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ENHANCEMENT OF EFFECTIVENESS OF PORT STATE CONTROL INSPECTION USING A HYBRID AHP-TOPSIS MODEL

Mohamed El-Wakeel[1], Said Abdelkader[2] & Ahmed Kassar[3]

[1]Marine Captain Lecturer, Arab Academy for Science, Technology and Maritime Transport, AASTMT, Egypt

[2]Profession of Mechanical Engineering, Arab Academy for Science, Technology and Maritime Transport, AASTMT, Egypt

[3]Dean, Maritime Postgraduate Studies Institute, Arab Academy for Science, Technology and Maritime Transport, AASTMT, Egypt

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ABSTRACT

During the end of the last century, marine accidents triggered the maritime community to apply and develop the international regulations for safety and environmental protection. Consequently, Port State Control (PSC) regulations were introduced as a new mechanism to enforce the implementation of such regulations, which aim to exclude the substandard ships from the seaborne fleet and ensure ships safety and reliability in clean seas. However, PSC of a port cannot inspect every ship calling at the port at any time; and a selecting ship for inspection system should be adopted due to time and resource limitations.

Two Multi-Criteria Decision Making (MCDM)approaches were first used to rank the alternatives; these approaches are the Weighted Sum Model (WSM) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).In this endeavor, ships to be inspected represent the alternatives and targeting factors represent the attributes; initial results are in favor of TOPSIS.

To further enhance the effectiveness of the selecting-ships-for-inspection system, the Analytic Hierarchy Process (AHP) was used to weigh the attributes through pairwise comparisons. Thus, a hybrid decision-making methodology that employs AHP and TOPSIS is recourse to. As such, AHP technique can be very useful in involving several decision-makers with multiple different factors to calculate the weight for each factor. On the other hand, TOPSIS technique is employed to rank the alternatives, based on their overall performance. An example is given to illustrate the proposed methodology.

KEYWORDS: *Port State Control (PSC), Weighted Sum Model (WSM), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Analytic Hierarchy Process (AHP)*

INTRODUCTION

United Nations Convention on the Law of the Sea (UNCLOS) Article 25 provides that the coastal state has the right, in the case of ships proceeding to internal waters or a call at a port facility outside internal waters, to take the necessary measures to prevent any breach of the conditions to which admissions to internal water is subject. Furthermore, Article 211 provides the basis for the establishment by a group of states of particular requirements for the prevention, reduction, and control of pollution of the marine environment as a condition for the entry of foreign ships into their ports or internal waters. Articles 218 and 226 enable a port state to enforce international anti-dumping and anti-pollution measures. Moreover, states are required by Article 219 to take administrative measures to prevent misbehaving ships from sailing. Legality for PSC inspections may be found in these Articles of UNCLOS, because it is possible for there to be an oil pollution threat, even if only bunkers, from any unseaworthy ship. The only limitation is that the steps taken be reasonable, public, and fair (Articles 25, 211, 218, 219 and 226 of the UNCLOS, 1982).

In March 1978, the grounding of the supertanker “Amoco Cadiz” off the coast of Brittany (France) resulted in a massive oil spill, causing a strong political and public outcry in Europe, calling for more stringent regulations with regard to the safety of shipping. This pressure resulted in a more comprehensive Memorandum of Understanding signed in Paris in 1982 and known as Paris MOU. Resolution A.682 (17) concerning regional cooperation in the control of ships and discharges, which was adopted by the IMO Assembly in 1991, acknowledged the performance of the Paris MOU in combating substandard ships and called on the parties to the IMO to consider concluding more regional arrangements (IMO Resolution A.687 (17), 1991). The MOUs cover nearly all the regions of the world, e.g. Tokyo MOU (1993), Caribbean MOU (1996), Mediterranean MOU (1997), Indian Ocean MOU (1998), Black Sea MOU (2000), and Riyadh MOU (2004).

The Memorandum of Understanding on PSC in the Mediterranean region (Med MOU) was the main focus of the current research. The Med MOU was established following a declaration by the European Community (EC) that it would finance a cooperation project supported by the IMO and ILO in an effort to increase the maritime safety of shipping and pollution prevention. The Med MOU was concluded in Malta; eight-member authorities signed it in July 1997: Algeria, Cyprus, Egypt, Israel, Malta, Morocco, Tunisia, and Turkey. Lebanon and Jordan have subsequently joined. Cyprus and Malta have also joined the Paris MOU, and Italy and Spain (Paris MOU members) are observers. Med MOU secretariat has been set up in Alexandria, Egypt and its information center in Casablanca, Morocco (Med MOU, memou.org).

