Freight transport planning: an optimisation model for the transalpine rail network

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Abstract

Strategies to improve rail transport are often based on infrastructure developments in order to eliminate the bottlenecks of the network. This is necessary but insufficient to change the modal split. It is also essential to improve the overall quality of the rail supply taking into account the shippers' needs, such as frequency and time of transport.

After a short literature analysis of the rail freight models, this paper describes an optimisation method for the planning of the freight rail services by using the infrastructures in an effective, rational and customers-oriented way. On the basis of an exogenous estimation of the demand, the model determines the frequencies of the freight trains and the routes of the freight flows by minimising total generalised costs. The generalised cost function comprehends the operating costs on the links and on the nodes of the rail network, as well as the monetary value of the transport time. Several type of nodes are considered: marshalling yards, border stations, nodes where additional locomotives are attached or detached, intermediate stops, and combined transport terminals. Capacity constraints for lines, nodes and trains are also taken into account. The explicit consideration of the train frequency allows the model to approximate the waiting time for connections and therefore to better estimate the total transport time for the freight demand with respect to other approaches.

The model has been applied to the north-west transalpine rail network for the PRIMOLA Interreg project. This case study is presented in the last part of the paper.

Keywords

rail freight – transalpine transport – optimisation model – Swiss Transport Research Conference – STRC 2001 – Monte Verità

1. Introduction

During the last decades, the international freight traffic has been characterised by a large increase in volume and by a substantial change in the modal split. In fact the demand growth has been almost completely absorbed by the road transport. In the case of the transalpine traffic[1], for instance, in the period 1970-1999 road transport has increased on average by 8.2% per year, while the rail one only by 1.7% per year. As a result, almost 63% of the transalpine traffic is presently moved by road (1999 data), while the road share was only 22% in 1970 and 44% in 1980[2].

Present strategies to improve rail transport are often based on infrastructure developments to eliminate the existing bottlenecks of the rail network. This is a necessary but insufficient condition to promote a re-equilibrium of the modal split. As shown by several surveys[3], a modal shift from road to rail can be achieved only by improving the overall quality of the rail transport supply taking into account the needs of the shippers, such as frequency and time of transport. As a matter of fact, a potential customer of rail assesses the quality of door-to-door service. Thus, he is indifferent to improvements concerning, for instance, the train speed over a line section, if that will not reduce the total delivery time.

Most freight transport models take into account only basic characteristics of the rail supply, such as transport time over railway lines and some estimation of lines and shunting costs. This kind of approach is unable to assess the real quality of service for two main reasons. Firstly, the complexity of the rail transport chain requires to take into account all the operations taking place on the network that have a significant impact on total cost and time. Examples of such operations are the marshalling of wagons at yards, the transhipments at intermodal transport terminals, or the controls and locomotive changes at border stations. Secondly, waiting time for connections represents a huge part of the total origin-to-destination transport time of wagons and consequently the frequency of the train services should be taken into account.

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[1] The rates of growth concern the traffic (in tonnes) through the crossings of the central part of the Alps, i.e. between the Mt. Cenis and the Brenner.

[2] Sources: GVF, Bern.

[3] See for instance Musso (1999).

Hence, rail planning methods should be focused not only on long-term strategic decisions about the *physical network*, such as building of new lines and facilities, doubling of existing sections, etc., but also on medium-term design of the *service network*. This term defines the set of train services to operate (each service being characterised in terms of origin, destination, route over the physical network, speed, capacity, frequency and other relevant parameters) in order to satisfy the existing demand.

The object of this paper is to present an optimisation model which deals with the selection of the routes on which services will be offered. On the basis of an exogenous estimation of the demand, the model determines routes and frequencies of the freight trains by minimising total generalised costs. The generalised cost function comprehends the operating costs on the links and on the nodes of the rail network, as well as the monetary value of the transport time. The latter factor is differentiated according to the demand segment, because the needs in terms of speed are not the same for all economic sectors.

The purpose of the model is not to specify a detailed schedule but rather to determine the best operating policies to use the rail transport in an effective, rational and customers-oriented way.

Although it is designed to be of general validity, the model has been set up to be particularly suitable for the optimisation of the rail transport through the Alps. A transalpine application of the model is described in the last section of the paper.

2. Literature review

Several efforts have been directed toward the formulation of *service network* planning models. The existing tools can be classified in two main groups: network simulation and optimisation models.

