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A REAL CASE STUDY ON TRANSPORTATION SCENARIO COMPARISON

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Abstract: This paper presents a real case study dealing with the comparison of transport scenarios. The study is conducted within a larger project concerning the establishment of the maritime traffic policy in Greece. The paper presents the problem situation and an appropriate problem formulation. Moreover a detailed version of the evaluation model is presented in the paper. The model consists of a complex hierarchy of evaluation models enabling us to take into account the multiple dimensions and points of view of the actors involved in the evaluations.

Keywords:

1. INTRODUCTION

Strategic planning of transportation facilities is an increasingly important issue in market oriented economies. The paper describes a real case study dealing with the evaluation of transportation scenario in the context of the deregulation of the maritime traffic in Greece (after the European Union guidelines).

Comparing and evaluating policies is not simple. The interested reader might see Stathopoulos, 1997 and Faivre d'Arcier, 1998. Apart from the usual uncertainty issues it should be noted that a scenario results from the composition of a large number of actions (see Pomerol, 2000). Even if each such action can be evaluated separately, there might be a combinational explosion in trying to evaluate the different scenarios. On the other hand, a comparison should be able to highlight the key differences among the different scenarios. Furthermore, it should be able to take into account the different points of view and the different dimensions under which the policy makers consider such scenarios. In the particular case of transportation scenarios, on the one hand there exist large groups of actors concerned with transportation policies which cannot be neglected, and on the other hand, each point of view is usually in by itself a complex evaluation model. Actually the case studied in this paper results in a hierarchy of evaluation models that compose the comprehensive evaluation model.

The research has been conducted within a large project aiming at building a decision support system for the analysis and evaluation of the maritime transportation policy in Greece. In this paper we do not discuss how the scenarios are composed (since they are defined by the policy maker or the user of the decision support system). We also consider that the suggested evaluation dimensions are "effective" in the sense that there exists the necessary information for all of them.

The paper is organised as follows. In Section 2 we describe the problem situation and the potential users of the model. In Section 3 we introduce the problem formulation as it has been conceived after a number of discussions with the potential users. Section 4 contains an extensive description of the evaluation model. Such a model is constructed in a hierarchy, each node of which is analysed in Section 4. The conclusive section discusses the model and indicates the next steps of the research.

2. PROBLEM SITUATION

The maritime network in the Aegean sea represents a big challenge for the policy makers of the Greek government and the administration. The "deregulation" foreseen for the year 2002 will introduce a further turbulence in an already critical situation. The model introduced is a part of a larger project aiming at aiding the Greek policy makers of the sector and the relevant actors to better understand the consequences of their actions on such a network. More specifically, it should help in evaluating specific actions alterating the configuration of the network. Who is the potential user of the comparison module? A highly ranked administrative and/or political officer. The model (as well as the whole project) is expected to be used both in "everyday" policy establishment and in strategic planning. We consider that such a potential user will use the comparison module for three main purposes:

- to justify (whenever possible) a number of administrative actions and political statements;
- to explain (at least partially) the behavious of the relevant actors operating in the network;
- to argue (for or against) a number of actions of other relevant actors operating on the network.

2.1. Methodological Considerations

A scenario comparison module in a Decision Support System should represent the preferences of an end-user (normally the client; see Landry et al., 1985, Vincke, 1992). The specific setting of this system did not define such an end-user, for which reason a number of hypotheses substitute the client's preferences in the problem formulation and the evaluation model.

In other terms, we assumed a prescriptive point of view considering a generic end-user with a rational model of the management of the maritime network (see Bell et al., 1988). Such a prescriptive approach is materialised through a number of "arbitrary" hypotheses, namely:

- in the definition of the reasons under which a given network configuration X can be considered better, or at least as good as, a network configuration Y for each leave of the hierarchy of criteria (hereafter X and Y will always represent network configurations; we will always omit to specify that, unless necessary);
- in the definition of the coalitions of criteria enabling to establish whether X is at least as good as Y in the parent nodes of the hierarchy (hereafter denoted as "winning coalitions").

Nevertheless, the end-user should be allowed to modify the parameters adopted in such a prescriptive approach in order to implement his(her) own policy. Under such a perspective we consider that in the implementation of the final version of the system it should be possible to:

- allow a technical end-user to modify the technical evaluations and comparison procedures at the leaves of the hierarchy;
- allow a political end-user to modify the definition of winning coalitions in any parent node of the hierarchy.

3. POBLEM FORMULATION

Consider the maritime transportation network of the Aegean Sea (hereafter called the network) as configured at a given moment. Consider a set of actions that could be undertaken on such a network by modifying either the supply conditions, or the demand or both. For each such modification a new configuration of the network can be considered as a result of the "simulation module" of the project.

1. The set of alternatives to be considered in the evaluation module is represented by such different configurations of the network.
2. The set of points of view to consider represents the points of view of the relevant actors operating on the network as strategically conceived by the potential user of the module. Such points of view are expected to be structured in n hierarchy of criteria.
3. The problem statement is a relative comparison of such configurations under a ranking purpose. However, it should be noticed that due to the low number of alternatives which are effectively considered at the same

time it could be expected that the main purpose of the comparison module will be the comparison itself rather than the ranking.

4. EVALUATION MODEL

In the following we will focus on the construction of the set of criteria. The set of alternatives corresponds to a number of potential configurations of the network following specific scenarios of actions.

4.1. Top-down analysis of the criteria set

At the first general level we consider three criteria corresponding to three types or groups of actors, the opinion of which is a concern of the user.

1. Quality of the Supply. The criterion should represent the preference of a generic individual (un-distinguishable) user of the network. The idea is that such a user will prefer any network configuration which provides faster, safer and reliable connections.
2. Network Efficiency. Under such a criterion we evaluate whether network A is at least as good as network B as far as the two main actors of the network are concerned: the ship owners and the government, under an "economic" point of view.
3. Demand Satisfaction. Such a criterion should consider the satisfaction of the three groups of users of the network: tourists, residents and carriers. We consider here the satisfaction of social groups and not of single users.

Criterion 1 is further decomposed in five criteria evaluating the quality of the supply:

1.1: frequency;

1.2: availability of direct connections;

1.3: perceived cost;

1.4: ship quality;

1.5: port quality.

In order to evaluate Frequency, three criteria will be considered:

1.1.1: week availability;

1.1.2: week distribution;

1.1.3: daily distribution.

Criterion 2 is further decomposed in two criteria:

2.1: efficiency of the private sector;

2.2: efficiency of the public sector.

