TRANSPORT COMPETITION ON A MULTIMODAL CORRIDOR BY ELASTICITY EVALUATION

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1. INTRODUCTION

The paper summarises a study on multimodal transport of freight demand along the north-south Italian corridor with the analysis of competition aspects as regards road, combined maritime-road and combined rail-road transport[1]. Domestic freight distance traffic in Italy is imbalanced: there is a net prevalence of road haulage that generates considerable external costs. Unlike what occurs in international trade, with a large proportion of maritime unitised traffic, in domestic traffic in Italy the combined maritime and railway mode is strongly penalised. This paper analyses the causes of this modal distortion and also tests some strategies for increasing competition of short sea shipping by a modelling approach.

The importance of freight demand modelling has recently increased in the literature. The analysis of international intercity trade is receiving increasing attention. Generally different criteria can be adopted for demand analysis as regards different level of data availability. The observation unit can be constituted by information aggregated at a certain geographical level such as: average traffic on link, generalised time and cost of travel, level of service etc. In other cases it requires more detailed data that can be obtained by a specific survey. Sometimes when the area involved is great a combination of the two techniques can be used (McFadden 1978).This is the approach we used in our analysis where we considered, as cargo unit, the most commonly used trailer 13.5 m long and the piggy back system.

According to data reported in MTS (Minister of Transport Statistics) the percentages of goods transported on short sea shipping is constant in time, amounting to 18% of the total transported. There has by contrast been an increase in road transport percentages. In terms of tonne-km transported, in 2002 about 66% of freight travelled on wheels in Italy. It is evident that the transfer of a considerable quantity of goods to alternative modes becomes a priority for a policy of modal split readjustment.

2. INTERCITY FREIGHT MODELLING IN THE LITERATURE

The framework of the intercity freight model, as defined in the literature, classified as aggregate/disaggregate behavioural models, multi-regional input-output model and dynamic system schematisation of the four macro areas, is represented below.

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- *Aggregate models* reported in the literature are the so-called “abstract mode’’ proposed by Quandt and Baumol (1966). Subsequently Morton (1969), Boyer (1977) and Levin (1978) introduced the modal split model “aggregated logit”. The relatively simple structure makes it particularly interesting for practical application, particularly on large scale analysis, despite the absence of theoretical support. Oum (1979), Friedlander and Spady (1980) proposed a set of models based on production factor pricing. In 1982 Lewis and Widup estimated a modal split model, between rail-road systems, by the Oum cost function.

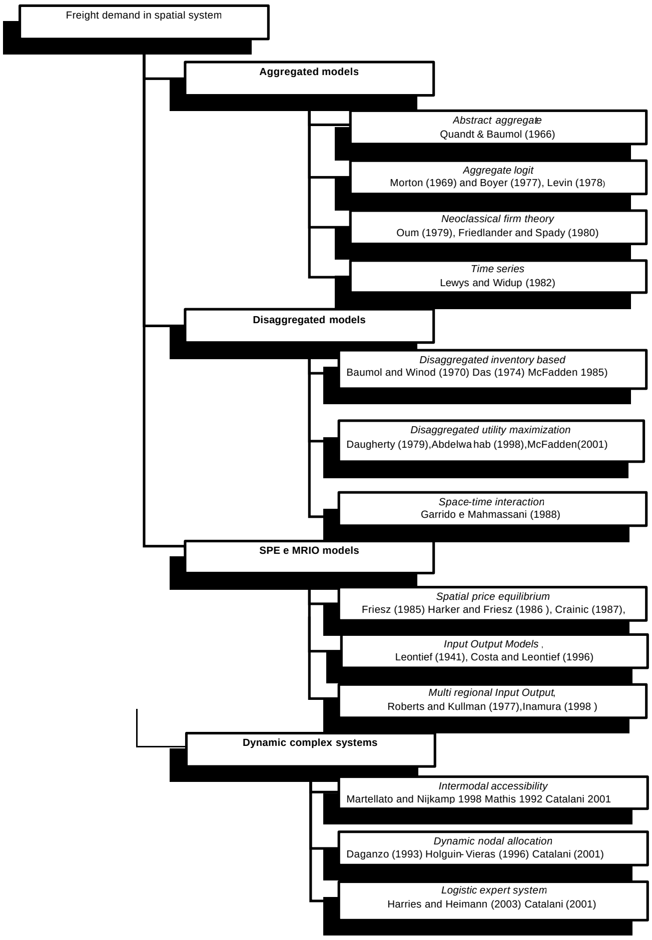
- *Disaggregated models* consider the single unit of the shipper’s decision to send goods. Disaggregated models appear more interesting from the theoretical point of view than aggregate ones. The three most important theoretical areas are those relative to behavioural, inventory and space temporal models. The behavioural model reproduces the process of utility maximisation in the choice between random alternatives as by the McFadden approach (1974). In the inventory category whose empirical application began during 1970s-1980s with Baumol and Vinod (1970), Das (1974), McFadden and Winston (1981), McFadden (1985), there has been a recent analysis of shipment consolidation and inventory management policy. A last recent class of space – temporal interaction had been proposed by Garrido and Mahmassani (1998, 2000), who analysed each forwarder sending goods in the course of a year.

