A COMPARISON OF THE APPLICATIONS OF TODIM AND THOR TO AN IMPORTANT ENVIRONMENTAL PROBLEM

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Abstract

This paper presents the application of two discrete multicriteria methods TODIM and THOR to an important environmental problem. In the case study reported in this paper three major water treatment (ballast water) technologies have been evaluated. Those were indeed evaluated separately both by TODIM and THOR according to five major criteria: practicability; biological effectiveness; cost/benefit ratio; time frame within which standards could be implemented; and environmental impact of the process' sub-products. While TODIM has elements both from the American and the French School of MCDA, THOR relies on the treatment of imprecision within the context of French School methods. After structuring the problem in a clear way and consulting different experts, the two separate applications of both TODIM and THOR were performed. The conclusion was that these two methods, although conceptually and analytically quite different, lead to practically the same results.
Key-words: Maritime transportation, Multicriteria decisions, Prospect theory

Resumo

Este artigo apresenta a aplicação de dois métodos discretos de apoio multicritério à decisão, TODIM e THOR, a um importante problema ambiental. No estudo de caso aqui relatado avaliam-se três principais tecnologias para tratamento da água de lastro. Fazem-se as avaliações separadamente segundo os critérios de praticidade, eficácia biológica, quociente beneficio/custo, horizonte de tempo para implantação de padrões necessários e impacto ambiental dos subprodutos de cada processo. Enquanto o método TODIM possui, em sua formulação analítica, tanto elementos da escola norte-americana como da escola francesa, o sistema, THOR calca-se na abordagem da imprecisão por meio das teorias de conjuntos nebulosos ou aproximativos, no contexto dos métodos da escola francesa. Após estruturar-se o problema de avaliação multicritério e de consultar-se diferentes especialistas, efetuam-se as aplicações dos dois métodos. A conclusão essencial é que ambos, embora fundamentados em bases conceituais e analíticas distintas, conduzem a praticamente os mesmos resultados.
Palavras-chave: Transporte marítimo, Decisões multicritério, Teoria dos prospectos

1. Introduction

The introduction of invasive marine species into new environments by ships' ballast water, attached to ships' hulls and via other vectors has been identified as one of the four greatest threats to the world's oceans. The other three are land-based sources of marine pollution,

overexploitation of living marine resources and physical alteration/destruction of marine habitat. Shipping moves over 80% of the world's commodities and transfers approximately 3 to 5 billion tons of ballast water internationally each year. A similar volume may also be transferred domestically within countries and regions each year. Ballast water is absolutely essential to the safe and efficient operation of modern merchant ships, providing balance and stability to unloaded ships. However, it may also pose a serious ecological, economic and health threat.
Here it is worth observing that ballast is any material used to weight and/or balance an object. One example is the sandbags carried on conventional hot-air balloons, which can be discarded to lighten the balloon's load, allowing it to ascend. Ballast water is therefore water carried by ships to ensure stability, trim and structural integrity. Ships have carried solid ballast, in the form of rocks, sand or metal, for thousands of years. In modern times, ships use water as ballast (IMO, 2011a).
It is estimated that at least 7,000 different species are being carried in ships' ballast tanks around the world (Figure 1). The vast majority of marine species carried in ballast water do not survive the journey, as the ballasting and deballasting cycle and the environment inside ballast tanks can be quite hostile to organism survival. Even for those that do survive a voyage and are discharged, the chances of surviving in the new environmental conditions, including predation by and/or competition from native especies, are further reduced. However, when all factors are favorable, an introduced species by survive to establish a reproductive population in the host environment, it may even become invasive, out-competing native species and multiplying into pest proportions (IMO, 2011a).

