demand vector made up by O-D flows for all modes and segments;
- **d'** is the initial estimate O/D vector derived from the model;
- **f'** is the vector of "external" information including both partial O/D flows and counts on the network links;
- **H** is the assignment matrix (h_{l} being the percentage of the i-th O/D flow contributing to "external" information element l);
- **V** and **W** are the dispersion matrices for the error vectors in initial O/D estimates and of "assignment" equations.

Forecasts of "future" O/D matrices are obtained by "pivoting" on the corrected present O/D matrices. Models are applied to future scenarios and variations with respect to present model estimates are applied to corrected present O/D matrices per mode and market segment:

$$d_{odFC}(s,m) = d_{odAC}(s,m) \cdot d_{odFM}(s,m) / d_{odAM}(s,m) \qquad (4)$$

where

- $d_{odAM}(s,m)$ = present number of trips between origin o and destination d belonging to segment s with mode/service m, derived from the model
- $d_{odAC}(s,m)$ = corresponding value of the "corrected" matrix
- $d_{odFM}(s,m)$ = corresponding future value from models
- $d_{odFC}(s,m)$ = corresponding future value "conditional" to corrected present estimate

IMPACT MODELS

One of the aims of the SISD is to estimate the likely effects or impacts of different transport policy actions.

Various impacts have been taken into account and are simulated following different modelling approaches.

Impacts on users

For each market segment, or aggregations of them, the following quantities are computed:

- Average travel time and monetary cost by mode, through network and assignment models averaging over feasible paths and, if needed, time slices for each O/D pair.
- Average generalized travel cost by mode, as a linear combination of travel time and monetary cost with value of time (V.O.T.) coefficients specific to the market segment for each O/D pair.
- Average perceived travel (dis)utility by mode, as "logsum" variables computed on path choice models for each O/D pair.
- Average perceived travel (dis)utility by O/D pair, as logsum variables computed on mode and path choice models for each O/D pair.
- Average perceived passenger travel utility by Origin zone ("active" accessibility), as logsum variables on destination, mode and path choice models for passengers, for each zone.
- Average travel satisfaction as logsum variables of frequency, destination, mode and path choice models, for each zone.

All averages are weighted with relevant coefficients. Overall market values of the above impacts are also computed.

Impacts on operators (including public agencies)

Technical and economic impacts on operators are computed.

- Saturation degrees of infrastructures and services.

  For all infrastructures (both linear and terminals), ratios between average vehicle flows and capacity are computed.

  For road links vehicular flows by time slice are obtained through assignment models; flow/capacity ratios are also used for computing HCM levels of service.

  For railways and air links, average daily vehicle flows are computed from passenger and freight line service models.

- Investment cost functions are calibrated for infrastructures, vehicles and technologies.

  Infrastructure investment cost models for different typologies (eg motorway, road and railway sections, stations, airports, intermodal freight centers) and contexts (eg mountain, plain, urban) have been calibrated on recent market prices, distinguishing by cost type (eg., work, materials, rents).

- Operating cost functions have been specified and calibrated for freight and passenger services differentiating by mode and service type. In particular, cost functions are distinguished according to infrastructure operators and service operators, even in those cases where the two functions are merged in the same company.

  In both cases cost functions distinguish between fixed and variable costs, ie depending on marginal variations of service quantity.

Impacts on safety and pollution

Functions relating accidents to average flows and road type (risk indicators) will be calibrated on historical data.

Emission functions for CO, VOC, NO_x, and TPM proposed in CORINAIR (1991) are associated to road links and applied to are the present and forecasted mix of circulating vehicles.

These functions relate emissions to average speed and flows as resulting from assignment'models:

$$PS_a = \sum_h f_{ah} \cdot D_h \sum_{vc} w_{vc}^{ah} \left(k + a v^b + c V_{vc,h}^d \right) la \tag{5}$$

where

PS_a : polluting substance PS emitted on road link a

f_{ah} : av. total flow on link a in time slice h

D_h : duration of time slice h

wah_{vc} : fractions of vehicle class vc on link a in time slice h

l_a : length of link a

k,a,b,c,d : constants of vehicle class vc unit emission model

V_{vs} : av. speed of vehicle type vc on link a in time slice h

SURVEYS

In addition to official statistical sources (National Censuses, Operators data etc) a number of ad hoc surveys have been carried to calibrate demand models and feed the SISD data base.

A summary of the survey types, their quantities and execution periods are reported in Table 4.

Telephone interviews and panels aimed to obtain data to calibrate travel demand models and have been carried out both in winter and summer; a sub-sample is repeated to monitor variations, over time, of model parameters. Interviewees are requested to provide travel diaries of all extra urban trips undertaken in the previous two-week period as well as socio-economic characteristics of the individual and his/her household.

Road counts and road-side interview sections are located on regional cordons in order to correct region-to-region O/D matrices for road passengers and to obtain direct estimates of freight O/D matrices by road-side truck-driver interviews.

Other surveys were aimed at estimating present international demand and calibrating aggregate demand models (border, airport, port interviews) both for freight and passengers.

Table 4 **Surveys for the Italian SISD**

Survey type	Quantity	Period
Telephone household interviews	4,500	July 94
	4,000	September 94
	10,000	March-April 95
Household Panel	1,700	July 95
	1,300	September 95
	1,000	Winter 96
Classified bidirectional traffic counts	138	July 94
	138	March-April 95
Road-side interviews of lorry drivers	23,000	July 94
	23,000	March 95
Road-side interviews of car drivers at border cordons	5,500	July 94
	5,500	March 95
On-board interviews of railway passengers at border cordons	2,500	July 94
	2,500	March 95
Interviews of passengers at international airports	4,000	July 94
	4,000	March 95
Interviews of passengers at international ports	4,000	July 94

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