In both cases we analyse lines exploitation and port exploitation:

2.1.1: efficiency of private lines;

2.1.2: efficiency of private ports (if any);

2.2.1: efficiency of public subsidised lines (if any);

2.2.2: efficiency of port administration.

Three types of ports are considered: national, regional and local ones. We therefore have:

2.1.2.1: efficiency of national private ports (if any);

2.1.2.2: efficiency of regional private ports (if any);

2.1.2.3: efficiency of local private ports (if any);

2.2.2.1: efficiency of national port administration.

2.2.2.2: efficiency of regional port administration.

2.2.2.3: efficiency of local port administration.

Criterion 3 is further decomposed into three criteria representative of the three groups the satisfaction of which has to be considered:

3.1: residents (R) – demand;

3.2: tourists (T) – demand;

3.3: carriers (C) – demand.

For each group we consider two criteria: one concerning the quantitative satisfaction of the demand, the second concerning the qualitative level of satisfaction (how many "important" connections are satisfied), obtaining:

3.1.1: Quantitative (R) – demand;

3.1.2: Qualitative (R) – demand;

3.2.1: Quantitative (T) – demand;

3.2.2: Qualitative (T) – demand;

3.3.1: Quantitative (C) – demand;

3.3.2: Qualitative (C) – demand.

The final hierarchy is shown in Fig. 1.

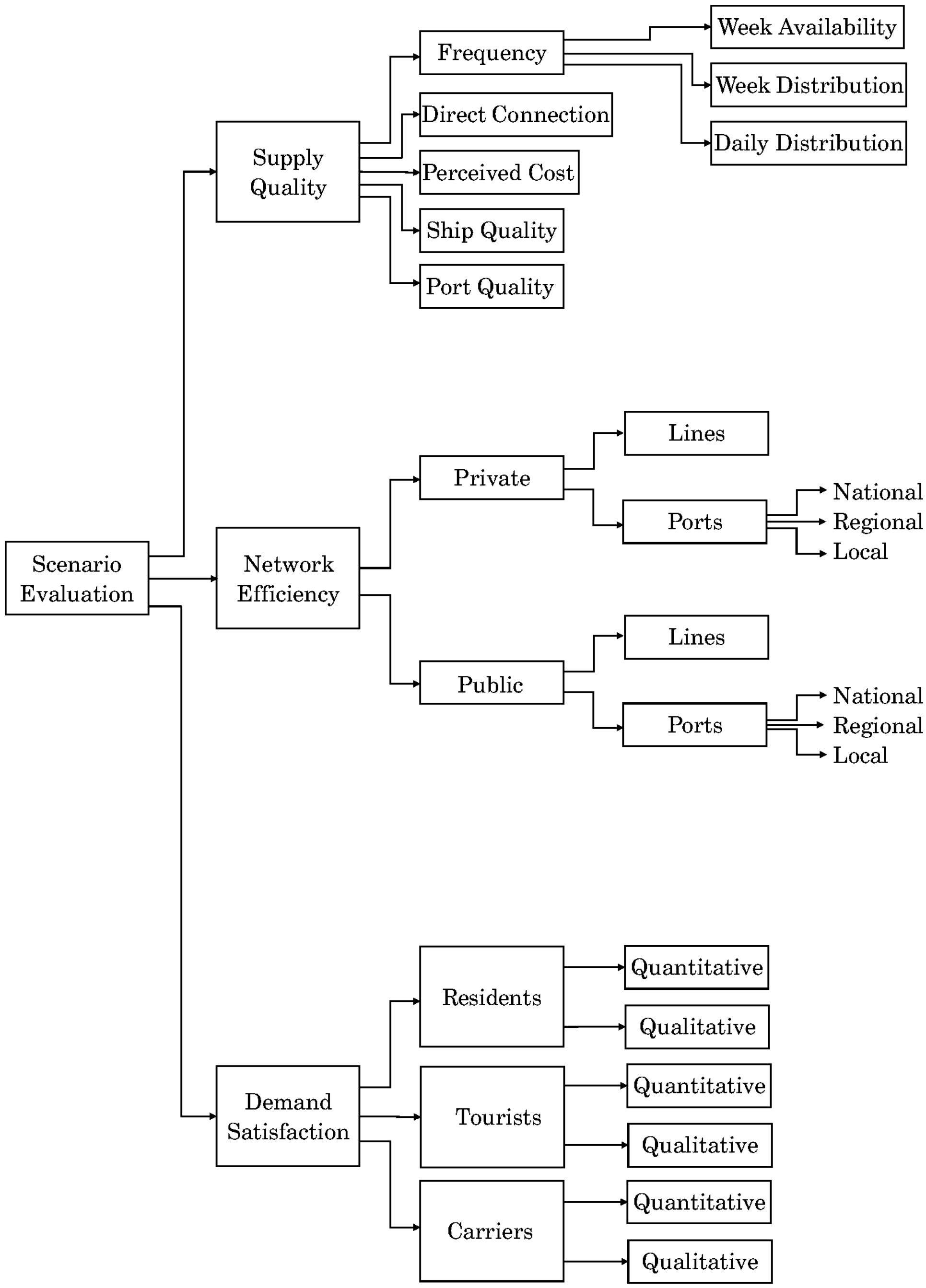

Figure 1: The hierarchy of criteria

4.2. Bottom-up analysis of the evaluation model

1.1.1. Consider the network as $n \times n$ matrix (n being the ports considered in the network). We consider the matrix N_0 where element x_{ij}^0 denotes the number of direct connections available weekly between nodes i and j of the network. In the same way we consider matrix N_1 (x_{ij}^1 being the number of connections available weekly between nodes i and j of the network using one intermediate connecting port) and matrix N_2 (x_{ij}^2 being the number of connections available weekly between nodes i and j of the network using two intermediate connecting ports). We denote by $N_t = N_0 + N_1 + N_2$ the matrix whose generic element x_{ij}^t denotes the number of connections available weekly between nodes i and j of the network using two intermediate connecting ports at most.