- *Spatial price equilibrium (SPE) and multiregional input-output models* are freight demand applications where price dynamicity is considered based on the deterministic behaviour of the demand. This problem from a certain standpoint can be formulated as a linear programming approach. Major interest was raised by the input-output model based on Leontief’s theory (1972) and subsequently the multiregional input-output model of Chenery-Moses (1978). Their application is now widely used and can be classified into two different approaches: the first concerns fixed coefficients and the latter elastic ones with the interaction of behavioural models.

- *Dynamic system analysis (DSA)* comprises the logistic interaction between shippers and carriers as main actors of supply chain management. This application is particularly suited for intermodal management of traffic and routing system optimization problems specifically in the maritime sector. Several studies should be considered (Holguin-Vieras and Walton 1996; Catalani 1998, 2001 Harrier, Heiman, Hinenthal 2003).Generally all these models are used to examine the logistical performance and impacts of different types of freight distribution or nodal control for accessibility improvements.

Figure 1 summarises the state of the art in the sector with particular emphasis on more recent dynamic systems. The use of advanced dynamic systems such as expert systems or dynamic GIS for controlling intermodality, handling and rail-truck movements, can be strongly recommended. Unitised traffic control in nodal points generally increases terminal productivity but requires management of a great quantity of data. The increasing use of GIS may avoid investments in new infra-structures by rationalizing all the intermodal cycle of freight flows (Catalani 1998). Particularly useful is the visualization of stacking spaces with computerized mapping.

Figure 1. Intercity freight demand modeling



An expert system is a method to solve very structurally complex problems, in the presence of a margin of uncertainty. It is designed to simulate both the knowledge and the rational behavior of human experts specifically in the transport sector. It is particularly suited to solving problems of transport routing with many variables by automatic elaboration. In the literature there are few simulations in the discrete routing domain. With such models it is possible to approach dynamic problems with the artificial intelligence method. It is a new frontier of analysis which includes integration between network and dynamic systemic application.

3. COMPETITIVENESS EVALUATION BY MNL AND DEA

The approach used for modal split analysis consists essentially of a RUM model applied to an Italian corridor. Demand elasticity evaluation (DEA) will be based on McFadden’s theory of testing strategy for increasing short sea shipping over other land competitors. The multinomial logit model applied as noted in the literature (McFadden, Ben Akiva, Cascetta 1981, 1986, 1998) based on the following utility function and probability distribution:

$$f_U(x) = \frac{1}{q}\exp\left[-(x-V)/q - f\right]\exp\left[-\exp\left[-(x-V)/q - f\right]\right] \qquad (1)$$

$$F_U(x) = \Pr[U \le x] = \exp[-\exp(-(x-V)/q - \Phi)] \tag{2}$$

where:

$f_U(x)$	Probability function of random variable U.
$F_U(x)$	Distribution function of random variable U.
Φ	Eulero constant ($\Phi \approx 0{,}577$).
?	Parameters to be estimated .