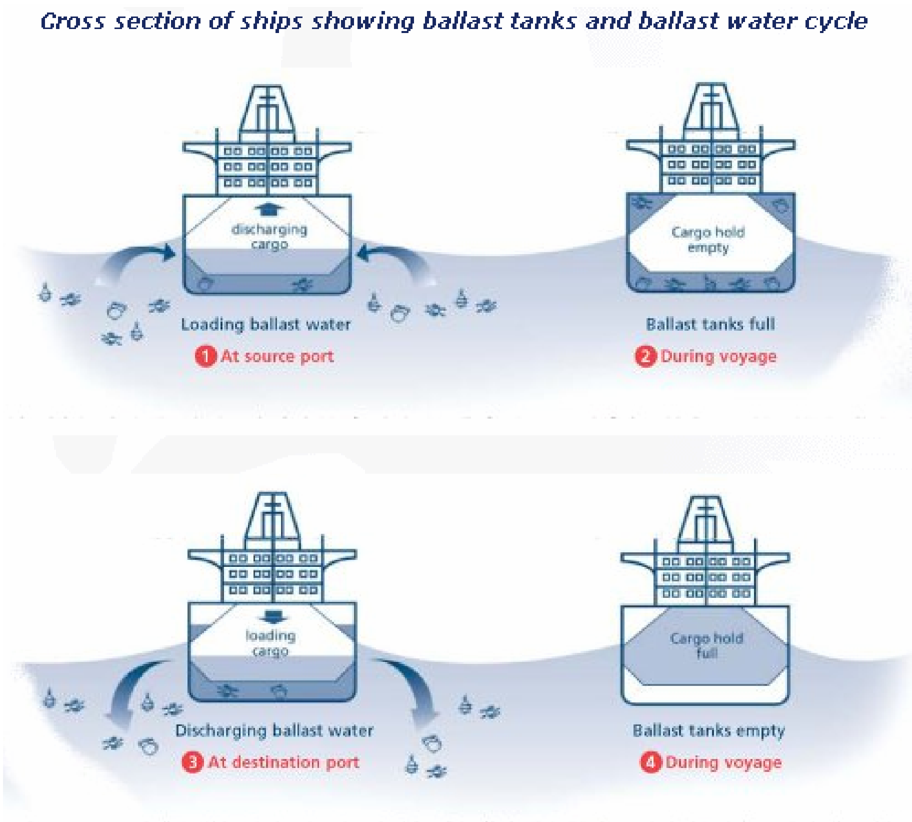

Figure 1 – Ballast water cycle. Source: IMO, 2011a.

In Figure 1 the ship is initially (1) unloaded and therefore with no ballast. The sea water then functions as ballast water. Next (2), the ship moves with ballast water taken from the starting

port. Then (3) the ship discharges ballast water and places exogenous marine life in the destination port. In (4) the ship is loadless and does not require ballast water anymore.
As the situation becomes more and more serious, the International Maritime Organization (IMO) has sponsored international meetings to found out courses of action to meet this challenge, where the subject is discussed by the IMO Member States.
As a result, whole ecosystems are being changed. In the USA, the European Zebra Mussel Dreissena polymorpha has infested over 40% of internal waterways and may have required between US$ 750 million and US$ 1 billion in expenditure on control measures between 1989 and 2000. In southern Australia, the Asian kelp Undaria pinnatifida is invading new areas rapidly, displacing the native seabed communities. In the Black Sea, the filter-feeding North American jellyfish Mnemiopsis leidyi has on occasion reached densities of 1kg of biomass per m^2. It has depleted native plankton stocks to such an extent that it has contributed to the collapse of entire Black Sea commercial fisheries. In several countries, introduced, microscopic, 'red-tide' algae (toxic dinoflagellates) have been absorbed by filter-feeding shellfish, such as oysters. When eaten by humans, these contaminated shellfish can cause paralysis and even death. The list goes on, hundreds of examples of major ecological, economic and human health impacts across the globe. It is even feared that diseases such as cholera might be able to be transported in ballast water (IMO, 2011a).
Invasive marine species are one of the four greatest threats to the world's oceans. Unlike other forms of marine pollution, such as oil spills, where ameliorative action can be taken and from which the environment will eventually recover, the impacts of invasive marine species are most often irreversible (IMO, 2011b)

Representative Ballast Capacities

VESSEL TYPE	DWT	BALLAST CONDITION			
		NORMAL (tonnes)	% of DWT	HEAVY (tonnes)	% of DWT
Bulk carrier	250,000	75,000	30	113,000	45
Bulk carrier	150,000	45,000	30	67,000	45
Bulk carrier	70,000	25,000	36	40,000	57
Bulk carrier	35,000	10,000	30	17,000	49
Tanker	100,000	40,000	40	45,000	45
Tanker	40,000	12,000	30	15,000	38
Container	40,000	12,000	30	15,000	38
Container	15,000	5,000	30	n/a	
General cargo	17,000	6,000	35	n/a	
General cargo	8,000	3,000	38	n/a	
Passenger/RORO	3,000	1,000	33	n/a	

Figure 2 – The distribution of Ballast Water within a vessel will depend on the design criteria, size and strength of the vessel. Source: Australian Quarantine & Inspection Service, 1993.

DWT: Deadweight tonnage (also known as **deadweight** abbreviated to **DWT**, **D.W.T.**, **d.w.t.**, or **dwt**) is a measure of how much weight a ship is carrying or can safely carry.