LITERATURE REVIEW

This review covers two important inter-related topics: Port State Control (PSC) and Multi-Criteria Decision Making (MCDM) models.

Port State Control (PSC)

Hare (1997) offers one of the first contributions on the effectiveness of PSC in showing how the proliferation of regional MOUs has significantly diminished the potentials for substandard ships to participate in international commerce. Attempts were made to analyze the effect of PSC inspections on the probability of casualty by Knapp and Franses. Knapp and Franses (2007) analyzed the effect of PSC inspections on the probability of casualty according to targeting ships, ship types, flag states, classification societies, and detained ships. Furthermore, Knapp and Franses (2008) used data on detentions from different MOUs, split into six different ship types (general cargo, dry bulk, container, tanker, passenger, and other ship types) and eight categories of deficiencies. Authors conclude that the ship profiles are given by age, type, classification society and ship owner would not vary significantly across various PSC regimes and those differences would come from the use of deficiencies in determining detention. Knapp and Velden (2009) recommend accelerating the harmonization process by putting more emphasis on the harmonization of inspection procedures, combined training of PSC officers and the use of combined datasets across regimes.

Cariou, et al, (2009) investigated the determinants of the number of deficiencies and of the probability of detention. The results show that the main contributors to detention are the age of the ship at inspection, the recognized organization and the place where the inspection occurs. Mejia, et al (2010) investigated the newly implemented PSC system in Taiwan. The major contents include the introduction of the system and the analysis of the ship's inspection results over the past four years. The research further discusses some in-depth issues about the system including the difficulties of the implementation and the inadequacies of the system. Rodrigo and Steliana (2010) established a common criterion for PSC of ships, harmonizing procedures on inspection and detention and taking into account the commitment made by the maritime authority of Romania. Moreover, Elwakeel (2010) studied the role of classification societies in the PSC system to ensure ships safety and reliability in clean seas. This research recommended that more co-operation and exchange of data is required. Also, it concluded that the PSC system must be more efficient, and detentions-of-ship statistics should not be regarded as an efficient PSC system, in order to get an enhanced and better targeted PSC and reduction of the number of inspection of ships of good ship operators.

Sam and Jong (2012) examined the regional MOUs with a focus on their operational strengths and weaknesses. Also, they discussed the regional PSC MOU regimes systematically in order to show a degree of comparison between them and to evaluate which MOUs may need more assistance. Some of the regional MOUs, e.g., the Caribbean, Abuja, and Riyadh MOUs have not fully participated in PSC that can be perceived as important programs to deal with substandard ships. Elwakeel (2012) examined the achievements of Egyptian PSC for the years 2002-2010, according to the requirements of the Med MOU, and found that the rate of inspection up to 53% (more than required by the MOU 15%), a positive sign indicates that the Egyptian PSC is doing its job efficiently with regard to foreign ships visiting ports. But, the research concluded that the higher inspection number does not ensure the elimination of the substandard ships.

Multi-Criteria Decision Making (MCDM)

MCDM problems are common in everyday life and are usually of large scale. The rapid development in computer science has led to the development of rigorous approaches for solving MCDM problems. A MCDM approach is a procedure that specifies how indicator information is to be processed in order to choose the best alternatives where many criteria have come into existence. The process involves analyzing the different criteria and finding their weights.

MCDM approaches have been applied to different fields including economics, health, industry, computer science and risk management. MCDM approaches are numerous and the last decades have intensified the interest in the application of formalized decision-analytical tools, due to the complexity of problems as well as the higher availability of data. Comparative studies of such approaches have been conducted in order to show their salient features, potential capabilities and limitations, e.g. Martin, et al (2013); Schinas (2014); El Sayed, et al (2014); Pangsri (2015); Kolios, et al. (2016) and Gratl, et al (2017).

The current research endeavors to address the effectiveness of the PSC programmes and to assess the methods which are used to select ships for inspection. Reasons to further develop the PSC programmes and ways to improve the effectiveness of the selection system are addressed. So, the first research aspect puts emphasis on risk level determination approach to identify ships with high-risk level before conducting on-board inspection, and thereby reduce ship delays due to unnecessary inspections. The second aspect is to provide a risk-based model capable of catching substandard ships.