Based on stability as regards the property of maximisation, it is possible to derive probability and inclusive utility as follows:

$$P(j) = \Pr(U_j > U_{M'}) = \int_{-\infty}^{+\infty} F_{U_{M'}}(x) \cdot f_{U_j}(x)dx \tag{3}$$

$$V_{M'} = q \ln \sum_{k \neq j} \exp(V_k / q) \tag{4}$$

$$p(j) = \int_{-\infty}^{+\infty} \exp\left\{- \exp\left[- \frac{(x - V_M)}{q} - f\right]\right\} \cdot \exp\left\{- \exp\left[- \frac{(x - V_j)}{q} - f\right]\right\} \cdot \frac{1}{q} \cdot \exp\left[- \frac{(x - V_j)}{q} - f\right] dx = \tag{5}$$

Hence the expression:

$$p(j) = \frac{\exp(V_j/q)}{\sum_k \exp(V_k/q)} \tag{6}$$

that defines probability with the multinomial logit model.

The direct elasticity on the arc (Oum, 1987, McFadden, 1978) is expressed as the percentage variation of the probability of choosing alternative j, in relation to the percentage variations of an attribute k, being variations of the attributes assumed finite, of the same alternative X_{kj}:

$$E_{kj}^{p[j]} = \frac{\Delta p[j]}{p[j]} \bigg/ \frac{\Delta X_{kj}}{X_{xj}} \tag{7}$$

Similarly, cross elasticity is the percentage variation of choice probability of alternative j, in relation to the percentage variation of an attribute k, relative to another alternative h, X_{kh}:

$$E_{kh}^{p[j]} = \frac{\Delta p[j]}{p[j]} \Big/ \frac{\Delta X_{kh}}{X_{xh}} \qquad (8)$$

In the case of infinitesimal variations of the attributes, we have

$$E_{kj}^{p[j]} = \frac{\partial p[j] X_{xj}}{p[j] \partial X_{kj}} \qquad (9)$$

$$E_{kh}^{p[j]} = \frac{\partial p[j] X_{xh}}{p[j] \partial X_{kh}} \qquad (10)$$

The elasticity (Oum 1992, Cascetta 1998) can be expressed analytically in compact mode, by:

$$E_{kj}^{p[j]} = (1 - p[j]) X_{kj}\, b_k / q \qquad (11)$$

$$E_{kh}^{p[j]} = -p[j] X_{kh}\, b_k / q \qquad (12)$$

From equations (11) it emerges that direct elasticity is positive if attribute X_{kj} is positive and if the relative coefficient $ß_k$ is positive. In other words, the probability variation of choice will increase if the value of an attribute which represents a utility is increasing (ß positive). The higher the value of coefficient $ß_k$ and attribute X_{kj}, and the lower the probability of alternative j, the greater will be the elasticity in absolute value. Same consideration, with inverted signs, derives from (12).

4. FROM THE DISAGGREGATED TO THE AGGREGATE MODAL SPLIT MODEL

The model elaboration starts with a SP survey, at local scale, of a few shippers interviewed, that must send a good from a central Italian region to the others. In the survey we assumed that the choice was made by the shipper and not as often happens by the forwarders. The transport modes considered are:

- road transport;
- combined ferry-road;
- combined rail-road

Shippers analysed were chosen according to their size and activity, such as timber-work, clothing and shoe manufacturing. The estimate of parameters $ß_k$ derives by a SP survey .It has been calibrated with Alogit model that allows the goodness of each attribute to be ascertained (Catalani, 2001).

From the methodological point of view the intercity model extends the results of the previous partial model elaborated on the results of SP survey on the sample of shippers The results of the survey were used as a theoretical basis on which to develop the modal split model described below. In particular the coefficients $ß_k$ were used to test a large scale intercity model later corrected with aggregate data as below.

The method of aggregated calibration was used to improve the estimate of parameters obtained with disaggregated calibration. The aim of this type of calibration is to find the optimal values of coefficients ß, estimated above with generalised least square, that minimize the sum of differences:

$$b_z^* = \arg\min \sum_j \left(\sum_n \sum_m j_{n,m}[j] \right) \tag{13}$$

The complete modal split model was applied to the intermodal transport of trailers at a domestic scale, extending the focus throughout Italy.

The developed model, though derived from the previous one, particularly in functional form, utility function and alternatives considered, was constructed *ex novo* on the basis of trade between Italian provinces on major traffic corridors. However, the coefficients, $ß_k$, of the systematic utility are for each alternative attribute the same because they are the best to simulate the shipper's choice. The survey field responds to the optics of the research, with the limit that will be evidenced below. The transport alternatives analyzed are the most important ones in Italian domestic traffic.