We consider only the upper (or lower) triangular part of N_t under the hypothesis that the number of connections between i and j is usually symmetric. If it is not the case, we take the minimum between the two numbers. We denote the cardinal of the upper triangular part of matrix N_t as $|N_t|$. From matrix N_t we are able to compute a diagram of frequencies as follows:

- n_t^1 : number of couples in N_t having less than 5 connections weekly;
- n_t^2 : number of couples in N_t having less than 10 and more than 5 connections weekly;
- n_t^3 : number of couples in N_t having less than 30 and more than 10 connections weekly;
- n_t^4 : number of couples in N_t having less than 50 and more than 30 connections weekly;
- n_t^5 : number of couples in N_t having less than 100 and more than 50 connections weekly;
- n_t^6 : number of couples in N_t having more than 100 connections weekly;

Consider two alternatives X and Y . Then X is better than Y $(X \succ Y)$ iff:

$$\frac{n_t^1(X)}{|N_t|} < \frac{n_t^1(Y)}{|N_t|} \quad \textbf{OR}$$

$$\frac{n_t^1(X)}{|N_t|} = \frac{n_t^1(Y)}{|N_t|} \;\; \textbf{and} \;\; \frac{n_t^2(X)}{|N_t|} < \frac{n_t^2(Y)}{|N_t|} \quad \textbf{OR}$$

$$\frac{n_t^1(X)}{|N_t|} = \frac{n_t^1(Y)}{|N_t|} \;\; \textbf{and} \;\; \frac{n_t^2(X)}{|N_t|} = \frac{n_t^2(Y)}{|N_t|} \;\; \textbf{and} \;\; \frac{n_t^3(X)}{|N_t|} < \frac{n_t^3(Y)}{|N_t|} \quad \textbf{OR}$$

...etc...

NB. This is a lexicographic comparison of the diagrams associated with X and Y (to be compared with Dubois and Prade, 1983). The reader should note that, due to the fact that $\frac{n_t^1(X)}{|N_t|}+\cdots+\frac{n_t^6(X)}{|N_t|}=1$, if $\frac{n_t^i(X)}{|N_t|}<\frac{n_t^2(Y)}{|N_t|}$, then there exists a $j>i$ for which $\frac{n_t^j(X)}{|N_t|}>\frac{n_t^j(Y)}{|N_t|}$. Further on, if $\forall i<6$ $\frac{n_t^i(X)}{|N_t|}=\frac{n_t^i(Y)}{|N_t|}$, then also $\frac{n_t^6(X)}{|N_t|}<\frac{n_t^6(Y)}{|N_t|}$. Therefore the comparison procedure guarantees that X will be considered better than Y if effectively the supply of X is better than the one in Y.

1.1.2. Consider again matrix N_t. Such a matrix can be viewed as the sum of $N_{1t}+N_{2t}+\cdots+N_{7t}$ where N_{1t} denotes matrix N_t for day 1 (Monday),..., N_{7t} denoting matrix N_t for day 7 (Sunday). N_{lt} will denote matrix N_t for the generic day l between nodes i and j of the network which uses two intermediate connecting ports at most. We are now able to compute a new matrix M_t where the generic element

$$y_{ij}^t=\frac{\max_l(x_{ij}^{lt})-\min_l(x_{ij}^{lt})}{\max_l(x_{ij}^{lt})}$$

$y_{ij}^t=1$ is the worst case since it denotes the existence of a situation where there are days with a maximum of supply and days with no supply at all.

$y_{ij}^t=0$ is the best case since it denotes the existence of a situation where the supply is the same each day.

From matrix M_t we are able to compute a diagram of frequencies as follows:

- m_t^1 : number of couples in M_t such that $y_{ij}^t \le 0.2$;
- m_t^2 : number of couples in M_t such that $0.2<y_{ij}^t \le 0.4$;
- m_t^3 : number of couples in M_t such that $0.4<y_{ij}^t \le 0.6$;
- m_t^4 : number of couples in M_t such that $0.6<y_{ij}^t \le 0.8$;
- m_t^5 : number of couples in M_t such that $0.8<y_{ij}^t \le 1$.

Consider two alternatives X and Y. Then X is better than Y ($X \succ Y$) iff:

$$\frac{m_t^1(X)}{|M_t|}>\frac{m_t^1(Y)}{|M_t|} \quad \textbf{OR}$$

$$\frac{m_t^1(X)}{|M_t|}=\frac{m_t^1(Y)}{|M_t|} \textbf{ and } \frac{m_t^2(X)}{|M_t|}>\frac{m_t^2(Y)}{|M_t|} \textbf{ OR}$$

$$\frac{m_t^1(X)}{|M_t|}=\frac{m_t^1(Y)}{|M_t|} \textbf{ and } \frac{m_t^2(X)}{|M_t|}=\frac{m_t^2(Y)}{|M_t|} \textbf{ and } \frac{m_t^3(X)}{|M_t|}>\frac{m_t^3(Y)}{|M_t|} \textbf{ OR}$$

...etc...

NB. The same reasoning concerning the properties of the lexicographic comparison also applies here.

1.1.3. Consider matrix N_{3t}, the choice of day 3 (Wednesday) being arbitrary. We take $N_{3t} = N_{3t1} + \cdots + N_{3t4}$ where N_{3th} corresponds to a specific slot of the day (the slots being: 1, 0.00-6.00 am.; 2, 6.00-12.00 am.; 3, 12.00-6.00 pm.; 4, 6.00-12.00 pm.). Element x_{ij}^{ht} will denote the number of connections available in day 3 during the slot h between nodes i and j of the network, using at most two intermediate connecting ports. We are now able to compute a new matrix D_t where the generic element

$$z_{ij}^t = \frac{\max_l(x_{ij}^{ht}) - \min_l(x_{ij}^{ht})}{\max_l(x_{ij}^{ht})}$$

$z_{ij}^t = 1$ is the worst case since it denotes the existence of a situation where there are slots with a maximum of supply and slots with no supply at all.

$z_{ij}^t = 0$ is the best case since it denotes the existence of a situation where the supply is the same all slots.

From matrix K_t we are able to compute a diagram of frequencies as follows:

- k_t^1 : number of couples in K_t such that $z_{ij}^t \leq 0.2$;
- k_t^2 : number of couples in K_t such that $0.2 < z_{ij}^t \leq 0.4$;
- k_t^3 : number of couples in K_t such that $0.4 < z_{ij}^t \leq 0.6$;
- k_t^4 : number of couples in K_t such that $0.6 < z_{ij}^t \leq 0.8$;
- k_t^5 : number of couples in K_t such that $0.8 < z_{ij}^t \leq 1$.