Simulation models have been used for quite a long time by railway companies. They simulate the movements of trains and cars through the rail network, on the basis of a given structure of the rail services. The results allow the user to evaluate the performance for a given service network. A simulation model for the European rail freight transport has been recently developed by the University of Hanover (Siefer and Böcker, 1997, Böcker, Sewcyk et al., 1999).

This kind of models provide a detailed representation of all the operations that compose the rail transport chain and, therefore, give quite accurate estimates of the origin-to-destination transport time. The main limitation of this approach is that simulation models are not able to generate new operating strategies and to find an overall "best" solution to the planning problem. Moreover, simulation tools calculate the routing of the freight over the service network on the basis of the operation delays over line and nodes of the network, generally without taking into account the cost of these operations.

Optimisation models are therefore more suitable to generate network-wide operating policies aiming to improve the quality of service by taking into account operating costs. Important contributions in this area are the following:

- Crainic, Ferland et al. (1980 et 1984) developed a rail network optimisation model where the transport demand is assigned to the service network composed by the set of feasible train routes. For each flow the model estimates the possible itineraries consisting of a sequence of train services and of the marshalling operations performed at the intermediate yards. The objective function is the minimisation of the total operating costs and of the total value of the operation delays. The problem is solved by an iterative approach between two sub-problems, the assignment of the demand over a given service network, and the modification of the service frequencies in order to improve the solution, given a certain traffic assignment.
- Assad (1980a) considers a similar problem, but his model is less detailed in the representation of yard operations. The author considers only the delays of yard operations, and not their costs, because he makes the hypothesis of fixed yard resources. Line operations are considered only in terms of costs.

- Keaton (1989 and 1992) formulated another service network optimisation model which is characterised by the "pure strategy", i.e. each flow O-D is assigned to only one itinerary over the service network. The author stresses the importance of taking into account the fixed train costs which are sometimes neglected in this kind of models;
- Haghani (1987 and 1989) proposed a combined model for service network design and empty wagons distribution. The formulation is a demand assignment problem over a time-space network where different nodes represent the state of the same physical node at different times. This method allows the user to take into account demand fluctuation over time and to define not only the frequency, but also the optimal interval between two consecutive trains. However, such approach is more useful for short-term planning, because demand variation over time and empty wagons availability should be given as input in the model.
- Martinelli and Teng (1994 and 1996) used neural networks to solve the freight traffic assignment problem over itineraries consisting of a predefined succession of trains. Objective function is the minimisation of the total time spent in the system by the freight. The approach seems promising in terms of computational time, but it does not take into account the operating costs. Besides, operation delays are represented in an extremely simplified way.

Most of the reviewed models have been designed as tactical tools for a single railway company, and transport demand is supposed to be known in advance in terms of flows between rail station or yards. Therefore, some modifications are needed to make these approaches suitable for medium-term planning of international (multi-operator) rail freight services:

- as input, it should be possible to use demand data expressed in terms of flows between zone of origin and zone of destination, instead of between yards;
- the specific aspects of international transport (border crossings) should be taken into account;
- combined transport services and operations should be explicitly integrated in the model.

On the basis of these points, we have developed a new rail freight optimisation model. The general formulation of the problem and the solving approach are similar to the ones proposed by Crainic, Ferland et al (1980 et 1984), while the representation of the rail transport supply is quite different in order to take into account the specific issues listed above. The role of fixed train costs will be explicitly considered, as suggested by Keaton (1989).

3. The model

As shown by the literature review, the minimisation of the total generalised costs (given by the sum of the costs of the operations and of the monetary value of the transport time) is a promising approach to rail service network design. It allows the planner to take into account both the necessity of the rail companies to contain the operating costs and the needs of the customers in terms of quality of service. That lead to an overall efficiency of the system.

The model we have developed is based on this optimisation approach. Most of the existing models have been developed for United States or Canadian railways. With respect to them, our model tries to capture the essential elements of European international rail operations. Border crossing controls are, for instance, explicitly taken into account.

The other specific requirements of our planning problem – stated at the end of the previous section – are also taken into account: they include, among others, the demand known in terms of zone O-D matrix, and the need to consider combined transport.

3.1 Representation of the demand

Transport demand is an exogenous input data to the model. For each segment, it is expressed in terms of weekly tonnage between each pair of zones.