The probability functions used in the model are those reported below.

$$p[r] = \frac{\exp V_r}{\exp_{V_r} + \exp V_{fr} + \exp V_r} \tag{14}$$

$$p[fr] = \frac{\exp V_{MS}}{\exp V_S + \exp V_{MS} + \exp V_{FS}} \tag{15}$$

$$p[rr] = \frac{\exp V}{\exp V_S + \exp V_{MS} + \exp V_{FS}} \tag{16}$$

where:

$p[S]$	probability of choosing road transport
$p[MS]$	probability of choosing combined ferry-road
$p[FS]$	probability of choosing combined rail-road
Vr	systematic utility of road transport.
Vfr	systematic utility of combined ferry-road.
Vrr	systematic utility of combined rail-road.

The systematic utility function is represented by:

$$Vr = b_1 C_S + b_2 T_S \qquad (17)$$

$$Vfr = b_1 C_{MS} + b_2 T_{MS} + b_3 \qquad (18)$$

$$Vrr = b_1 C_{FS} + b_2 T_{FS} + b_4 \qquad (19)$$

where :

$Cr\,; Cfr\,; C_{rr}$	monetary costs
$T_S\,; T_{MS}\,; T_{FS}$	time of the three modes
b_1	coefficient of monetary cost
b_2	coefficient of time
$b_3; b_4$	coefficient of specific alternative (CSA).

4.1. Determinant link and O-D matrix construction

Inside the corridor, the most important links were defined between provinces by means of a survey so as to be able to apply the model. Delimitation to the provincial scale allows us to construct good O-D matrices for each transport mode. The maritime corridors are reported in figure 2. The provinces chosen for insertion in the matrices exclude those with links of less than 500 km.

Subsequently all *transversal* links were excluded from the analysis, that is all links from northwest to southeast in which the road link conjunction terminal nodes (ports) have greater weight in terms of distance with regard to the main segment. Based on such considerations regions and provinces were selected to be inserted in the analysis, short sea shipping routes, rail-road links, port and railway terminals, with respective observed flows. Besides, we excluded those routes with very low traffic. Finally, the regions and provinces thus identified were inserted in four matrices, relative to macro areas of trade involved, as reported in table 1.

Figure 2. The corridors in short sea shipping (excluding Sardinia)

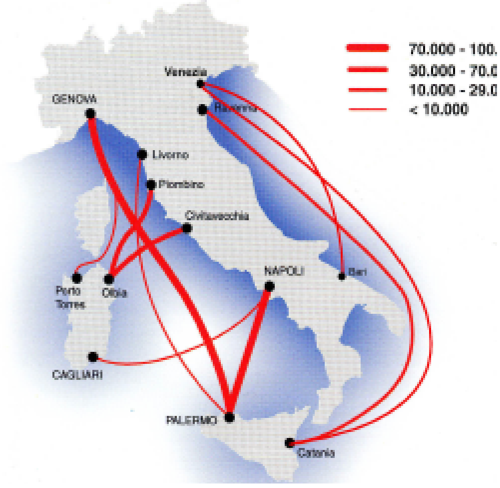


Table 1 . O/D matrices and trade macro areas

Matrix	Macro areas		
1	Southwest Italy. (Sicily, Calabria)	⇔	-Northwest Italy (Liguria, Tuscany, Piemonte, Lomb.)

2	Eastern southern Italy (Sicily, Calabria)	⇔	-Northeast Italy (Emilia Romagna, Veneto, Trentino,)
3	Southern Italy (Puglia, Basilicata)	⇔	Northeast Italy (Veneto, Trentino, Friuli)
4	Southern Italy (Campania, Basilicata)	⇔	Sicily

4.2 Pricing and timing data base

To explicit the utility function we determined all costs and timings of transport from the theoretical point of view. In this context it is important to specify that the shipper’s preference is also affected by other parameters such as transport direction, logistic nodes, door-to-door condition, etc.

Table 2 below reports a link exemplification based on pricing and timing relative to the modes involved.In the combined transport, as regards ferry and rail, to calculate monetary cost and transit time, it was necessary to subdivide the transport into its components. With regard to timing, pick-up and delivery time need to be added. As regards combined ferry-road, the pricing used is inclusive of port fees.

