SITING OF MULTIMODAL TRANSPORT PLATFORMS AND EVALUATION OF THEIR ECONOMIC EFFECTS

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Abstract

The paper presents a new formulation of the multi-objective procedure that compares and classifies the projects by means of an algorithm and presents a twofold advantage: firstly, excluding all recourse to value judgments, it proposes a ranking based on the deviation from the ideal solution to normalise the measure of objective attainment and, secondly, it combines the final evaluation with a cost-benefit analysis to obtain a series of stability functions.

INTRODUCTION

Evaluation of the effects of the creation of major transport infrastructures represents one of the aims of certain techniques (the so-called multi-criteria or multi-objective techniques) that were proposed at the beginning of the 1970s and, accepting the differences between individual projects and the multiplicity of objectives, set out to solve the problem of merging heterogeneous decision elements.

The present paper presents a new formulation of the multi-objective procedure that compares and classifies the projects by means of an algorithm and presents a twofold advantage: firstly, excluding all recourse to value judgements, it proposes a ranking based on the deviation from the ideal solution to normalise the measure of objective attainment and, secondly, it combines the final evaluation with a cost-benefit analysis to obtain a series of stability functions capable of orientating the policy-maker towards the "optimal" problem solution.

The communication terminates with an application of the model that seeks to evaluate the effects produced on freight flows, road safety, atmospheric pollution, location of economic activities, etc., by the realisation in Italy of the recently proposed network of transport platforms, the so-called *Interporti* (interports).

FORMALISATION OF THE PROCEDURE

The work here reported aimed at identifying a procedure and, consequently, a mathematical model that, within the ambit of the general theory of multi-objective analysis, would exclude the use of value judgements for normalising the measure of objective attainment and, more generally, selecting the optimal solution of the problem under consideration. The search for such a model is deemed to be of great importance, because the limit of multi-criteria or multi-objective analysis is essentially represented by the introduction of subjective valuations.

This limit has caused the scientific world to level strong criticism against this type of analysis, which is generally held to be non-scientific, because the solution of the problem may depend not only on the particular project alternatives considered, but also on the group of experts to whom the analysis and the valuations are entrusted.

The procedure proposed herein excludes the use of value judgements within the evaluation process and relies exclusively on analyses of the mathematical or numerical type. Consequently it assures both the uniqueness of the solution and its non-ambiguity, a feature that was amply confirmed in a series of successive trials in which different groups evaluated the same projects.

Project selection

As is normally the case in the analysis of transport problems, the first step of the procedure consists of pinpointing the project alternatives, which can be represented by a single intervention (be it infrastructural or operational) or by a set of interventions that, taken together, constitute a project solution. For each such project, obviously, one has to define the functional and technical characteristics and calculate both the investment and the operating costs.

Identification of the objectives

Multi-objective analysis seeks to pinpoint the solution that is optimal in relation to a series of special objectives to be attained, so that the efficacy of each individual project has to be measured against these objectives. Over and above selecting the project, one must therefore also define the objectives to be attained, indeed, these objectives may even affect the definition of the projects to be considered for analysis purposes. As far as works of public interest are concerned, the task of identifying the objectives falls to the political decision-maker. The task of the technician (and often a decisive one), on the other hand, is that of transforming the general orientations proposed by the politician into clearly defined objectives that can be objectively measured (quite independently of the units of measurement), and this is a necessary and indispensable condition for the model here constructed.

Measure of objective attainment

Once both projects and objectives have been defined, the procedure requires the evaluator to take each of the n projects ($P_1, ..., P_n$) and to measure the extent to which it attains the r objectives ($O_1, ..., O_r$), expressing the result in each case in the units of measurement of the objective under consideration.