Since in the model each demand segment is characterised by the value of the transport time, ideally speaking it is necessary to cluster the transport demand according to the delivery time requirements of each shipper. On the other hand, available data about transport flows are not disagregated enough to allow such approach. Thus, we have taken into account the type of the products[4] and we have also considered as distinct groups the freight moved by either maritime

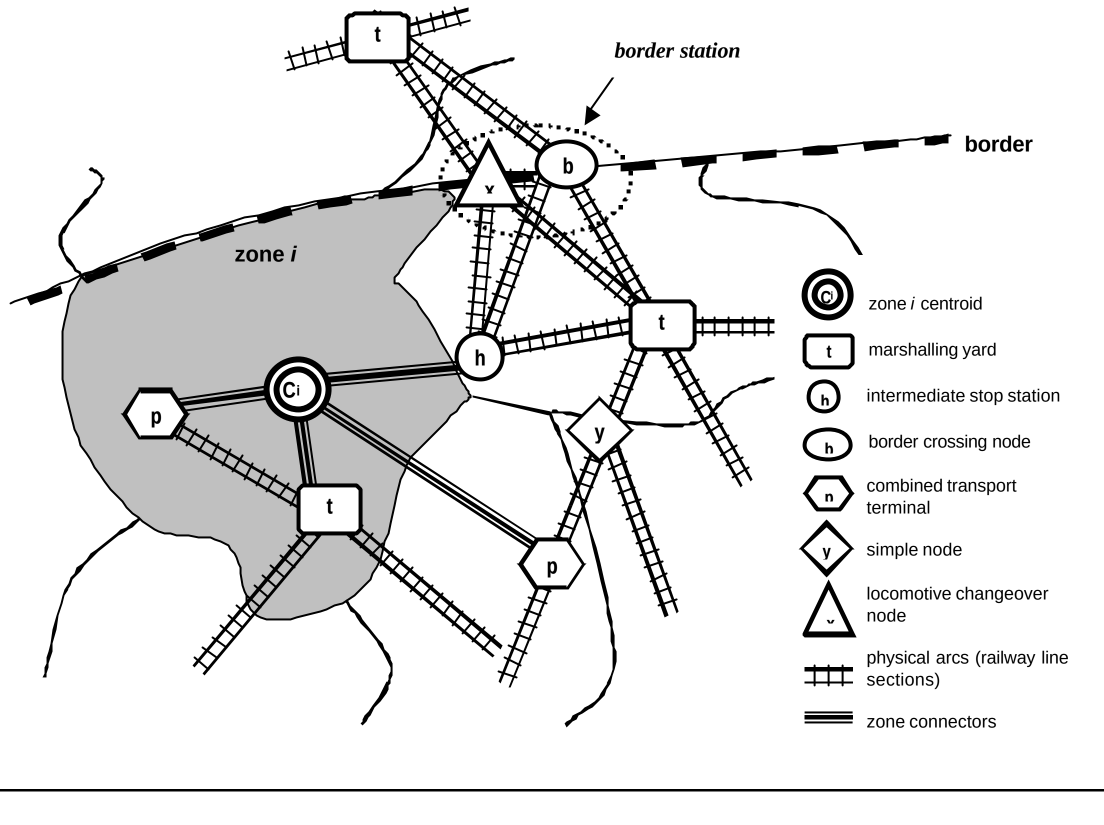
[4] The value of the transport time depends on several characteristics that are linked to the type of the product: the value of the product (affecting the capital costs while the good is transported), the position of the good in the production chain (e.g. some intermediate products have narrow delivery time-windows in order to avoid disruption in the production process), its perishability, etc. The characteristics of the shipper (size, logistic organisation, etc.) are also a key issue, but unfortunately available data often do not allow the planners to take into account this dimension, especially when dealing with forecast of future demand.

or ground combined transport. As a result, twelve freight groups have been identified: maritime combined transport freight, ground combined transport freight, as well as the ten groups of the NST[5] classification. If needed, the model allows the user to segment the demand in a different way.

3.2 Representation of the supply

The *base network* of the model is shown in the figure 1. Freight flows are moved over this network which consists of the physical rail network (line sections, yards, border stations, combined transport terminals, etc.) as well as of the zone connectors.