Consider two alternatives X and Y. Then X is better than Y $(X \succ Y)$ iff:

$$\frac{k_t^1(X)}{|K_t|} > \frac{k_t^1(Y)}{|K_t|} \textbf{ OR}$$

$$\frac{k_t^1(X)}{|K_t|} = \frac{k_t^1(Y)}{|K_t|} \textbf{ and } \frac{k_t^2(X)}{|K_t|} > \frac{k_t^2(Y)}{|K_t|} \textbf{ OR}$$

$$\frac{k_t^1(X)}{|K_t|} = \frac{k_t^1(Y)}{|K_t|} \textbf{ and } \frac{k_t^2(X)}{|K_t|} = \frac{k_t^2(Y)}{|K_t|} \textbf{ and } \frac{k_t^3(X)}{|K_t|} > \frac{k_t^3(Y)}{|K_t|} \textbf{ OR}$$

...etc...

NB. The same reasoning concerning the properties of the lexicographic comparison also applies here.

1.1. Consider two network configurations X and Y. Then X is at least as good as Y under criterion 1.1 ($X \succeq_{1.1} Y$) iff:

- $\forall j, X \succ_{1.1.j} Y$ **OR**
- $X \succeq_{1.1.1} Y$ and $X \succeq_{1.1.2} Y$.

In other words, for X to be at least as good as Y as far as the frequency criterion is concerned, both criteria have to be fulfilled 1.1.1 (week availability) and 1.1.2 (week distribution).

1.2. Consider again matrix N_0. In such a matrix we consider only direct connections. From such a matrix we are able to compute a diagram of frequencies as follows:

- d_t^1 : number of couples in N_0 having less than 5 connections weekly;
- d_t^2 : number of couples in N_0 having less than 10 and more than 5 connections weekly;
- d_t^3 : number of couples in N_0 having less than 30 and more than 10 connections weekly;
- d_t^4 : number of couples in N_0 having less than 50 and more than 30 connections weekly;
- d_t^5 : number of couples in N_0 having less than 100 and more than 50 connections weekly;
- d_t^6 : number of couples in N_0 having more than 100 connections weekly;

Consider two alternatives X and Y. Then X is better than Y ($X \succ Y$) iff:

$$\frac{d_t^1(X)}{|N_0|} < \frac{d_t^1(Y)}{|N_0|} \textbf{ OR}$$

$$\frac{d_t^1(X)}{|N_0|} = \frac{d_t^1(Y)}{|N_0|} \text{ and } \frac{d_t^2(X)}{|N_0|} < \frac{d_t^2(Y)}{|N_0|} \text{ OR}$$

$$\frac{d_t^1(X)}{|N_0|} = \frac{d_t^1(Y)}{|N_0|} \text{ and } \frac{d_t^2(X)}{|N_0|} = \frac{d_t^2(Y)}{|N_0|} \text{ and } \frac{d_t^3(X)}{|N_0|} < \frac{d_t^3(Y)}{|N_0|} \text{ OR}$$

...etc...

NB. The same reasoning concerning the properties of the lexicographic comparison also applies here.

1.3. Consider matrix N_t. For each couple of nodes i, j with a non zero entry in the matrix we compute a generalised cost as follows:

$$c_{ij} = v_t \left(\sum_{x \in i\mathcal{P}j} t_x + \sum_{y \in i\mathcal{N}j} t_y + \sum t_P \right) + \sum_{x \in i\mathcal{P}j} p_x$$

where:

- t_x : is the travelling time for arc x ;
- t_y : is the connecting time for node y ;
- t_P : is a penalty time for each connection;
- p_x : is the price (economy fare) for travelling through arc x ;
- $i\mathcal{P}j$: is the path (set of arcs) connecting node i to node j ;
- $i\mathcal{N}j$: is the path (set of nodes) connecting node i to node j ;
- v_t is the value of time.

We are now able to define a matrix P_t containing the generalised costs for all couples of nodes. From matrix P_t we are able to compute a diagram of frequencies as follows:

- p_t^1 : number of couples in P_t such that $c_{ij} \leq 1000$;
- p_t^2 : number of couples in P_t such that $1000 < c_{ij} \leq 5000$;
- p_t^3 : number of couples in P_t such that $5000 < c_{ij} \leq 10000$;
- p_t^4 : number of couples in P_t such that $10000 < c_{ij} \leq 20000$;
- p_t^5 : number of couples in P_t such that $20000 < c_{ij}$.

Consider two alternatives X and Y . Then X is better than Y $(X \succ Y)$ iff:

$$\frac{p_t^5(X)}{|P_t|} < \frac{p_t^5(Y)}{|P_t|} \text{ OR}$$

$$\frac{p_t^5(X)}{|P_t|} = \frac{p_t^5(Y)}{|P_t|} \text{ and } \frac{p_t^4(X)}{|P_t|} < \frac{p_t^4(Y)}{|P_t|} \text{ OR}$$

$$\frac{p_t^5(X)}{|P_t|} = \frac{p_t^5(Y)}{|P_t|} \text{ and } \frac{p_t^4(X)}{|P_t|} = \frac{p_t^4(Y)}{|P_t|} \text{ and } \frac{p_t^3(X)}{|P_t|} < \frac{p_t^3(Y)}{|P_t|} \text{ OR}$$

...etc...

NB. The same reasoning concerning the properties of the lexicographic comparison also applies here.

1.4. For this criterion the basic information concerns the knowledge on the operating fleet. Set V the set of all vessels operating on the network. We consider a frequency diagram as follows:

- v^1 : number of vessels less than 5 years old;
- v^2 : number of vessels less than 10 years and more than 5 old;
- v^3 : number of vessels less than 15 years and more than 10 old;
- v^4 : number of vessels less than 20 years and more than 15 old;
- v^5 : number of vessels less than 25 years and more than 20 old;
- v^6 : number of vessels more than 25 years old.

Consider two alternatives X and Y. Then X is better than Y $(X \succ Y)$ iff:

$$\frac{v^6(X)}{|V|} < \frac{v^6(Y)}{|V|} \text{ OR}$$

$$\frac{v^6(X)}{|V|} = \frac{v^6(Y)}{|V|} \text{ and } \frac{v^5(X)}{|V|} < \frac{v^5(Y)}{|V|} \text{ OR}$$

$$\frac{v^6(X)}{|V|} = \frac{v^6(Y)}{|V|} \text{ and } \frac{v^5(X)}{|V|} = \frac{v^5(Y)}{|V|} \text{ and } \frac{v^4(X)}{|V|} < \frac{v^4(Y)}{|V|} \text{ OR}$$

...etc...

NB. The same reasoning concerning the properties of the lexicographic comparison also applies here. The reader should also notice that we avoid to compute an average age of the fleet. The reason for this choice is that the image of the fleet and the safety of travelling are always perceived by the users on the basis of the worst possible case. In order to be coherent with the sense of this criterion (how a generic user perceives the supply), we decided to adopt the above approach.