BW:

2. The Case Study

Two multicriteria methods, TODIM and THOR, were used in the case study. The steps below were followed:
Step 1: identify in all proposals submitted by IMO Member States the relevant criteria;
Step 2: submit this set of criteria to IMO Member States;
Step 3: obtain the consensus about the criteria set;
Step 4: identify the alternatives that solve the problem;
Step 5: submit the alternatives to IMO Member States;
Step 6: identify the importance to criteria by their relative weights;
Step 7: order the alternatives by both TODIM and THOR.
The two multicriteria methods allowed incorporating the value judgment of the IMO Member States taking into account their preferences and interpreting the procedure as a learning process. Thus, it helps to select the best ballast water exchange and treatment methods.
In order to apply this methodology to the case under consideration, relevant factors have been identified. They are: Practicability; Biological effectiveness (including pathogens); Cost/benefits; Time frame within which the standards could be practically implemented; and Environmental impact of the process' sub-products.

3. Methodology

3.1 The TODIM Method

The TODIM method (an acronym in Portuguese of Interactive and Multicriteria Decision Making) (Gomes and Rangel, 2009) is a discrete multicriteria method founded on Prospect Theory (Kahneman and Tversky, 1979). While all other discrete multicriteria methods assume that the decision maker always looks for the solution corresponding to the maximum of some global measure of value – for example, the highest possible value of a multiattribute utility function, in the case of MAUT (Keeney and Raiffa, 1993) –TODIM makes use of a global measurement of value calculable by the application of Prospect Theory. In this way, the method is based on a description, proved by empirical evidence, of how people effectively make decisions in the face of risk. Although not all multicriteria problems deal with risk, the shape of the value function of TODIM is the same as the value function of Prospect Theory. The multiattribute value function of TODIM is built in parts, with their mathematical descriptions reproducing that gain/loss function. The global multiattribute value function of TODIM therefore aggregates all measures of gains and losses over all criteria.
The concept of introducing expressions of losses and gains in the same multiattribute function, present in the formulation of TODIM, gives this method some similarity to the PROMÉTHÉE methods, which make use of the notion of net outranking flow (Brans and Mareschal, 1990). TODIM indeed maintains a similarity with outranking methods, because the global value of each alternative is relative to its dominance over other alternatives in the set. In its calculations the TODIM method must test specific forms of the losses and gains functions. Each one of the forms depends on the value of one single parameter. The forms, once validated empirically, serve to construct the additive difference function of the method. This notion of an additive utility function is taken from Tversky (1969). From the construction of that additive difference function, which performs as a multiattribute value function and, as such, must also have its use validated by the verification of the condition of mutual preferential independence (Clemen and Reilly, 2001), the method leads to a global ordering of the alternatives. It can be observed that the construction of the multiattribute value function, or additive difference function, of the TODIM method is based on a projection of the differences between the values of any two alternatives (perceived in relation to each criterion) to a reference criterion.

The TODIM method makes use of paired comparisons between the decision criteria, using technically simple resources to eliminate occasional inconsistencies arising from these comparisons. It also allows value judgments to be carried out in a verbal scale, using a criteria hierarchy, fuzzy value judgments and making use of interdependence relationships among the alternatives. It is a non-compensatory method in the sense that tradeoffs are not dealt with in the modeling process (Bouyssou, 1986).
Consider a set of n alternatives to be ordered in the presence of m quantitative or qualitative criteria, and assume that one of these criteria can be considered as the reference criterion. After the definition of these elements, experts are asked to estimate, for each one of the qualitative criteria c, the contribution of each alternative i to the objective associated with the criterion. This method requires the values of the evaluation, of the alternatives in relation to the criteria, to be numerical and to be normalized; consequently the qualitative criteria evaluated in a verbal scale are transformed into a cardinal scale. The evaluations of the quantitative criteria are obtained from the performance of the alternatives in relation to the criteria, such as, for example, the level of noise measured in decibels, the power of an engine measured in horsepower or a student's mark in a subject etc.
TODIM can therefore be used for qualitative as well as quantitative criteria. Verbal scales of qualitative criteria are converted to cardinal ones and both types of scales are normalized. The relative measure of dominance of one alternative over another is found for each pair of alternatives. This measure is computed as the sum over all criteria of both relative gain/loss values for these alternatives. The parts in this sum will be either gains, losses, or zeros, depending on the performance of each alternative with respect to every criterion.
The evaluation of the alternatives in relation to all the criteria produces the matrix of evaluation, where the values are all numerical. Their normalization is then performed, using, for each criterion, the division of the value of one alternative by the sum of all the alternatives. This normalization is carried out for each criterion, thus obtaining a matrix, where all the values are between zero and one. It is called the matrix of normalized alternatives' scores against criteria. The application of TODIM then proceeds towards the computation of the overall value for each alternative. This is accomplished by making use of expressions for the gain/loss branches of the prospect theoretical value function. The mathematical formulas embedded in TODIM have been presented elsewhere and will not be reproduced here. An important parameter of TODIM is θ, the attenuation factor of the losses; different choices of θ lead to different shapes of the prospect theoretical value function in the negative quadrant. The global measures obtained of alternatives' values computed by TODIM permit the complete rank ordering of all alternatives. A sensitivity analysis should then be applied to verify the stability of the results based on the decision makers' preferences. The sensitivity analysis should therefore be carried out on θ as well as on the criteria weights, the choice of the reference criterion, and performance evaluations.