The Weighted Sum Model (WSM) approach, which is currently used by the Med MOU, is one of the Multi-Criteria Decision Making (MCDM) approaches, which has its limitations and shortcomings. Therefore, other MCDM approaches are reviewed, focusing on their salient features, potential capabilities and fields they have been applied in.

In the next section, more light is shed on the chosen approaches. Possible integration of such approaches, in order to come up with a hybrid approach which combines the advantages of such approaches and diminishes their limitation, will be investigated.

METHODS AND PROCEDURES

The Weighted Sum Model (WSM), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Analytic Hierarchy Process (AHP) approaches are of special interest in this endeavor. In the following sections, WSM, TOPSIS and AHP approaches are described, governing equations presented and procedures of application outlined.

Weighted Sum Model (WSM)

The WSM is a simple approach, probably the simplest, applicable to single-dimensional cases, due to the fact that it follows an intuitive process. For the case of *m* alternatives and *n* factors, the total value of the *i*- th alternative, A_i, is given by the following equation (Fishburn, 1967):

$$A_i = \sum_{j=1}^{n} a_{ij}\, w_j \quad (1)$$

where $i = 1, \ldots, m$, $j = 1, \ldots, n$, a_{ij} is the value of the *i*-th alternative with respect to the *j*-th factor and w_j is the weight of the *j*-th factor. Each alternative is compared to the rest of the alternatives; the optimal alternative is the closest one to the best value.

In the Med MOU, however, each factor is assigned a different range of points in accordance with its relative weight in respect to the other factors. As such, Equation (1) reduces to the simpler form:

$$A_i = \sum_{j=1}^{n} a_{ij} \quad (2)$$

Thus, the WSM approach involves the following series of successive steps:

Step 1: Define the problem.

Step 2: Assign points to each factor.

Step 3: Add up all the points for each alternative (Eq. 2).

Step 4: Rank alternatives as endingly according to the sum obtained.

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS approach was developed by Hwang and Yoon (1981) and further developed by Hwang, et al. (1993). This approach assumes that each factor has a tendency of monotonically increasing or decreasing utility which leads to easily define the positive and the negative ideal solutions. To evaluate the relative closeness of the alternatives to the ideal solution Euclidean distance approach is proposed. A series of comparisons of these relative distances will provide the preference order of the alternatives (Triantaphyllou, et al. 1998).

The TOPSIS approach first converts the various factors dimensions into non-dimensional factors. The concept of TOPSIS is that the chosen alternative should have the shortest distance from the Positive Ideal Solution (PIS) and the farthest distance from the Negative Ideal Solution (NIS). This approach is used for ranking purpose and to get the best performance in MCDM. The TOPSIS approach involves the following series of successive steps:

Step 1: Define the problem and specify the solution desired.

Step 2: Construct the normalized decision matrix

The purpose of this step is to facilitate intra-factor comparisons by eradicating the effect of the dimensions so all factors are measured in dimensionless unit. After identifying m alternatives and n factors, the normalized decision matrix is established. The normalized value $r_{ij}$is calculated from Equation (3), where a_{ij} is the i-th factor value for alternative j, $i = 1, . . . ,n$ and $j = 1, . . . , m$.

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{j=1}^{m} a_{ij}^2}} \quad (3)$$

Step 3: Construct the weighted normalized decision matrix

The weighted normalized values v_{ij} is calculated from Equation (4), where w_j is the weight of j-th factor, $i = 1, . . . ,n$ and $j = 1, . . . , m$.

$$v_{ij} = w_j \times r_{ij}, W = \{w_j , \sum_{j=1}^{n} w_j = 1\} \quad (4)$$

Step 4: Determine the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS)

The PIS (A^+) and NIS (A^-) are derived as shown below,

$$A^+ = (v_1^+, \dots \dots, v_n^+) = \{Max_j \, v_{ij}\} \quad (5)$$

$$A^- = (v_1^-, \dots \dots, v_n^-) = \{Min_j \, v_{ij}\} \quad (6)$$

Step 5: Calculate the distance from the PIS and NIS

The n-dimensional Euclidean Distance, (D_j^+) is calculated from Equation (7), as the separation of every alternative from the PIS. The separation from the NIS, (D_j^-) is given by Equation (8).

$$D_j^+ = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^+\right)^2} \quad (7)$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^-\right)^2} \quad (8)$$

Step 6: Calculate the relative closeness to the ideal solution.