- In order to consider the port quality we take into account three dimensions:
  - capacity of the port;

– existence of passengers facilities;
– accessibility of the port (parking lots, roads, etc.)

The necessary information comes out from a survey conducted within the larger project, a part of which this research report is. From the available information we are able to give the following values for the capacity dimension:

– large (L: more than 3 vessels simultaneously);
– average (A: 2 vessels simultaneously);
– small (S: only one vessel possible).

The facilities are evaluated on a binary basis: they exist (Y) or not (N). Accessibility is evaluated on three values: good (G), average (A), bad (B). The four classes of port quality are defined as follows:

– Good: $G = \{(L,Y,G),(A,Y,G)\}$;
– Fair: $F = \{(A,Y,A),(L,Y,A),(S,Y,A),(S,Y,G)\}$;
– Acceptable: $A = \{(L,Y,B),(A,Y,B),(L,N,G),(A,N,G),(L,N,A),(A,N,A),(S,Y,B),(S,N,G)\}$;
– Bad: $B = \{(S,N,B),(L,N,B),(A,N,B),(S,N,A)\}$.

Then considering set (complete or sample) of ports (P) we can again define a diagram of frequency:

– p_G : number of ports of good quality;
– p_F : number of ports of fair quality;
– p_A : number of ports of acceptable quality;
– p_B : number of ports of bad quality.

Consider two alternatives X and Y. Then X is better than Y $(X \succ Y)$ iff:

$$\frac{p_G(X)}{|P|} > \frac{p_G(Y)}{|P|} \textbf{ OR}$$

$$\frac{p_G(X)}{|P|} = \frac{p_G(Y)}{|P|} \textbf{ and } \frac{p_F(X)}{|P|} > \frac{p_F(Y)}{|P|} \textbf{ OR}$$

$$\frac{p_G(X)}{|P|} = \frac{p_G(Y)}{|P|} \textbf{ and } \frac{p_F(X)}{|P|} = \frac{p_F(Y)}{|P|} \textbf{ and } \frac{p_A(X)}{|P|} > \frac{p_A(Y)}{|P|} \textbf{ OR}$$

...etc...

1. Given two network configurations X and Y we have to establish whether X is at least as good as Y when all the five criteria defining the supply quality are considered. Our suggestion is that the "winning coalitions" enabling to establish the above statement are:

- the unanimity set (all five criteria agree that X is at least as good as Y);
- any coalition of four criteria (all criteria, but one, agree that X is at least as good as Y);
- any coalition including criteria 1.3, 1.4 and one among the other ones.

Further on, no veto should be expressed against X. Such a veto may occur in the following situations (considering a set of alternative network configurations $\mathcal{F} = \{X, Y, Z, ...\}$):

- X cannot be at least as good as Y if X is the worst on criterion 1.1 and Y is the best;
- X cannot be at least as good as Y if X is the worst on criterion 1.4 and Y is the best;

In order to compute a ranking of set $\mathcal{F}$ associated with criterion 1, denote $S_1(X,Y)$ the binary relation "X is at least as good as Y" on criterion 1 on set $\mathcal{F}$ and then compute a score:

$$\sigma(X) = |\{Y \in \mathcal{F} : S_1(X,Y)\}| - |\{Y \in \mathcal{F} : S_1(Y,X)\}|$$

and rank the alternatives by decreasing values of such score.

2.1.1. For this criterion we consider a set of (15) "lines" established by maritime administration authority. By "line" a subset of connections on part of the network (usually corresponding to a precise geographical area) is intended. For each line we know the company (vessel owner) and the vessels which it operates with. From the economic analysis of the existing network we are able to compute:

- c_{ijl} : cost of vessel l, of company j, in line i;
- r_{ijl} : income of vessel l, of company j, on line i.

We are therefore able to compute a cost c_{ij} and income r_{ij} for each line i and company j through the formula:

$$c_{ij} = \sum_l c_{ijl} \qquad r_{ij} = \sum_l r_{ijl}$$

We define as efficiency of company j on line i the index

$$k_{ij} = \max\left(0, 1 - \frac{c_{ij}}{r_{ij}}\right)$$

In presence of a profitable exploitation of line i by company j the ratio $\frac{c_{ij}}{r_{ij}}$ tends to become the lowest possible. In order to invert the index we consider the complement of the ratio. In case of a loss the index could become negative, the reason for which it is bounded to 0.

We are now able to compute an efficiency index for line i as $e_i = \max_j(k_{ij})$. In other words, the efficiency of line i is the best possible among the competing companies on the same line.

For a given network configuration X we are able to compute an efficiency index $E(X)$ as follows:

$$E(X) = 1 - \prod_i (1 - e_i(X))$$

Such a dual geometric means among the lines tends to improve faster as the efficiency index of each single line improves. When we consider different network configurations with marginal improvements on some lines the index will be able to positively discriminate them.

2.1.2.1. For each national level port privately administrated we can compute as efficiency index:

$$\forall i \in N^P, \quad p_i = \max\left(0, 1 - \frac{c_i}{r_i}\right)$$

where:

- N^P : is the set of national level ports privately administrated;
- c_i : is the administration cost of port i ;
- r_i : is the income of port i .

We can therefore compute the index $p_{N^P} = 1 - \prod_i (1 - p_i)$. If there are no national level ports privately administrated, we consider $p_{N^P} = 1$.

2.1.2.2. For each regional level port privately administrated we can compute an efficiency index:

$$\forall i \in R^P, \quad p_i = \max\left(0, 1 - \frac{c_i}{r_i}\right)$$

where:

- R^P : is the set of regional level ports privately administrated;
- c_i : is the administration cost of port i ;
- r_i : is the income of port i .

We can therefore compute the index $p_{R^P} = 1 - \prod_i (1 - p_i)$. If there are no national level ports privately administrated, we consider $p_{R^P} = 1$.

2.1.2.3. For each local level port privately administrated we can compute an efficiency index:

$$\forall i \in L^P, \quad p_i = \max\left(0, 1 - \frac{c_i}{r_i}\right)$$

where:

- L^P : is the set of local level ports privately administrated;
- c_i : is the administration cost of port i ;
- r_i : is the income of port i .

We can therefore compute the index $p_{L^P} = 1 - \prod_i (1 - p_i)$. If there are no national level ports privately administrated, we consider $p_{L^P} = 1$.