Figure 1 Base network



These connectors link the centroids of the zones with some of the railway nodes. These latter nodes are the access / egress point of the rail network (yards, combined transport terminals or

[5] NST: *Nomenclature Statistique des Transports*.

stations where train services make intermediate stops to take or leave some wagons). Thus, zone connectors can represent either:

- a movement of wagons by feeder trains services from small freight stations or private sidings to a main yard or to a station where the wagons can be added on freight trains that stop there (or vice versa);
- a road transport of Intermodal Transport Units[6] (ITU) between their origin and a combined transport (CT) terminal (or vice versa).

The base network consists of several elements: centroids, nodes representing either physical locations of the rail network or specific operations that take place over them, physical links (line sections[7]), and zone connectors. The nodes of the base network are marshalling yards (where incoming freight trains are decomposed and their wagons are sorted and assembled into departing trains), intermediate stop stations (described above), border crossing nodes (representing administrative and technical operations that take place on the border stations), locomotive changeover nodes (representing either the change of the locomotive at border stations, or the coupling / uncoupling of an additional locomotive at the beginning / end of a steep line section), combined transport terminal (ITU transhipment sites), and simple nodes (junctions between lines, or points where the characteristics of the line section change). If a station has more than one function, it is split in several nodes, each one representing one of these functions. It is typically the case of border stations, where border controls, locomotive changeover and sometimes also marshalling take place. The nodes and the physical links are called the *physical network*.

Over the *physical network* circulate the trains that move the freight flows. A *service* is a set of trains having the same characteristics in terms of origin, destination, route through the physical network, intermediate stops, types of products that can be transported, capacity, speed[8],

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[6] Containers, swap bodies, piggyback trailers.

[7] These links are mono-directional. Thus, each line section is split in two mono-directional links (as far as traffic in both directions is allowed).

[8] To simplify the model, we combined the speed and the capacity of the service in one parameter called "type" of service. In the first application of the model, we have considered three types of services (type1: 800 t trains running at 80-100 km/h; type 2: 1400 t trains running at 80-100 km/h; type 3: 800 t trains running at 120 km/h for CT services).

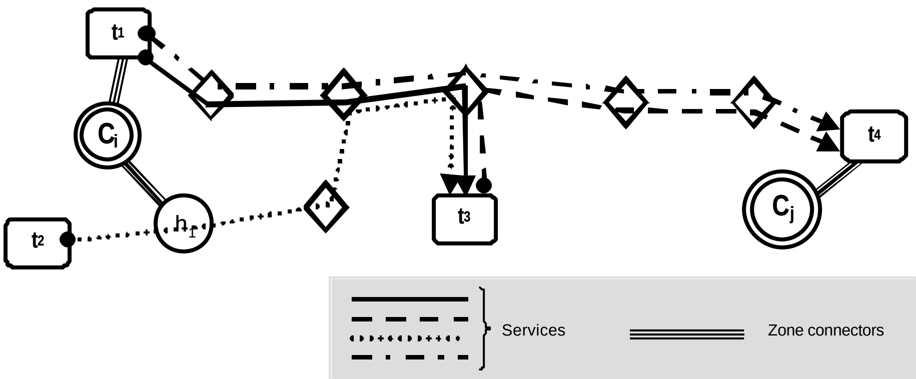
priority[9], type of locomotive (multi-voltage or not), and frequency. The feasible services are given by the user as input, except the value of their frequencies, which will be determined by the model. A zero frequency as result will imply that the corresponding service will not be offered. The whole set of train services is the *service network*.

A demand flow can be routed in one or more ways from its origin zone to its destination zone. Each of these ways is called an *itinerary* and is defined by the corresponding flow, the initial zone connector, the sequence of the services where the flow travels, and the final zone connector (figure 2). The model generates the itineraries for each flow during the resolution process.

Figure 2 Example of itineraries

the flow between zone i and zone j can be routed:

- via the connector C_i – t_1, the direct service t_1-t_4 and the connector t_4 – C_j;
- via the connector C_i – t_1, the services t_1-t_3 and t_3 – t_4, and the connector t_4 – C_j;
- via the connector C_i – h_1; the service t_2 – t_3 from its intermediate stop in h_1, the service t_3 – t_4, and the connector t_4 – C_j;



3.3 Model formulation

The objective function to be minimised is the sum of the total operating costs and delays (due to the train journeys, sorting of wagons at yards, loading of ITU at CT terminals, intermediate stop operations, border crossings, locomotive changes, and access/egress on the rail network).