This leads to the construction of a project-objectives (P/0) matrix M_1 made up of the elements $X_{i,j}$, where:

i = 1,...,n = project index

j = 1,....,r = objective index

$$
M_1 = \begin{array}{c|cccccc}
 & \multicolumn{5}{c}{\textbf{Objectives}} \\
\textbf{Projects} & O_1 & O_2 & O_j & O_r & \\
\hline
P_1 & X_{1,1} & X_{1,2} & \cdots\cdots & X_{1,r} & \cdots\cdots \\
P_2 & X_{2,1} & X_{2,2} & \cdots\cdots & X_{2,r} & \cdots\cdots \\
 & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\
 & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\
P_i & \cdots\cdots & \cdots\cdots & X_{i,j} & \cdots\cdots & \cdots\cdots \\
 & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\
 & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\
P_n & X_{n,1} & X_{n,2} & \cdots\cdots & X_{n,r} & \cdots\cdots
\end{array}
$$

The generic element $X_{i,j}$ of the matrix M_1 represents the extent to which objective j is attained by project i, the value being measured in the units of measurement peculiar of that particular objective. The objectives in the matrix, of course, will be represented by mathematical expressions to be maximised or minimised, viz.:

$$O_j = \text{Min } X_{i,j} \quad \text{for each i} \qquad (1)$$

$$O_{j+1} = \text{Max } X_{i,j+1} \quad \text{for each i} \qquad (2)$$

For example, objective (j) could be the *generalised transport cost* and objective (j+1) could stand for the *accessibility of the transport system.*

The objectives, moreover, could also be subject to constraints of various kinds: threshold values established by legislation (as for atmospheric pollutants and noise) would be a case in point.

Normalisation of the P/O matrix

Since the attainment each objective has been measured in terms of the units of measurement of that particular objective, the elements of the matrix M_1 are not homogeneous and cannot therefore be summed. No judgement can thus be expressed as regards the projects that are being compared. Before such a judgement can be made, one has to perform a normalisation process to transform the measure of the objectives expressed in terms of the variables $X_{i,j}$ into a measure based on an adimensional variable capable of expressing the attainment of each individual objective. At this point, therefore, the procedure introduces a specific function known as *utility function.*

This function is measured by means of an adimensional index number; it is characteristic of each objective and can be expressed in the form

$$U = U\,(O_j) = [0,1]. \qquad (3)$$

The definition of the utility functions represents a delicate step of the procedure here proposed, because it is associated with the risk of once again introducing subjective valuation elements into the numerical process of looking for the optimal solution. As explained in the description of the model (see next paragraph), the utility function is constructed from objective reference elements that do not in any manner or wise depend on the constructed analysis system.

When the matrix M_1 is normalised by the substitution of these utility functions, we obtain a second matrix M_2 made up of the value elements $U_{i,j}$, viz.:

$M_2 =$

	Objectives				
Projects	O_1	O_2	O_j	O_r	
P_1	$U_{1,1}$	$U_{1,2}$	......	$U_{1,r}$·	......
P_2	$U_{2,1}$	$U_{2,2}$	......	$U_{2,r}$	......
	......	......	......	......	......
	......	......	......	......	......
P_i	......	......	$U_{i,j}$	......	......
	......	......	......	......	......
	......	......	......	......	......
P_n	$U_{n,1}$	$U_{n,2}$	......	$U_{n,r}$	......

Finding the optimal solution

The solution algorithm of the model is based on looking for the maximum of the utility function defined over the r objectives O_j, ie

$$\text{Max } U\,(O_1,\ldots,O_r) \qquad (4)$$

within the set constituted by the n projects $(P_1,\ldots,P_n)$.

On the assumption (albeit not a very realistic one) that all the various objectives are of the same importance for the collectivity, ie that they have equal weight ($K_j=1$ for every j), the overall valuation of each project P_i is obtained from the sum of the ith line of matrix M_2, namely

$$U_1 = U_{i.1} + U_{i,2} + \ldots + U_{i,r} \qquad (5)$$

and the optimal project will then be identified by the value

$$U_i = U_i \text{ max}. \qquad (6)$$

In actual practice, however, the assumption that all the objectives are of equal importance is extremely restrictive and the simple procedure just outlined cannot therefore be used in the greater part of cases. We must therefore assume that the various objectives have different weights for the collectivity, that they have different values of K_j. Nevertheless, if the collectivity (or its representatives) are capable of expressing the *cardinal values* of the weights, it becomes even easier to pinpoint the optimal solution. In that case, rather than calculating the sum of the line parameters of the matrix M2, the valuation can be made by obtaining a linear combination of these parameters and the weights, ie

$$U_{1,k} = K_1{*}U_1 + K_2{*}U_{i,2} + \ldots + K_r{*}U_{1,r} \qquad (7)$$

and the optimal project will be the one for which

$$U_{i,k} = U_{i,k} \text{ max}. \qquad (8)$$

But even this second assumption—knowledge of the cardinal values of the weights—is unduly optimistic.