2.1.2. For a given network configuration X we can now compute an efficiency index for the private port administration as:

$$p_P(X) = 1 - [(1 - p_{N^P}(X))(1 - p_{R^P}(X))(1 - p_{L^P}(X))] .$$

2.1. For a given network configuration we can now compute an efficiency index for the private management as:

$$P(X) = E(X) p_P(X)$$

The higher such an index, the better the network configuration is.

2.2.1. For any network configuration there might exist specific lines that the public administration might subsidise (or administrate directly) in order to maintain a public service available although not profitable. For each such line $i \in S$ (S being the set of subsidised lines) we consider the cost c_i and the support s_i provided by the public administration. For each such line we can compute an efficiency index

$$\forall i \in S, \quad l_i = 1 - \frac{s_i}{c_i}$$

such that $l_i = 0$ corresponds to lines totally subsidised. For a given network configuration X we can compute an efficiency index of the public subsidising as

$$l(X) = 1 - \prod_{i \in S} (1 - l_i(X))$$

2.2.2.1. For each national level port administrated by the public sector we can compute an efficiency index:

$$\forall i \in N^B, \quad p_i = \max\left(0, 1 - \frac{c_i}{r_i}\right)$$

where:

- N^B : is the set of national level ports administrated by the public sector;
- c_i : is the administration cost of port i ;
- r_i : is the income of port i .

We can therefore compute the index $p_{N^B} = 1 - \prod_i (1 - p_i)$.

2.2.2.2. For each regional level port administrated by the public sector we can compute an efficiency index:

$$\forall i \in R^B, \quad p_i = \max\left(0, 1 - \frac{c_i}{r_i}\right)$$

where:

- R^B : is the set of regional level ports administrated by the public sector;
- c_i : is the administration cost of port i ;
- r_i : is the income of port i .

We can therefore compute the index $p_{R^B} = 1 - \prod_i (1 - p_i)$.

2.2.2.3. For each local level port administrated by the public sector we can compute an efficiency index:

$$\forall i \in L^B, \quad p_i = \max\left(0, 1 - \frac{c_i}{r_i}\right)$$

where:

- L^B : is the set of local level ports administrated by the public sector;
- c_i : is the administration cost of port i ;
- r_i : is the income of port i .

We can therefore compute the index $p_{L^B} = 1 - \prod_i (1 - p_i)$.

2.2.2. For a given network configuration X we can now compute an efficiency index for the ports administrated by the public sector as:

$$p_B(X) = 1 - [(1 - p_{N^B}(X))(1 - p_{R^B}(X))(1 - p_{L^B}(X))]$$

2.2. For a given network configuration X we can now compute an efficiency index for the public sector management as:

$$B(X) = l(X) p_B(X)$$

The highest such an index, the better the network configuration.

2. Given two network configurations X and Y, we consider that X is at least as good as Y under the network efficiency criterion iff it is the case for both the private and the public sectors.

Denote by $S_2(X,Y)$ the binary relation "X is at least as good as Y on criterion 2", we have:

$$S_2(X,Y) \textbf{ iff } P(X) \geq P(Y) \textbf{ and } B(X) \geq B(Y)$$

NB. Instead of the unanimity role adopted here it is possible to privilege one of the two efficiency indices (the private or the public one) choosing one of the two as the criterion enabling the relation S_2 and endowing the other one with a veto power in case the relevant efficiency index is below a given treshold.

The same ranking procedure used for criterion 1 is used also for criterion 2 in order to define a ranking on a given set ($\mathcal{F}$) of alternative network configurations.

3.1.1. Consider matrix N_0 (number of links with 0 connections for each couple of nodes of the network). We are able to associate a capacity $\pi_{ij}^{0R} = \sum_l \pi_{ijl}^{0R}$ to each non zero entry of the matrix, where π_{ijl}^{0R} stands for the capacity of vessel l operating on the link $i-j$ (during the winter period, considered as the standard offer for the residents (R) of the nodes of the network).

Consider now matrix N_{01} (number of links with at most one connection). Clearly, to each non zero entry of N_{01} we can associate a capacity $\pi_{ij}^{1R} = \min(\pi_{ix}^{0R}, \pi_{xj}^{0R})$ (x being the intermediate node). In the same way, considering matrix N_t (number of links with at most two connections), we associate capacities $\pi_{ij}^{tR} = \min(\pi_{ix}^{0R}, \pi_{xy}^{0R}, \pi_{yj}^{0R})$ (x, y being the intermediate nodes). Finally we can define a matrix C^R of capacities such that $\pi_{ij}^{R} = \max(\pi_{ij}^{0R}, \pi_{ij}^{1R}, \pi_{ij}^{tR})$.

On the other hand, we can (through the transportation model) make an estimation of the demand of transportation of the residents (we denote it as matrix D^R with entries d_{ij}^R). We are now able to build a matrix Θ^R whose entries represent the saturation index of each link:

$$\eta_{ij}^R = \max\left(0, 1 - \frac{d_{ij}^R}{\pi_{ij}^R}\right)$$

Clearly, index η_{ij}^R value 0 occurs when the demand exceeds the capacity.

From matrix Θ^R we are able to compute a diagram of frequencies as follows:

- θ_R^1 : number of couples in Θ^R such that $\eta_{ij}^R \leq 0.2$;
- θ_R^2 : number of couples in Θ^R such that $0.2 < \eta_{ij}^R \leq 0.4$;
- θ_R^3 : number of couples in Θ^R such that $0.4 < \eta_{ij}^R \leq 0.6$;
- θ_R^4 : number of couples in Θ^R such that $0.6 < \eta_{ij}^R \leq 0.8$;
- θ_R^5 : number of couples in Θ^R such that $0.8 < \eta_{ij}^R \leq 1$.

Consider two alternatives X and Y . Then X is better than Y $(X \succ Y)$ iff:

$$\frac{\theta_R^1(X)}{|\Theta^R|} < \frac{\theta_R^1(Y)}{|\Theta^R|} \textbf{ OR}$$

$$\frac{\theta_R^1(X)}{|\Theta^R|} = \frac{\theta_R^1(Y)}{|\Theta^R|} \textbf{ and } \frac{\theta_R^2(X)}{|\Theta^R|} < \frac{\theta_R^2(Y)}{|\Theta^R|} \textbf{ OR}$$

$$\frac{\theta_R^1(X)}{|\Theta^R|} = \frac{\theta_R^1(Y)}{|\Theta^R|} \textbf{ and } \frac{\theta_R^2(X)}{|\Theta^R|} = \frac{\theta_R^2(Y)}{|\Theta^R|} \textbf{ and } \frac{\theta_R^3(X)}{|\Theta^R|} < \frac{\theta_R^3(Y)}{|\Theta^R|} \textbf{ OR}$$

...etc...