The decision variables of the problem are:

[9] This parameter affects the duration of the border crossing and intermediate stops.

- x_{it} = volume of traffic (tonnes) of a given flow assigned to the itinerary *it*, where *it* is one of the feasible itineraries for that flow;
- *q(s)* = weekly frequency of the train service *s*.

The problem can be formulated as follows:

$$\text{Minimise } \Phi(x,q) = W(x,q) + \sum_s Y_s(q)$$

where *x* is the vector $(x_1, x_2, \ldots x_{it}, \ldots x_I)$ of the traffic of all the flows travelling on the considered itineraries, *q* is the vector of services frequencies, *W(x,q)* is the total cost (of operations and of delays) generated by the use of the itineraries, and $Y_s(q)$ are total cost of offering the rail services at the frequencies *q*. *W(x,q)* represents therefore the variable cost of transporting the freight by a service network operated at level *q*, while $Y_s(q)$ corresponds to the fixed cost of the trains of the service *s* (crew wages, locomotive depreciation and maintenance).

The model is subject to the following constraints:

- line section capacity,
- train service capacity (in terms of both tonnage and length),
- marshalling yard capacity,
- border nodes capacity,
- combined transport terminal capacity,
- specialisation of access / egress nodes (CT terminals for CT flows, other nodes for other freight),
- limitation of some services to some demand segment.

as well as to the usual constraints of flow conservation and non-negativity of the traffics x_{it}. The service frequencies *q(s)* must be integer and ≥ 0.

Capacity constraints are transformed in penalties terms on the objective function. These penalty terms are the product of a penalty cost (fixed arbitrarily high) and the square of the difference between the traffic over the line or node, and its capacity.

The new objective function is named *F'(x,q)*.

3.4 Cost and delays formulas

The particular functional form of the terms of the objective function will not be discussed in detail here (detailed formulation may be found in Guglielminetti and Leyvraz, 2000). We summarise only the type of costs and delays that have been taken into account to represent the consumption of resources and of time due to the movement of the freight through the nodes and the lines of the network:

- marshalling yard operations:
  - yard delay per unit of traffic due to the operations for train reception, classification and assembly (represented by a linear function[10] of the traffic volume in transit through the yard),
  - yard connection delay, that is the time the assembled trains have to wait before the departure, assumed as equal to half of the average interval between the trains of the requested service,
  - yard operating cost, expressed as a fixed cost per sorted wagon,
- border node operation (formalities between networks, such as technical visit of wagons, transmission of carriage documents, and customs controls if still existing):
  - border node delay, proportional to the number of wagon in the train (each wagon requiring a fixed time),
  - border node cost, represented by a fixed cost per wagon,
- locomotive changeover node operation:
  - locomotive changeover node delay, represented by a fixed delay per train (if the node is a border crossing and the service is pulled by a multi-voltage locomotive, this delay is only equal to the time needed to change the crew),
  - locomotive changeover node cost, represented by a fixed cost per train (if the node is at a border and the service has a multi-voltage locomotive, this cost is equal to 0),
- intermediate stop operation:
  - delay for the freight already charged on the train that stops at the node (corresponding to the duration of the stop),
  - delay for the freight on the wagons that are coupled to the train at the stop (represented by a fixed cost as well as by a connection delay depending on the train frequency),

[10] Several authors have modelled these operations as queuing system, but some hypothesis of this approach (random distribution of arrivals, constant distribution of service time) are not consistent with the real functioning of yard operations, as shown by Martland, 1982. A study has been carried out about the Lausanne yard by our Institute and it has confirmed this evidence.

- delay for the freight on the wagons that are uncoupled from the train at the stop (represented by a fixed time per wagon),
- cost for couple / uncouple the wagons to the train, formulated as fixed cost per wagon,
- fixed stop cost per train, due to the wages of the train crew and therefore proportional to the stop duration,

- combined transport terminal operation:
  - delay for the loading of the ITU on a wagon between the lorry entrance in the terminal and the end of the transhipment (represented as a fixed time per wagon),
  - delay for the train preparation before the departure (fixed time per train),
  - connection delay, depending on the frequency of the departing train,
  - average delay for the unloading of the ITU (depending on the number of wagons in the train, because including the waiting time for the preceding wagons to be unloaded),
  - cost for loading / unloading the ITU on / from a wagon (fixed cost per wagon),
- line operation
  - travel time for each line section, formulated as a fixed delay per train,
  - variable routing cost, represented as a cost per unit of traffic,
  - fixed routing cost, represented as a fixed cost per train,
- zone connector operation
  - connector delay corresponding to the transport time between the origin of the flow and the access point of the network and represented by a fixed delay per tonne,
  - connector cost corresponding to the cost for moving the freight between its origin and the access point of the network (fixed cost per tonne).