Table 2 Timing and pricing on domestic multimodal systems

road		Milano			
		Overall road link			total
Palermo					
	Time (h)				44.62
	Price (€)				1784.4

sea	*road*	Milano						
		Road link		Sea link		Road link		total
Palermo		Paler	Paler	Paler	Genova	Genova	Milano	
	Time (h)		0		29		3.64	32.64
	Price (€)		0		503.29		361.52	864.61

rail	*road*	Milano						
		Road link		Rail link		Road link		total
Palermo		Paler	Paler	Paler	Milano	Milano	Milano	
	Time (h)		0		36.5		0	36.5
	Price (€)		0		1065.4		0	1065.4

4.3 Aggregate model calibration by traffic counts

Traffic composition and subdivision is important for aggregate calibration. As regards road transport, the main source was the Central Statistical Institute with the data of a survey of vehicles larger than 3.5 tonnes, from which trailer data were extrapolated. Of greater complexity is the situation for combined transport due to the considerable presence of private operators who are generally somewhat unwilling to collaborate. The lack of statistical surveys forces us to use data observed on the main link with a consequent increase in the data aggregation level.

Table 3 – Observed flows (Various Sources)

Trading area	Road	Ferry-road	Rail-road	Total
Sicily/Calabria ⇔ Liguria/Piemonte/ Lombardia/Val d'Aosta	3,126,087	2,287,690	585,542	5,999,319
Sicily/Calabria ⇔ Tuscany	257,712	912,000	33,915	1,203,627
Sicily/Calabria ⇔ Emilia Romagna	2,024,799	778,100	538,230	3,341,129
Sicily/Calabria ⇔ Veneto/Trentino/Friuli	658,771	90,270	278,830	1,027,871
Puglia/ Basilicata ⇔ Veneto/Trentino/Friuli	2,842,754	16,065	23,030	2,881,849
Campania/ Basilicata ⇔ Sicily	3,691,519	1,054,500	36,602	4,782,621
Total	12,601,642	5,138,625	1,496,149	19,236,416

Particular data were supplied by port authorities and shipping companies. For railway traffic we reported data of the Railways Cargo Division of intermodal unitised traffic (UTI) of trailers and piggy back. Table 3 above summarises for 2000 all the observed traffic on the multimodal network system.

At this point we implemented the intercity modal split model as the first step by using the coefficients ß$_k$ calculated by SP survey as described in section 4 above. However, considering the limitation of the field survey on which ß$_k$ was calibrated, further calibration is required with aggregate data relative to link traffic. With the coefficients ß$_k$ calculated with Alogit, it was possible to determine systematic utility and calculated probability of choice.

Subsequently, we determined the values of the ASA coefficients (Alternative Specific Attribute), ß$_3$ and ß$_4$, for combined transport with the generalised least squares approach. It consents to calculate final choice probability. Parameters ß$_k$ after calibration are reported in table 4.

Table 4 – Parameters ß$_k$ after aggregate calibration

	ß$_1$ (time)	ß$_2$ (cost)	ß$_3$ (CSA rr)	ß$_4$ (CSA fr)
Estimate	-1.197	-0.9263	-1.348	0.1019

After defining function utility attributes and calibrating the modal split model it was possible to determine the utility function definitively.

5. TRANSPORT DEMAND ELASTICITY

As noted in the literature, one of the potentials of logit models is elasticity evaluation. With this algorithm it is possible to test the model for future demand forecasting and scenarios particularly to focus on strategies to reduce congested traffic. In this context the incidence of a pricing reduction on modal split by arc elasticity was analysed. The two scenarios consider a pricing reduction of 30% in the two combined traffic flows. The results of these two hypotheses are shown in tables 5 and 6.

As can be seen from the elasticity ?, a reduction of pricing of combined ferry road would induce an increase in traffic for this mode against a reduction in the other modes. The direct elasticity of combined ferry-road ?=-0. 77, signifies that a reduction in the cost of this mode will be accompanied by a probable less than proportional increase in choice. On the other hand a cross elasticity of road transport of ?=0.3, as regards a pricing variation of combined ferry-road, will induce a less than proportional choice probability of road transport.