NB. The same reasoning concerning the properties of the lexicographic comparison also applies here.

3.1.2. Consider again matrix D^R (the demand matrix) and specifically its reduction Δ^R such that $\forall i,j \ d_{ij}^R > \delta$ (δ being a threshold to be defined).
Then for a given network configuration we can compute an index

$$\rho^R(X) = \frac{|\{ij : d_{ij}^R > \delta \text{ and } \pi_{ij}^{0R} = 0\}|}{|\Delta(X)|}$$

that represents the ratio of "important links" (the ones where $d_{ij}^R > \delta$) that are not satisfied $(\pi_{ij}^{0R} = 0)$. The lowest the index, the better the network configuration.

3.1. Given any two network configurations X and Y we consider that X is at least as good as Y as far as the residents demand satisfaction is concerned $(S_{3.1}(X,Y))$ iff it is the case for criterion 3.1.1 and the index of criterion 3.1.2 is not superior to 0.6. More formally:

$$S_{3.1}(X,Y) \textbf{ iff } S_{3.1.1}(X,Y) \textbf{ and } \rho^R(X) < 0.6$$

3.3.1. Consider matrix N_0 (number of links with 0 connections for each couple of nodes of the network). We are able to associate a capacity $\pi_{ij}^{0T} = \sum_l \pi_{ijl}^{0T}$ to each non zero entry of the matrix, where π_{ijl}^{0T} stands for the capacity of vessel l operating on the link $i-j$ (during the summer period, considered as the standard offer for the tourists (T) of the nodes of the network).

Consider now matrix N_{01} (number of links with at most one connection). Clearly to each non zero entry of N_{01} we can associate a capacity $\pi_{ij}^{1T} = \min(\pi_{ix}^{0T}, \pi_{xj}^{0T})$ (x being the intermediate node). In the same way, considering matrix N_t (number of links with at most two connections), we associate capacities $\pi_{ij}^{tT} = \min(\pi_{ix}^{0T}, \pi_{xy}^{0T}, \pi_{yj}^{0T})$ (x, y being the intermediate nodes). Finally we can define a matrix C^T of capacities such that $\pi_{ij}^{T} = \max(\pi_{ij}^{0T}, \pi_{ij}^{1T}, \pi_{ij}^{tT})$.

On the other hand we can (through the transportation model) make an estimation of the demand of transportation of the tourists (we denote it as matrix D^T with entries d_{ij}^T). We are now able to build a matrix Θ^T whose entries represent the saturation index of each link:

$$\eta_{ij}^T = \max\left(0, 1 - \frac{d_{ij}^T}{\pi_{ij}^T}\right)$$

Clearly index η_{ij}^T value 0 occurs when the demand exceeds the capacity.

From matrix Θ^T we are able to compute a diagram of frequencies as follows:

- θ_T^1: number of couples in Θ^T such that $\eta_{ij}^T \le 0.2$;
- θ_T^2: number of couples in Θ^T such that $0.2 < \eta_{ij}^T \le 0.4$;
- θ_T^3: number of couples in Θ^T such that $0.4 < \eta_{ij}^T \le 0.6$;
- θ_T^4: number of couples in Θ^T such that $0.6 < \eta_{ij}^T \le 0.8$;
- θ_T^5: number of couples in Θ^T such that $0.8 < \eta_{ij}^T \le 1$.

Consider two alternatives X and Y. Then X is better than Y $(X \succ Y)$ iff:

$$\frac{\theta_T^1(X)}{|\Theta^T|} < \frac{\theta_T^1(Y)}{|\Theta^T|} \textbf{ OR}$$

$$\frac{\theta_T^1(X)}{|\Theta^T|} = \frac{\theta_T^1(Y)}{|\Theta^T|} \textbf{ and } \frac{\theta_T^2(X)}{|\Theta^T|} < \frac{\theta_T^2(Y)}{|\Theta^T|} \textbf{ OR}$$

$$\frac{\theta_T^1(X)}{|\Theta^T|} = \frac{\theta_T^1(Y)}{|\Theta^T|} \textbf{ and } \frac{\theta_T^2(X)}{|\Theta^T|} = \frac{\theta_T^2(Y)}{|\Theta^T|} \textbf{ and } \frac{\theta_T^3(X)}{|\Theta^T|} < \frac{\theta_T^3(Y)}{|\Theta^T|} \textbf{ OR}$$

...etc...

NB. The same reasoning concerning the properties of the lexicographic comparison applies here also.

3.2.2. Consider again matrix D^T (the demand matrix) and specifically its reduction Δ^T such that $\forall i, j \; d_{ij}^T > \delta$ (δ being a threshold to be defined).
Then for a given network configuration we can compute an index

$$\rho^T(X) = \frac{|\{ij : d_{ij}^T > \delta \text{ and } \pi_{ij}^{0T} = 0\}|}{|\Delta(X)|}$$

that represents the ratio of "important links" (the ones where $d_{ij}^T > \delta$) that are not satisfied $(\pi_{ij}^{0T} = 0)$. The lowest the index, the better the network configuration.

3.2. Given any two network configurations X and Y we consider that X is at least as good as Y, as far as the tourists demand satisfaction is concerned $(S_{3,2}(X,Y))$ iff it is the case for criterion 3.2.1 and the index of criterion 3.2.2 is not superior to 0.7. More formally:

$$S_{3,2}(X,Y) \textbf{ iff } S_{3,2,1}(X,Y) \textbf{ and } \rho^T(X) < 0.7 .$$

3.3.1. Consider matrix N_0 (number of links with 0 connections for each couple of nodes of the network). We are able to associate a capacity $\pi_{ij}^{0T} = \sum_l \pi_{ijl}^{0T}$ to each non zero entry of the matrix, where π_{ijl}^{0CW} stands for the trucks capacity of vessel l operating on the link $i-j$ (during the winter period).
Consider now matrix N_{01} (number of links with at most one connection). Clearly, to each non zero entry of N_{01} we can associate a capacity $\pi_{ij}^{1CW} = \min(\pi_{ix}^{0CW}, \pi_{xj}^{0CW})$ (x being the intermediate node). In the same way, considering matrix N_t (number of links with at most two connections), we associate capacities $\pi_{ij}^{tCW} = \min(\pi_{ix}^{0CW}, \pi_{xy}^{0CW}, \pi_{yj}^{0CW})$ (x, y being the intermediate nodes). Finally, we can define a matrix C^{CW} of capacities such that $\pi_{ij}^{CW} = \max(\pi_{ij}^{0CW}, \pi_{ij}^{1CW}, \pi_{ij}^{tCW})$.
On the other hand, we can (through the transportation model) make an estimation of the demand of transportation of the carriers (we denote it as matrix D^{CW} with entries d_{ij}^{CW}). We are now able to build a matrix Θ^{CW} whose entries represent the saturation index of each link:

$$\eta_{ij}^{CW} = \max\left(0, 1 - \frac{d_{ij}^{CW}}{\pi_{ij}^{CW}}\right)$$

Clearly, index η_{ij}^{CW} value 0 occurs when the demand exceeds the capacity. In the same way we can compute an index for the summer period as far as the carriers demand is concerned

$$\eta_{ij}^{CS} = \max\left(0, 1 - \frac{d_{ij}^{CS}}{\pi_{ij}^{CS}}\right)$$

and compute an overall index $\eta_{ij}^{C} = \eta_{ij}^{CS}\eta_{ij}^{CW}$ thus defining a new matrix Θ^C.

From matrix Θ^C we are able to compute a diagram of frequencies as follows:

- θ_C^1: number of couples in Θ^C such that $\eta_{ij}^C \le 0.2$;
- θ_C^2: number of couples in Θ^C such that $0.2 < \eta_{ij}^C \le 0.4$;
- θ_C^3: number of couples in Θ^C such that $0.4 < \eta_{ij}^C \le 0.6$;
- θ_C^4: number of couples in Θ^C such that $0.6 < \eta_{ij}^C \le 0.8$;
- θ_C^5: number of couples in Θ^C such that $0.8 < \eta_{ij}^C \le 1$.

Consider two alternatives X and Y. Then X is better than Y $(X \succ Y)$ iff:

$$\frac{\theta_C^1(X)}{|\Theta^C|} < \frac{\theta_C^1(Y)}{|\Theta^C|} \quad \textbf{OR}$$

$$\frac{\theta_C^1(X)}{|\Theta^C|} = \frac{\theta_C^1(Y)}{|\Theta^C|} \quad \textbf{and} \quad \frac{\theta_C^2(X)}{|\Theta^C|} < \frac{\theta_C^2(Y)}{|\Theta^C|} \quad \textbf{OR}$$

$$\frac{\theta_C^1(X)}{|\Theta^C|} = \frac{\theta_C^1(Y)}{|\Theta^C|} \quad \textbf{and} \quad \frac{\theta_C^2(X)}{|\Theta^C|} = \frac{\theta_C^2(Y)}{|\Theta^C|} \quad \textbf{and} \quad \frac{\theta_C^3(X)}{|\Theta^C|} < \frac{\theta_C^3(Y)}{|\Theta^C|} \quad \textbf{OR}$$

...etc...

NB. The same reasoning concerning the properties of the lexicographic comparison applies here also.

3.3.2. Consider again matrix D^{CW} (the demand matrix) and specifically its reduction Δ^{CW} such that $\forall i,j \ d_{ij}^{CW} > \delta$ (δ being a threshold to be defined).
Then for a given network configuration we can compute an index

$$\rho^{CW}(X) = \frac{|\{ij : d_{ij}^{CW} > \delta \text{ and } \pi_{ij}^{0CW} = 0\}|}{|\Delta(X)|}$$

that represents the ratio of "important links" (the ones where $d_{ij}^{CW} > \delta$) that are not satisfied $(\pi_{ij}^{0CW} = 0)$. The lowest the index, the better the network configuration.

In the same way we can compute an index for the summer period

$$\rho^{CS}(X) = \frac{|\{ij : d_{ij}^{CS} > \delta \text{ and } \pi_{ij}^{0CS} = 0\}|}{|\Delta(X)|}$$

enabling to define an overall index $\rho^{C}(X) = \rho^{CS}(X)\rho^{CW}(X)$.

3.3. Given any two network configurations X and Y we consider that X is at least as good as Y as far as the carriers demand satisfaction is concerned $(S_{3.3}(X,Y))$ iff it is the case for criterion 3.3.1 and the index of criterion 3.3.2 is not superior to 0.7. More formally:

$$S_{3.3}(X,Y) \ \textbf{iff} \ S_{3.3.1}(X,Y) \ \textbf{and} \ \rho^{C}(X) < 0.7$$

3. Given any two network configurations X and Y we consider that X is at least as good as Y as far as the demand satisfaction is concerned $(S_3(X,Y))$ iff it is the case for criterion 3.3 and criterion 3.2 and there is no strong opposition from criterion 3.1. More formally:

$$S_3(X,Y) \ \textbf{iff} \ S_{3,3}(X,Y) \ \textbf{and} \ S_{3.2}(X,Y) \ \textbf{and} \ \neg V_{3,1}(X,Y)$$

where the situation of veto on criterion 3.1 may occur either because the index $\rho^{R}(X)$ is very bad, or because the ratio $\frac{\theta_R^1(X)}{|\Theta^R|}$ is very bad.

The same ranking procedure used for criterion 1 is used also in criterion 3 in order to define a ranking on a given set $(\mathcal{F})$ of alternative network configurations.

5. CONCLUSION

In this paper we present a detailed description of an evaluation model aimed at comparing different scenarios of the maritime transportation network in Greece (mainly in the Aegean Sea). The model is part of a larger decision support system to be used in the context of the transportation policy establishment.

The key characteristics of the model can be summarised to the following two points.

1. An explicit reference to the group of actors, the behaviour of which is expected to be considered by the model. From this point of view the model could help to justify and explain priorities that one or more actors could establish or consider.
2. A flexible use of different aggregation procedures along the nodes of the hierarchy of the evaluation criteria. It should be noted that in this version there have been established arbitrary "winning coalitions" in order to aggregate criteria to a higher level. However, such a choice has been made

in order to facilitate the presentation of the model and the implementation of the prototype. For everyday use of the model a procedure aiding the establishment of the "winning coalitions" has to be implemented.

The model has been conceptually and logically validated. The client considered that the model faithfully represented the way in which the scenarios should be evaluated. Furthermore, the coherence for each family of criteria has been tested. The model is now undergoing an extensive experimental validation in order to check its different parameters and to verify its consistency.

Moreover, a number of theoretical problems are under investigation:

- general models for frequency distributions comparison when a preference ordering applies on the related histogram;
- comparison patterns of qualitative distributions.

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