More frequently, indeed, the would-be evaluator finds that he is provided with nothing more than the *ordinal values* (or rankings) of these weights.

Assuming therefore that the representatives of the collectivity are capable of objectively expressing only the relative importance of the various objectives, we can obtain the following formalisation:

$$\sum_{j=1}^{r} K_j = 1 \tag{9}$$

where

$$K_j \geq 0 \tag{10}$$

and

$$K_1 \geq K_2 \geq \ldots. \geq K_r \tag{11}$$

The steps required for identifying the optimal solution are thus as follows:

I) Definition of an ordinal scale (ranking) of weights

II) Assignment of a first (tentative) set of cardinal values to the weights, subject to the constraint that the ranking order must be respected

III) Calculation of the structure value of each project $U_{i,k}$ and ascertainment of the project rankings

IV) Sensitivity analysis of the result and measurement of the stability of the solution

V) Appropriate modification of the cardinal values of the weights and repetition of steps III and IV

VI) Identification of the optimal solution by comparing the representative stability curves of the best solutions found by the procedure.

The perfected procedure also allows for the use of two particular constraint functions as analysis discriminants (in either continuous or discrete terms).

Firstly, in transport problems, as indeed quite generally in investment analysis and the theory of choices, it may be of decisive importance to identify the optimal solution that respects a given budget constraint.

Secondly, a classical cost/benefit analysis can be used to discriminate the projects among which the optimal solution is to be found (for example: by selecting the projects having an internal return greater than a specified threshold value).

USE OF THE ADOPTED PROCEDURE

The multi-objective procedure defined in the previous paragraph will here be used to compare and classify different potential locations of multimodal platforms. In these cases, indeed, cost/benefit analysis proves inadequate for assessing different project alternatives that, over and above minimising the generalised transport cost, set out to satisfy such variegated and often antagonistic objectives as avoiding environmental pollution, energy saving, and increased safety.

The formal structure of the procedure, schematically illustrated in Figure 1, can be developed by the following main steps.

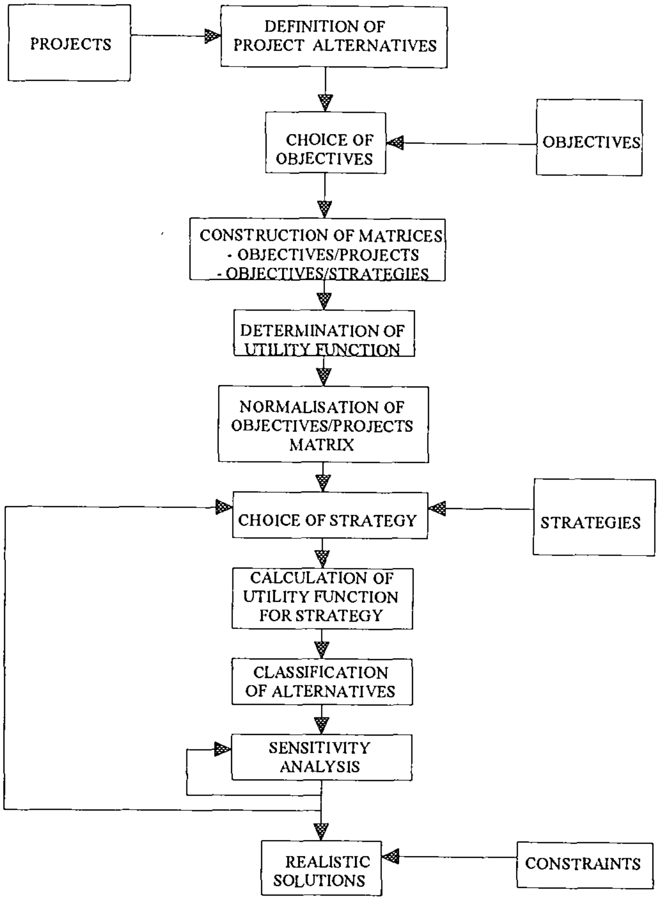

Figure 1 Phases of the procedure

a. Identification of the projects to be compared, and choice of the objectives and strategies that can be pursued by implementing the various project alternatives.