All these parameters depend on the characteristics of links and nodes of the base network. Many of them are also influenced by the characteristics of the service in terms of type (i.e. capacity and speed), priority, and availability or not of a multi-voltage locomotive.

3.5 Solution technique

Following the technique proposed by Crainic, Ferland et al. (1980 and 1984), the modified problem (objective function with penalty constraints) is solved by an heuristic approach based on a decomposing scheme which works alternately on the following sub-problems:

- given a certain level of service (in terms of frequencies offered on each train service), determination of the best traffic routing for each flow;
- given a traffic distribution, modification of the service frequencies to improve the objective function.

Initially, all service frequencies are set at relatively high values, taking into account also approximate capacity limits of the line sections that are part of the service path over the physical network.

In order to find the best route for each flow, the model works on an *exploded network*, the elements of which do not represent physical locations but instead "states" (such as beginning and end of an operation, etc.). The nodes of the exploded network are the centroids, the "service nodes" (corresponding to the nodes of the base network when crossed by a specified service) as well as some "ground nodes" that represent the beginning and the end of some operations (classification at yards, loading and unloading at CT terminals, coupling and uncoupling at intermediate stops). Service nodes are the service departure node of the physical network, two nodes for each physical node where operations take place, representing their beginning and their end (border formalities, locomotive changes, intermediate stops), as well as the service destination node. In terms of links, the exploded network is composed of the zone connectors, of operation links, of service "boarding / disembarking links", as well as of service running links. Operation links connect the beginning and the end of yard, CT terminal and intermediate stop operations. Boarding / disembarking links represent the process of putting / removing the freight on a service. Service links are the connections between the beginning and the end of operations that take place on the service (border formalities, locomotive changes, and intermediate stops), as well as journey links between two successive halts of the service.

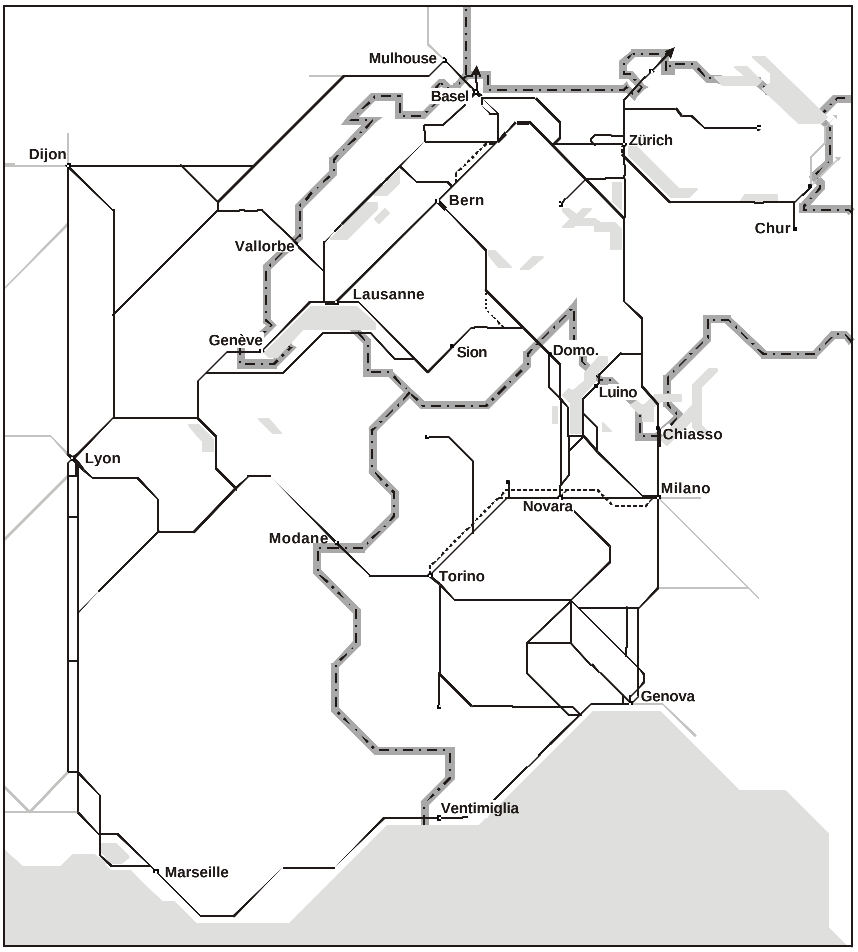
The model iterates between the sub-problems of traffic distribution and of frequency modification. The procedure will stop when the improvement of the solution obtained after a complete cycle is less than a predetermined value.