Tale 5 – Cost reduction of combined ferry-road of 30% ?C/C =-0.3

Transport	Observ prob	Calcul.prob	?p/p	? C_{fr}/C_{fr}	?=(?p/p)/(? C_{fr}/C_{fr})
Road	65.79	59.55	-0.09	--	0.3
Sea-Road	27.08	33.41	0.23	-0.3	-0.77
Rail-road	7.13	7.04	-0.01	--	0.03

Table 6 – Cost reduction of combined rail-road of 30% ?C/C =-0.3

Transport	Observ prob	Calcul.prob	?p/p	? C_{rr}/CF_{rr}	?=(?p/p)/(? C_{rr}/C_{rr})
Road.	65.79	63.55	-0.03	--	0.1
Sea-Road	27.08	26.08	-0.04	--	0.13
Rail-road	7.13	10.37	0.45	-0.3	-1.5

The same consideration can be made as regards timing. In this case the reduction in transit time can be induced by an improvement in logistic service and by bottleneck reduction of flows of good in nodal points. The results are represented in tables 7 and 8.

Table 7– Time reduction of combined sea road of 30% ?T/T =-0.3

Transport	Observed probability	Calculated probability	? p/p	? $_{MS}/T_{MS}$	?=(? p/p)/(?? $_{MS}/T_{MS}$)
Road	65.79	57.73	-0.12		0.4
Sea -Road	27.08	35.46	0.31	-0.3	-1.03
Rail-road	7.13	6.81	-0.04		0.13

Table 8 – Time reduction of combined rail-road of 30% ?T/T =-0.3

Transport	Obseved probability.	Calculated probability	?p/p	? T_{rr}/T_{rr}	?=(?p/p)/(?? $_{rr}/T_{rr}$)

Road	65.79	62.93	-0.04		0.13
Sea -Road	27.08	25.81	-0.05		0.17
Rail-road	7.13	11.26	0.58	-0.3	-1.93

Interestingly, the direct time elasticity of the two combined transport modes are both greater than one: ?=-1.03 and ?=-1.93). In other words, a reduction in transit times will result from a more than proportional increase in the choice probability of the mode. Finally, the 30% reduction in combined ferry and road prices has been quantified as in table 9 below.

There should be about 1,288,261 tonnes shifted on combined ferry-road and 498,668 on railways. Evidently, the same consideration can be extended to the time reduction or to the case of a hypothetical generalised increase in transport demand.

Table 9. Modal split with combined transport reduction.

	Combined ferry road		Combined rail road	
Transport	Tons	%	Tons	%
Road.	11,455,286	59.55	12,224,742	63.55
Sea -Road	6,426,886	33.41	5,016,857	26.08
Rail-road	1,354,244	7.04	1,994,817	10.37
Total	19,236,416	100	19,236,416	100

The results of punctual elasticity are reported in table 10 and 11. Direct elasticity are all negative while cross elasticity are all positive as expected. It may be noted that the lower the probability of choosing the mode the higher is direct elasticity in absolute terms. Highest values are for combined rail-road which is the least competitive mode. Finally, cross elasticity are equal for each alternative in respect of the IIA.

Table 10 – Point elasticity as regards cost

	C_{r}	C_{fr}	C_{rr}
?$_{r}$	-2.289792968	1.728296793	0.466808747
?$_{fr}$	4.403558202	-4.653169167	0.466808747
?$_{rr}$	4.403558202	1.728296793	-6.083151183

Table 11 – Point elasticity as regards time

	C_{r}	C_{fr}	C_{rr}
?$_{r}$	1.406281749	1.161811799	0.292822901
?$_{fr}$	2.704455651	-3.127996801	0.292822901
?$_{rr}$	2.704455651	1.161811799	-3.815879599

6. CONCLUSIONS

The paper showed that the modal split model used for shipper choice simulation allowed us to test hypotheses of modal readjustment. Analysis of timing and cost shows that combined transport competitiveness may gradually be improved. It is also evident that a further rise in competitiveness could stem from an improvement in intermodal accessibility. Direct and cross-elasticity analysis, on the other hand, evidenced an increasing quantity of combined maritime transport, with a diversion from road transport to other modes resulting from a reduction in transport pricing. Is it possible without state intervention?

It is true that all this can achieved by using intermodal infrastructures more efficiently. It is also clear that operators must operate in a market with conditions of equal competitiveness and railways should not operate under the state umbrella. In this scenario road transport must also have a greater interest in transport rationalisation based on integration between other modes. At last all this means that industry operates with increasing logistical possibilities and port efficiency such that short sea shipping can prevail over other modes.

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