3.2 The THOR System

The Multicriteria Decision Support System used in this study was THOR (an acronym for AlgoriTmo Híbrido de ApoiO MulticritéRio à Decisão para Processos Decisórios com Alternativas Discretas - Multicriteria Decision Support Hybrid Algorithm for Decision Making Processes with Discrete Alternatives) which simultaneously aggregates the concepts of Rough Set Theory, Fuzzy Set Theory and Preference Theory (Gomes *et al.*, 2008). THOR is therefore a multicriteria decision support system for the ranking of discrete alternatives, which eliminates redundant criteria simultaneously considering if the information is dubious – when using Rough Set Theory – and if there is an increase in imprecision in the decision process – in which case Fuzzy Set Theory is used. In this way, imprecision is quantified, using it in the multicriteria decision support process.
The concept of quantifying the imprecision associated with the weights and the classifications of the alternatives, put into operation in THOR, arises from the fact that the judgment values,

because of their inherent subjectivity, cannot always be expressed in secure and precise ways. When using THOR, the simultaneous input of data into the process from multiple decision makers is also permitted, enabling these to express their judgment values in scales of ratios, intervals or ordinals, in addition to the execution of the decision making process without necessarily attributing weights to the criteria (Gomes, 2005).

The analytical modeling embedded in THOR is based on the ELECTRE methods of the French School of Multicriteria Decision Support. In this way, the following additional elements may be necessary for the application of THOR: a weight for each criterion, representing the relative importance among them; a preference threshold (p) and another for indifference (q) for each criterion; discordance; and pertinence of the values of the weights attributed to the criterion, as well as the pertinence of the classification of the alternative in the criterion.

Given two alternatives *a* and *b*, three situations can be considered when THOR is used: S_1, S_2 and S_3. Situation S_1 only takes into account the alternatives *a* for which *a* P *b*, with *b* being any other alternative. In this way, comparing *a* with *b*, we can identify the criteria in which *a* P *b*, taking into consideration the thresholds of preference (P designates strict preference and Q designates weak preference), indifference and discordance, checking if the condition imposed is satisfied. If satisfied, we know that *a* dominates *b*. The binary relations P, Q, and I are defined as below. Equations (1), (2) and (3) designate the binary relations P, Q and I, respectively. The notation g(.) designates a criterion.

$$aPb \leftrightarrow g(a) - g(b) > +p \tag{1}$$

$$aQb \leftrightarrow q <| g(a) - g(b) | \leq p \tag{2}$$

$$aIb \leftrightarrow -q \,|\, g(a) - g(b) | \leq +q \tag{3}$$

We therefore have the following:

- Situation 1 (or S_1):

$$\sum_{j=1}^{n} (w_j \mid aP_j b) > \sum_{j=1}^{n} (w_J \mid aQ_j b \;\wedge\; aI_j b \;\wedge\; aR_j b \;\wedge\; bQ_j a \;\wedge\; bP_j a) \tag{4}$$

The context S_1 is characterized by the next fact: the sum of the weights of the criteria *j* such what *a* is strongly preferable *b* is bigger than the sum of the weights of the criteria *j* such what *a* is weakly preferable *b* more the sum of the weights of the criteria *j* such what *a* is indifferent *b* more the sum of the weights of the criteria *j* such what *a* is not comparable with *b* any more the sum of the weights of the criteria *j* such what *b* is weakly preferable *a* to any more the sum of the pesos of the criteria *j* such what *b* is strongly preferable to *a*.