The model has been implemented in FORTRAN.

4. Optimisation of transalpine rail freight services

The model has been used for the first time within the Interreg II project PRIMOLA (*PRojet Interrégional pour une MObilité durable des marchandises à travers Les Alpes*). Scenarios for optimisation of the rail services through the Alps have been evaluated at the horizon 2007 (corresponding to the opening of the new Lötschberg basis tunnel). The rail network taken into account consists of the corridors of the Western part of the Alps as well as by the main lines of Switzerland, Northwest Italy and Southeast France (see figure 3).

Figure 3 Transalpine network



Traffic data have been estimated on the basis of the forecasts of rail and combined transport demand for 2007. Data have been aggregated on 57 origin / destination zones and 12 demand segments. As a result, 2628 demand flows having a 2007 forecasted tonnage of more than 10 net tonnes per week have been selected for the optimisation process.

Some adaptations were necessary to make the model appropriate for this case study. They are described in the following paragraph.

4.1 Specific issues for the application of the model

4.1.1 Input data estimation

A considerable effort has been done to obtain accurate estimates of the input data about unitary delays and costs of the operations (i.e. for instance yard processing time, yard cost per wagon, etc.). As noted by Assad (1980b), the available costing information leaves much to be desired for modelling purposes. Besides the deficiency of some rail operators to know the distribution of their costs, data availability is presently affected by the increased competition in the railways sector. In order to preserve their market position or to avoid criticism about their cost efficiency, rail companies are less and less willing to disseminate data about their costs.

The authors who previously dealt with this kind of problem (see section 2) seem to have obtained the necessary data directly from the rail operator (little information about the estimation of input data is given in their papers). While applying our model to the transalpine traffic, we quickly realised that it was difficult to obtain data from rail companies, because of either unavailability or confidentiality. In addition, getting data from different operators states the problem of different estimation methods. Thus, we developed a calculation framework to estimate the cost data required by the model, taking into account the basic characteristics of the links and of the nodes of the physical network, and the unitary cost of the resources consumed to carry out the operations (such as hourly wages of a train crew, energy cost per kWh, etc.). Instead, the data about the duration of the operations has been obtained from the operators; in some cases of particular complication (such as border stations), we have personally visited the locations to check the accuracy of the data.

The costs taken into account in the model are medium-run marginal costs, i.e. the variation of operating costs due to an increase of one unit of the produced output (i.e. of one unit of traffic), under given conditions of infrastructure. Thus, medium-run marginal costs are those due to energy consumption, driving and ground personnel, rolling stock maintenance and depreciation, as well as the infrastructure maintenance due to the movement of an additional unit of traffic.

Table 1 summarises the cost factors taken into account. The cost calculation framework has been developed as an MS ACCESS database with 7 basis tables and 12 calculation queries.

Table 1 Cost factors taken into account

Link or node	Operating cost input for the model	Cost factors
Marshalling yards	fixed cost per wagon of the yard operations	yard ground staff; driving personnel of shunting locomotives; depreciation and maintenance of shunting locomotives; traction energy consumed by shunting locomotives; infrastructure maintenance
Border nodes	fixed cost per wagon of the border operations	personnel executing administrative and technical operations at border crossings; maintenance of tracks where wagons wait during border operations
Locomotive changeover nodes	fixed cost per train for locomotive changeover operations	if the node is a border station*: shunting energy; driving crew of the locomotives; depreciation and maintenance of the locomotives if the node is the end point of a link requiring multiple traction: shunting energy; employ of the crew driving the additional locomotive(s) during shunting; depreciation and maintenance of the additional locomotive(s)
Intermediate stops	fixed cost per wagon	shunting energy
	fixed cost per train	stopping train driving crew
CT terminal	cost for loading / unloading the ITU transportable by one wagon	charge prices for the transhipment operation**
Line section links	journey cost for one wagon circulating on the link	traction energy consumed to move the wagon; wagon depreciation and maintenance; infrastructure maintenance as a result of the wear and tear due to the transit of one wagon
	journey cost for a train circulating on the link	train driving crew; traction energy consumed for the movement of the train locomotive; depreciation and maintenance movement of the train locomotive; infrastructure maintenance as a result of the wear and tear due to the transit of the train locomotive