The relative closeness to the ideal solution of each alternative is calculated by Equation (9).

$$C_j = \frac{D_j^-}{D_j^+ + D_j^-} \quad (9)$$

Step 7: Rank the alternatives

Finally, after sorting the C_j values, all alternatives will be ranked based on the preference order.

Analytic Hierarchy Process (AHP)

AHP is a structured technique to organize and analyze MCDM problems, which was first proposed in 1970 by Saaty. The basic idea of the AHP is to capture experts' knowledge of phenomena under study, by means of pair-wise comparisons. The weight of each item (alternative/ factor) is evaluated, but the results of pair-wise comparisons are not 0, 1, but rather the degree is given by a numerical value (Saaty and Vargas 2001; Saaty2008). AHP approach is based on building the hierarchy for the problem in which the goal, factors, and alternatives are clearly identified. More on these hierarchies can be found in (Saaty, 1990; 1994; and 2008).AHP approach involves the following series of successive steps:

Step 1: Define the problem and specify the solution desired.

Step 2: Organize the problem as a hierarchy, as shown in Figure 1. The goal is at the top of the hierarchy; the next level includes the factors affecting the decision.

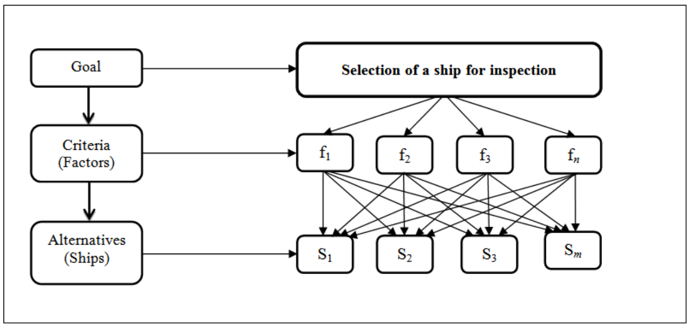

Figure 1: Hierarchy Structure

Step 3: Construct a pair-wise comparison matrix of the relevant contribution or impact of each factor on each governing factor in the next higher level. In this matrix, pairs of factors are compared with respect to a factor in the superior level. In comparing two factors, it is preferred to give a judgment that indicates the dominance as a whole number, shown as Table 1. The matrix has one position to enter that number and another to enter its reciprocal. Thus, if one factor does not contribute more than another, the other must contribute more than it. This number is entered in the appropriate position in the matrix and its reciprocal is entered in the other position.

Table 1: The Fundamental Scale of Importance

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
2	Weak or slight	Between 1 and 3
3	Moderate importance	Experience and judgment slightly favor one factor over another
4	Moderate plus	Between 3 and 5
5	Strong importance	Experience and judgment strongly favor one factor over another
6	Strong plus	Between 5 and 7
7	Very strong importance	A factor is favored very strongly over another; its dominance is demonstrated in practice
8	Very very strong	Between 7 and 9
9	Extreme importance	Evidence favoring one factor over another with the highest possible order of affirmation

Source: Saaty, 2008

Step 4: Obtain all judgments required to develop the set of matrices in step 3. If there are many experts participating, the task for each expert can be made simple by appropriate allocation of effort. Multiple judgments can be synthesized by using their geometric mean. The geometric mean is calculated from Equation (10), where $a_{ij}$is the factor in the expert's decision matrix and p is the number of experts, p=1, 2,…, k.

$$a_{ji} = \sqrt[p]{\pi(a_{ji})_k} \quad (10)$$

Step 5: Verify the consistency of judgments across the Consistency Index (CI) and the Consistency Ratio (CR). Equations (11), (12) and (13) are used to check the consistency of the pair-wise comparisons:

$$\lambda_{max} = \sum_{i=1}^{n} a_{ij} w_j \quad (11)$$

Where λ_{max} is the maximum Eigenvalue, a_{ij} represents how much more important factor i is than factor j with respect to the goal and w_j is the weight of importance of the j-th factor. The CI is defined as:

$$\text{CI} = \frac{\lambda_{max} - n}{n-1} \quad (12)$$

where n is the number of factors.