- Situation 2 (or S_2):

$$\sum_{j=1}^{n} (w_j \mid aP_j b \wedge\; aQ_j b) > \sum_{j=1}^{n} (w_J \mid aI_j b \;\wedge\; aR_j b \;\wedge\; bQ_j a \;\wedge\; bP_j a) \tag{5}$$

The context S_2 is characterized by the next fact: the sum of the weights of the criteria *j* such what *a* is strongly preferable *b* and is weakly preferable *b* is bigger than the sum of the weights of the criteria *j* such what *a* is weakly preferable *b* more the sum of the weights of the criteria *j* such what a is indifferent b more the sum of the weights of the criteria j such what a is not comparable with *b* any more the sum of the weights of the criteria *j* such what *b* is weakly preferable *a* to any more the sum of the weights of the criteria *j* such what *b* is strongly preferable to *a*.

- Situation 3 (or S_3):

$$\sum_{j=1}^{n}(w_j \mid aP_jb \wedge\ aQ_jb \wedge\ aI_jb) > \sum_{j=1}^{n}(w_J \mid aR_jb\ \wedge\ bQ_ja\ \wedge\ bP_ja) \qquad (6)$$

The context S_3 is characterized by the next fact: the sum of the weights of the criteria *j* such what *a* is strongly preferable *b* and is weakly preferable *b* her is indifferent *b* is bigger than the sum of the pesos of the criteria *j* such what *a* is weakly preferable *b* more the sum of the weights of the criteria *j* such what more the sum of the weights of the criteria *j* such what her is not comparable with *b* any more the sum of the weights of the criteria *j* such what *b* is weakly preferable her to any more the sum of the pesos of the criteria *j* such what *b* is strongly preferable to *a*. *R* stands for non-comparability. w_j, w are weight and *j* are criteria (j = 1, 2, …, n).

It should be noted that the last two situations (S_2 and S_3) are less rigorous than the first (S_1). This would lead to a smaller difference allowing one alternative to be classified better than another (Roy and Bouyssou, 1993).

Situation S_1 only takes into account the alternatives a for which *a* P *b*, with b being any other alternative. In this way, comparing a with b, we can identify the criteria in which *a* P *b*. This would then take into consideration the thresholds of preference, indifference and discordance. A checking would verify if the condition imposed is satisfied. If satisfied, we know that *a* dominates *b*. Afterwards, the criteria weights in which this condition was met are added. For another alternative *c*, the same procedure described previously is repeated. The final scoring of alternative a will be the sum of the values obtained.

For the situation S_2 the alternatives for which *a* P *b* and *a* Q *b* are taken into account. In situation S_3, the alternatives for which *a* P *b*, *a* Q *b* and *a* I *b* are taken into account.

Before we proceed showing how the two methods were combined one must clarify that both TODIM and THOR are noncompensatory methods in the sense that tradeoffs do not occur (Bouyssou, 1986). Weights should in principle reflect to some extent the degrees of relative importance or strength as estimated by decision agents along a numerical scale, such as from 0 to 10. This scale can be either a linear, cardinal scale or a ratio scale. A comparatively high criterion weight increases the chance that an alternative well classified according to that criterion is positioned in a high global rank. Neverthless, in some cases a relatively high weight for any given criterion does not necessarily mean that this is one of the most important criteria. For instance, given two conflicting criteria for completing a project, cost and time for completion, a decision maker initially considers cost as the most important among the two criteria. He therefore assigns a weight to cost that is much higher than the weight of time for completion. This is so because he expects to save some money to be assigned to other projects. However, although some alternatives are close to reaching below 80 % of the available budget, all alternatives are well above 90% of the time limit for completion. This is a typical situation in which an intracriteria analysis points out to the following fact: the criterion that had originally the smallest weight ends up being the most important between the two criteria.

4.1 Modeling and Computations with TODIM and THOR

4.1.1. Criteria

The detailed criteria, referring to the relevant factors identified, for quantitative measuring in association with a nominal scale or description, are reproduced in paragraph 4.1.2. They are numbered from 1 to 26 as shown in Figure 3. Each criteria presented shall be analyzed and represented using quantitative measuring. It can be done by assign a value in a nominal scale, by a value attributed to a yes or no answer, or by an interval scale or ration scale.

For this study the following was adopted:
(a) Restriction (veto criterion) – the system to be incorporated or selected shall not present any restrictions unacceptable.
(b) All criteria have the same weight (during the presentation of this article by Brazilian Delegation at IMO meeting, the IMO members did not achieve consensus about the weights).