b. Construction of the P/O matrix, the individual matrix terms being expressed in the units of measurement of each given objective; the individual objectives will of course be represented by mathematical relations to be either maximised (eg transport network accessibility) or minimised (eg generalised transport cost).

c. Construction of the objectives-strategies (O/S) matrix (with strategies to be defined as functions of the different scenarios envisaged); it will be up to the policy-maker to choose the priority objective or objectives and hence also the strategy to be pursued.

d. Determination of the utility functions for each objective. With a view to avoiding solutions that are relative rather than absolute in character, the model contains a system of average reference indices that express the utility values of the entire set of objectives, estimated from objective parameters and average reference conditions. (An asymptotic utility function was chosen in the case under consideration).

e. Normalisation of the matrix in b. above and construction of the matrix made up of the utility functions.

f. Reading of the cardinal value of the weights for each pursuable strategy, normalisation in the field (0-1), calculation of the utility function, valuation of each project alternative and classification (ranking) of the various alternatives.

g. Calculation of the stability of the identified solution by associating the weight of each objective with a variable error probability (sensitivity analysis).

h. Iteration of the model, starting from step f. and continuing until the solution is found to be stable, subsequently repeating the procedure for the other strategies under consideration.

A NUMERICAL APPLICATION

The proposed location of an intermodal terminal cannot be determined in a deterministic manner, but has to be identified by seeing the problem in the context of a system logic in which traditional transportation objectives have to coexist with objective of a socio-economic and environmental type.

The realisation of the particular multimodal platform known in Italy as *interporto* (= interport), a facility used for the service of freight transport that combines various functions, activities and services (see the illustration in Figure 2), must also take account of the other, already existing structures in order to obtain a network effect.

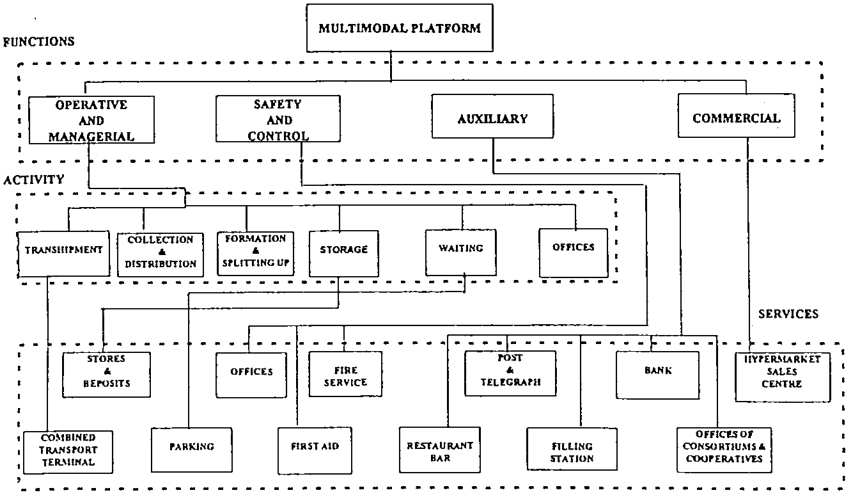

Figure 2 **Functional diagram of multimodal platform**

The procedure described herein was used to compare and classify the different locations postulated for the Italian multimodal platform network (39 interports) as illustrated in Figure 3. These locations were determined by a recent Ministry of Transport study, "*Piano quinquennale degli interporti*" (Five-Year Interport Plan).

The principal objectives selected to be pursued by the creation of these structures are reduction of the generalised transport cost, enhanced accessibility, greater safety, and the development of international intermodal transport. The value of the objective for the single structure considered has been obtained by using a selected indicator related to the objective itself.

Figure 3 **The Italian multimodal platforms network foreseen by the "Piano Quinquennale degli Interporti"**

The *generalised transport cost reduction* was calculated elaborating the results of a simulation for the year 2015 (high scenario), concerning the saving in the generalised transport cost according to the development of the railway intermodal transport.