* This cost subsists when the locomotive is not multi-voltage, otherwise the operation is not necessary and its cost is equal to 0.
** We assume that this price reflects the whole costs due to the operation (personnel, energy, equipment depreciation and maintenance).

4.1.2 Rail supply representation

As shown in figure 3, the physical network taken into account consists of the main railway lines of Switzerland, Northwest Italy and Southeast France. Each line section has been subdivided in two mono-directional physical links. Some additional links with operating costs and delays equal to zero have been added to the network to represent the connections between nodes representing different functions of the same physical node (see section 3.2). Table 2 shows the characteristics of the resulting network.

The 57 centroids are linked to the physical network by 2888 segment-specific zone connectors.

Table 2 Physical network for the transalpine case-study

Element	Quantity
Marshalling yards	40
Border nodes	12
Locomotive changeover nodes	55 (12 of which correspond to border crossings)
Intermediate stop nodes	86
Combined transport terminals	34
Simple nodes (junctions, etc.)	169
Line section links	918 (250 of which with zero cost and delay)

As stated, the list of the possible services is given by the user. The number of possible train paths over the network is high. In addition, a service can be type 1, 2 or 3 (see footnote 8) and have high or low priority; services running through different voltage systems can be pulled by single or by multi-voltage locomotives. All this generates a lot of possible services. Some rules can be used to reduce this number, but it is best to propose a wide range of services and then to leave to the model the selection of those that have to be offered. Hence, about 4000 services have been proposed at the beginning of the experimentation.

4.2 Model experimentation

Model experimentation on transalpine traffic is still under way. Final results are expected for April 2001.

The most time-consuming procedure is the traffic distribution over itineraries. In order to limit computational time, it was imposed that, at each iteration, each flow is routed only on one itinerary which is the "best" one, given the service level and the distribution of the other flows at that moment. This choice[11] is equivalent to the "pure strategy" proposed by Keaton (1989). Given this simplification, computational time is reasonable and the approach described in section 3.5 proved to be an efficient way to solve the optimisation problem.

[11] To avoid that this hypothesis affects too much the realism of the model, the biggest flows whose tonnage is > 3000 t / week have been split in several flows weighting 3000 tonnes or less. Since the routing is carried out for one flow per time, this procedure reduce the impact of the "pure strategy" approximation.

5. Conclusions

The developed model provides decision-makers with a lot of information:

- the selection of the optimal set of train services (if $q(s) = 0$, the corresponding service s will not be offered; if $q(s) > 0$, the service s should be run with frequency $q(s)$),
- the traffic routing (the optimal itinerary over the service network is determined for each flow),
- the feasible rail service quality for each flow, expressed as origin-to-destination transport time,
- the workload (in terms of number of trains or wagons) for each node and each link of the physical network.

The determination of the service frequencies is an important issue to define the medium-run train path needs per each line section. Thus, model results will be a useful input to capacity evaluation models, such as CAPRES (Curchod et Lucchini, 1999).

On the other hand, the best rail performances in terms of total transport time can be utilised to improve the estimation of the modal split within multi-modal freight models.

The model is a useful tool for medium-term planning aiming at the optimisation of rail freight supply. A first application on the transalpine traffic proved the feasibility of the approach. On the other hand, a large amount of data is needed. Due to the low availability of cost data, a specific cost-calculation tool has been developed to estimate the input required by the model.

We are now focussing on the improvement of the computational time and on the application of the model on three scenarios for the 2007 transalpine traffic. We also plan to perform a sensitivity analysis to test the importance of some input parameters, such as the value of time and the number of services proposed at the beginning.

Further work to improve the model should also concern the enhancement of the algorithm in order to allow traffic distribution on more than one itinerary per flow, as well as the implementation of graphical display module to help dealing with the considerable amount of output data generated by the model.

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