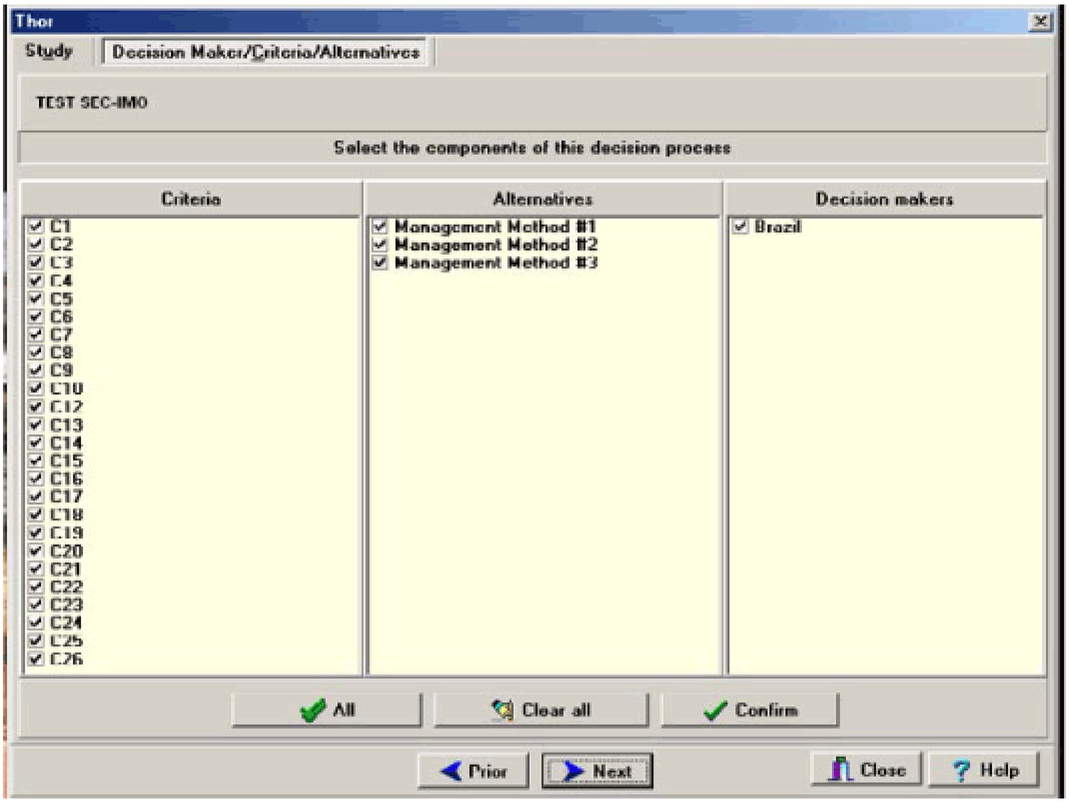

Figure 3 – Criteria and alternatives.

4.1.2. Questions

a) Practicability
a.1) Quantitative criteria
C_1 - what ballast flow rate range is the system applicable? (m^3/hour) (specify the minimum and maximum flow rate)
C_2 - what is the ship tonnage that the system can be applied to? (DWT) (specify the minimum and maximum tonnage)
C_3 - what is the additional workload on board? (man/hours)
C_4 - what is the highest sea state (in the Beaufort wind scale) on which the system can operate?
C_5 - what is the increase in tank's sediment caused by the system? (specify percentage)
a.2) Questions that need to be answered by a nominal scale, subject to association to a numerical scale of intervals or by a yes/no answer
C_6 - does the system present any risks to the ship's crew safety or to the crew? (-3, high risk; -2, medium risk; -1, low risk; 0, no risk)
C_7 - does the system affect the tanks' corrosion rate? (-2, increases the rate; -1, does not increase the rate; 0, reduces the rate)
C_8 - does the system dispense with the need to keep chemical products on board? (Yes or No)
C_9 - can the system be used in short voyages (up to 12 h)? (Yes or No)