In this simulation (Table 1) we can see different percentages of reduction of generalised transport cost obtained by the main structures in the 2000 scenario (only 14 "interporti" will be in use at that time) and in the 2015 "low" and "high" scenarios characterised by two different forecasts of GDP development.

The calculations were accomplished on the basis of the effective railroad rates, distance covered (derived from the official timetables), and truck rates per kilometre, obtained from specialised literature and from specific simulated rates.

Accessibility was calculated on the basis of an all-inclusive indicator that took into account the residual capacity of the railway corridors (in relation to the additional tasks derived from the development of intermodal traffic following the realisation of the new structure) and the additional capacity margins of the road network (due to the downturn in the number of heavy trucks that have to use it).

The *safety increase* was estimated by considering the reduced number of accidents in which heavy trucks would be involved. This would be a direct consequence of the smaller number of movements following the development of intermodal transport.

The *growth of international intermodal transport* was calculated by processing data concerning the quantity of goods with foreign origins or destinations that could potentially be attracted by intermodal transport following the activation of new multimodal platforms in the 2015 "high" scenario (Table 2).

Table 1 Percentage of reduction of the generalised transport cost obtained by the main intermodal platforms in the 2000 and 2015 "low" and "high" scenarios

Item Code	Interport	2000 Scenario	2015 Low Scenario	2015 High Scenario
1	Orbassano	6.74%	5.29%	5.27%
2	Rivalta Scrivia	5.47%	3.33%	3.33%
3	Lacchiarella Segrate	10.90%	9.22%	9.17%
4	Verona	3.15%	4.55%	4.54%
5	Padova	4.43%	4.44%	4.42%
6	Bologna	4.42%	4.53%	4.51%
7	Parma	3.43%	4.30%	4.28%
8	Livorno Guasticce	2.33%	2.50%	2.51%
9	Nola Marcianise	19.06%	8.90%	8.85%
10	Novara		3.98%	3.97%
12	Cervignano	4.15%	2.51%	2.53%
13	Ravenna		3.18%	3.17%
14	Prato	2.48%	3.48%	3.46%
15	Jesi	2.95%	1.55%	1.74%
16	Orte	13.90%	7.63%	7.60%
17	Civitavecchia		1.08%	1.08%
21	Termoli		1.56%	1.65%
22	Tito/Area Lucana		1.45%	1.45%
23	Bari		4.56%	4.54%
24	Area Ionico Salentina		2.10%	2.09%
25	Area Calabrese		2.90%	2.90%
26	Termini Imerese	16.58%	5.65%	5.64%
27	Catania		11.18%	11.18%
28	Cagliari		0.11%	0.11%

Table 2 Forecasted freight handled (ton/day) by different multimodal platforms in the 2015 "high" scenario

Item Code	Interport	National traffic	International traffic	Sea traffic
1	Orbassano	20572	2810	
2	Rivalta Scrivia	28089	6026	17053
3	Lacchiarella Segrate	55376	31602	
4	Verona	37135	15114	
5	Padova	42993	13582	8318
6	Bologna	34836	6978	
7	Parma	23507	6530	2471
8	Livorno Guasticce	22429	3660	4016
9	Nola Marcianise	61548	2890	4409
10	Novara	12389		
11	Bergamo			
12	Cervignano	15349	2686	6654
13	Ravenna	21615		3997
14	Prato	30204	3734	
15	Jesi	34015	2448	500
16	Orte	60691	7212	
17	Civitavecchia	11348		2873
21	Termoli	19376		136
22	Tito/Area Lucana	8709		
23	Bari	20590		10469
24	Area Ionico Salentina	8355		1277
25	Area Calabrese	8702		
26	Termini Imerese	4563	108	1490
27	Catania	11826		443
28	Cagliari	311		443

In Table 3 we can see the values of each indicator for the 39 interports analysed.