C_{10} - can the system be operated without complete re-circulation of the ballast water? (Yes or No)
C_{11} - is the system unaffected by incrustation that could lead to a drop in pressure and/or to a reduction in the flow rate? (Yes or No)
C_{12} - is the system being applicable to existing ships? (Yes or No)
C_{13} - are the ship's other functions independent from the system's operation? (Yes or No)
a.2) Questions that require detailed answers
C_{14} - does the system present any occupational hazard to the operator? Describe and quantify. (-3, high; -2, medium; -1, low; 0, no hazard)
b) Biological effectiveness (including pathogens)
b.1) Quantitative Criteria
C_{15} - how effective is the system in relation to the removal, elimination and inactivation/neutralization of aquatic organisms, apart from pathogens (according to the various taxonomic groups)? (quantify in terms of percentage, size and/or concentration of organisms)
C_{16} - same as 15 for pathogens.
b.2) Questions for which the answers should be either Yes or No
C_{17} - does the system eliminate cysts?
C_{18} - does the system allow the elimination of organisms when the water enters the tank?
C_{19} - is the system adequate for the elimination of all species or life stages that may present a hazard to the environment?
c) Cost-benefits
c.1) Quantitative criteria
C_{20} - what is the purchase cost? (US$)
C_{21} - what is the cost of installation? (US$)
C_{22} - what is the operational cost? (US$/ton)
C_{23} - what is the cost variation per ship size? (US$/ton)
C_{24} - what is the increase of fuel or oil consumption that is introduced by the use of this system on board? (percentage)
d) Time frame within which the standards could be practically implemented
d.1) Quantitative criteria
C_{25} - within which time frame could the standards be practically implemented? (no. of months)
e) Influence of the system's sub-products on the environment
e.1) Question for which the answer should be either Yes or No
C_{26} - is the system free from generating sub-products that can have an impact on the environment?
Observation: Undesirable outcomes are taken with negative values as well as those that have a negative impact with higher absolute values. According to that: *i)* In the criteria 3, 5, 20-24 and 25, negative values are assign for the lowest desirable feature; *ii)* In the criteria 8 to 13, 17, 18, 19 and 26, where the answers should be either "Yes" or "No", a value of 1 was assigned to a "Yes" answer (desirable) and a value of 0 to a "No" answer (undesirable); and *iii)* In the criteria 6, 7 and 14, verbal (or nominal) scales associated to a numerical scale have been created for test purposes.

4.1.2. Alternatives

The three alternatives that were evaluated both by TODIM and THOR are fictitious ballast water management technologies. They are described in Table 1. These three alternatives were considered as feasible by experts.

4.1.3. Evaluation matrix

The evaluation is presented in Table 1.

Criteria	Alternatives		
	Management Method 1	Management Method 2	Management Method 3
C_1	Maximum 15,000 m^3/h Minimum 100 m^3/h	Maximum 14,000 m^3/h Minimum 200 m^3/h	Maximum 13,000 m^3/h Minimum 300 m^3/h
C_2	Maximum 450,000 DWT Minimum 450 DWT	Maximum 350,000 DWT Minimum 350 DWT	Maximum 250,000 DWT Minimum 450 DWT
C_3	90 man/h	80 man/h	90 man/h
C_4	7	8	10
C_5	10 %	12 %	5 %
C_6	-1	-2	-3
C_7	-2	-1	-3
C_8	1	1	0
C_9	1	1	0
C_{10}	1	1	0
C_{11}	0	1	1
C_{12}	0	1	1
C_{13}	0	0	1
C_{14}	0	-1	-2
C_{15}	93 %	92 %	90 %
C_{16}	90 %	88 %	91 %
C_{17}	1	0	1
C_{18}	1	0	0
C_{19}	0	1	1
C_{20}	US$ 200,000.00	US$ 210,000.00	US$ 220,000.00
C_{21}	US$ 10,000.00	US$ 21,000.00	US$ 1,000.00
C_{22}	0.02 US$/ton	0.03 US$/ton	0.04 US$/ton
C_{23}	US$ 9	US$ 8	US$ 6
C_{24}	3 %	8 %	1 %
C_{25}	6 months	8 months	9 months
C_{26}	0	1	0

Table 1 – Evaluation matrix

All values in the above matrix were normalized and transformed into maximization criteria for the use of the TODIM method. The THOR method used data as shown in Table 1.

4.2. Applications of TODIM and THOR

Table I presents an example utilization of this method using the three management methods. It is difficult, in the following table, to find out the best management method. This problem becomes even more complicated if we consider that there are several ballast water treatment methods currently being discussed at IMO and not just the three ones used as example.

4.2.1. Results from using TODIM

The application of TODIM took into consideration three possible situations: (i) attenuation factor θ equal to 1.0 (less risk proneness); (ii) θ equal to 10.0 (greater risk proneness); and (iii) θ equal to 5.0 (an intermediate value between the two previous extreme situations). Results from the computations are presented in Table 2.

Alternatives	θ = 1.0	θ = 5.0	θ = 10.0
A_1	1.000	1.000	1.000
A_2	0.808	0.000	0.000

A_3	0.000	0.210	0.425

Table 2 – Performance of the three alternatives according to the TODIM method

4.2.2. Results from using THOR

Figure 4 shows the outputs from using THOR.

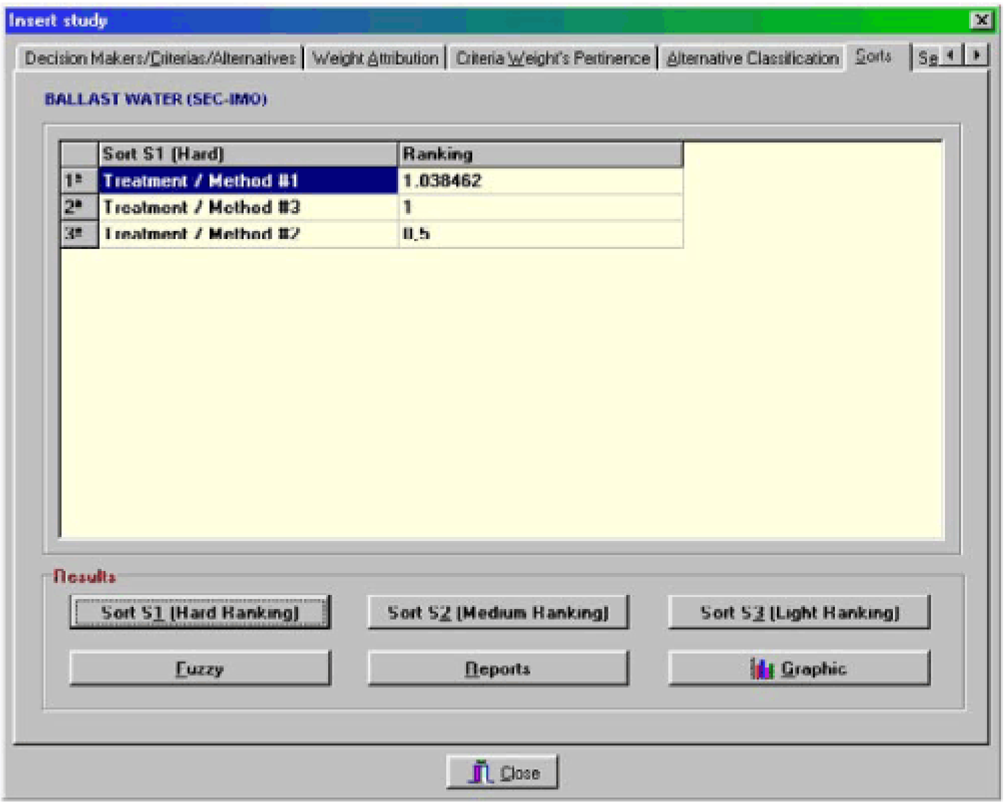

Figure 4 – THOR results.

The three alternatives were evaluated according to criteria 1, 2, 3, 20, 21, 22, 23 and 25 by ratio scale. Alternatives were evaluated according to criteria 5, 15 and 16 by an interval scale. Alternatives were evaluated with respect to all other criteria by using a nominal scale associated to a interval scale.

5. Conclusion

Using the software THOR, it can be seen that the Management Method 1 is the best method, slightly better than Management Method 3. There was indeed an ordinal agreement in the outputs from TODIM and THOR when θ was made equal to 5.0 and to 10.0. Both methods then produced the following rank: A_1□A_3□A_2. When θ was equal to 1.0, however, there was a discordance between TODIM and THOR concerning the last two alternatives: A_1□A_2□A_3 from TODIM and A_1□A_3□A_2 from THOR. Nevertheless, since this was a problem in the choice of a technology, for practical purposes it was concluded that the two methods produced a similar results. Taking into account the computations from TODIM for θ equal to 5.0 and to 10.0, and the outputs from using THOR, it was clear that A_2 could be ignored. Therefore if a rank were to be produced only A_1 and A_3 would be in that rank. The final results is that A_1 should be the best choice.

It is worth noting that although the two methods rely on different bases they produced in essence the same results. Two other applications of both TODIM and THOR have confirmed the convergence of results in spite of the conceptual and technical differences between the two methods (Gomes *et al*., 2009; Gomes *et al*., 2010). The TODIM method is founded on the paradigm of Prospect Theory and data are aggregated by means of building an additive value function. On the other hand the THOR system relies on the notion of outranking and does not take into account the attitude of a decision maker facing risk. The fact that they produce similar results suggests that structuring a decision problem in a comprehensive way and applying a method correctly may be at least as important as the technical characteristics of the method per se.

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