Table 3 Values of indicators for the 39 interports

Item Code	Interport	Generalised cost reduction	Accessibility	Safety	Freight increasing intern'al O/D
1	Orbassano	XX	XX	XX	XX
2	Rivalta Scrivia	XX	XX	XX	XX
3	Lacchiarella S.	XXX	XXX	XXX	XXX
4	Verona	XX	XX	XX	XXX
5	Padova	XX	XX	XX	XXX
6	Bologna	XX	XX	XX	XX
7	Parma	XX	XX	XX	XX
8	Livorno Guasticce	X	X	X	XX
9	Nola Marcianise	XXX	XXX	XXX	XX
10	Novara	XX	XX	XX	X
11	Bergamo	X	X	X	X
12	Cervignano	X	X	X	X
13	Ravenna	XX	XX	XX	X
14	Prato	XX	XX	XX	XX
15	Jesi	X	X	X	XX
16	Orte	XXX	XXX	XXX	XX
17	Civitavecchia	X	X	X	X
18	Frosinone	X	X	X	X
19	Salerno	X	X	X	X
20	Vairano Caianello	X	X	X	X
21	Termoli	X	X	X	X
22	Tito/Area Lucana	X	X	X	X
23	Bari	XX	XX	XX	X
24	A. Ionico Salentina	X	X	X	X
25	Area Calabrese	X	X	X	X
26	Termini Imerese	XX	XX	XX	X
27	Catania	XXX	XXX	XXX	X
28	Cagliari	X	X	X	X
29	Como	X	X	X	X
30	Varees	X	X	X	X
31	Cremona	X	X	X	X
32	Trento	X	X	X	X
33	Vicenza	X	X	X	X
34	Portogruaro	X	X	X	X
35	Rovigo	X	X	X	X
36	Vittorio Veneto	X	X	X	X
37	Savona-Vado L.	X	X	X	X
38	Arezzo	X	X	X	X
39	Pescara	X	X	X	X

Note:
Value of the indicator: X high, XX medium, XXX low.

The different strategies that could be pursued by the realisation of these new structures were expressed by the relative weights assigned to the objectives. For example, if increased safety is the priority strategy to be pursued, the weight assigned to the objective "safety" would be greater—double in the case under consideration—than the weight assigned to all the other objectives, as shown in Table 4.

Lastly, Figure 4 provides a brief summary of the classification obtained for the structures (interports) under consideration in relation to each of the pursued strategies.

Analysis of sensitivity to the variations in relative weights confirmed the stability of obtained classifications.

Table 4 **Weights assigned to objectives (in %), in relation to the various feasible strategies**

Objectives	Strategies			
	A	B	C	D
Generalised cost reduction	40	20	20	20
Increased accessibility	20	40	20	20
Increased safety	20	20	40	20
Growth of international intermodal transport	20	20	20	40
Total	100	100	100	100

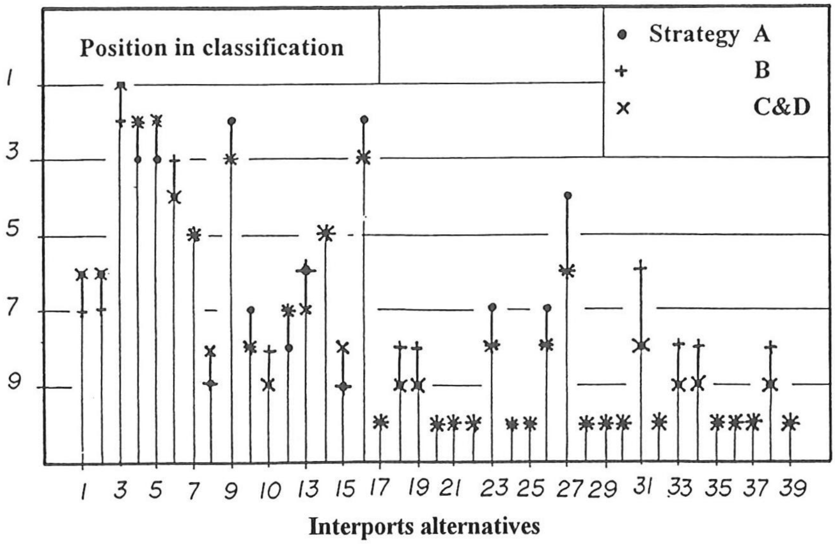

Figure 4 **Classification obtained with use of multi-criteria analysis for different feasible strategies**

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