The CR is obtained by dividing the CI value by the Random Consistency Index (RCI), as given in Table 2, that is:

$$\text{CR} = \frac{\text{CI}}{\text{RCI}} \quad (13)$$

If CR $\leq$ 0.1, the degree of consistency is considered satisfactory, whereas CR > 0.1 means that serious inconsistencies may exist.

Table 2: Random Consistency Index (RCI) values for different values of *n*

n	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty, 2008

Step 6: Perform steps 3, 4, and 5 for all levels and clusters in the hierarchy.

Step 7: Calculate the weight of each factor by using equation (14), where, a_{ij} is the entry of row i and column j in a comparison matrix of order n and W_k is the weight of a specific factor k in the pairwise comparison matrix, k = 1, 2,…, n.

$$W_k = \frac{1}{n} \left(\sum_{j=1}^{n} (a_{kj} / \sum_{i=1}^{n} a_{ij} \right) \quad (14)$$

Step 8: Use hierarchical composition to weigh the priorities by the weights of the factors, and take the sum over all weighted priority entries corresponding to those in the next lower level and so on. The result is an overall priority for the lowest level of the hierarchy. If there are several outcomes, their geometric average may be taken.

Step 9: Finally, all alternatives will be ranked based on the overall weight of each alternative.

CASE STUDY

In the case study considered herein, it is assumed that ten ships are calling at a hypothetical port to visit; for ease of discussion, the ships will be coded S_1, S_2, S_3,…, S_{10}. The PSC office has only four officers taking charge of on-board inspections. Each officer can check one ship per day. So, four ships are to be inspected, and PSC officials need to choose four ships out of the ten to be inspected, and the challenge here is how to choose these four ships effectively. To do so, ranking the ten ships was conducted using the WSM, TOPSIS and hybrid AHP-TOPSIS approaches, respectively. The analysis is conducted using original data consisting of results from PSC inspections carried out by the Memorandum of Understanding on PSC in the Mediterranean region (Med MOU) from January 1, 2017, to March 31, 2017.

At first, the WSM approach is applied; according to the Med MOU targeting system, the ranking of these ships is carried out in respect to eight factors. Every PSC boarding generates a detailed inspection report containing the following particulars on the foreign ship calling port: ship age (f_1), ship type (f_2), ship flag (f_3), number of deficiencies (f_4), number of detentions (f_5), classification society (f_6), number of outstanding deficiencies (f_7) and the time since last inspection (f_8). The targeting system used by the Med MOU and the Target Factors Value (TFV) and ship targeting priority are listed in *Appendix A*. PSC inspection records kept by the Med MOU during 2017 were used to select 10 ships, and their particulars recorded by the PSC are represented in *Appendix B*. The particulars were assigned to the assumed ships S_1, S_2, S_3,…, S_{10}. The system gives a higher priority to ships having a higher TFV. The rank of each ship is calculated by using Equation (2). Table 3 lists the results obtained and is called the PSC decision matrix. Figure 2 shows the evaluation results and the ranking of the ten ships according to the WSM.

Ships classified by the targeting system as Priority I (very high) and Priority II (high) are subject to extremely onerous sanctions such as port entry denial and the restriction of cargo operations. Moreover, these ships must be supervised by a priority in the process of ascension to conduct checks to comply with the rules and binding international conventions. On the other hand, ships classified by the targeting system as Priority III (medium) is not targeted for inspections and can be allowed to the port and complete the cargo operations. The reason behind the selection of ships S_2, S_5, S_9 and S_{10}, for inspection, is due to the increase in some values of targeting factors. For instance, S_2 has two bigger values: ship age (47 points) and the number of deficiencies (48 points), thus resulting in a very high targeting priority. Ships S_5, S_9 and S_{10} have similar situations.

Table 3: PSC Decision Matrix (TFVs)

Factor / Ship	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	Total TFV	Rank
S_1	27	00	00	09	00	00	02	03	41	6
S_2	47	04	08	48	00	10	14	02	133	1
S_3	00	04	00	08	00	00	02	02	16	9
S_4	14	04	11	23	15	10	00	03	80	5
S_5	41	04	17	21	15	10	02	06	116	2
S_6	05	04	00	03	00	00	02	01	15	10
S_7	13	04	00	05	15	00	00	01	38	7
S_8	10	04	00	08	00	00	00	02	24	8
S_9	23	04	00	42	15	10	06	06	106	3
S_{10}	25	04	02	27	30	00	10	06	104	4

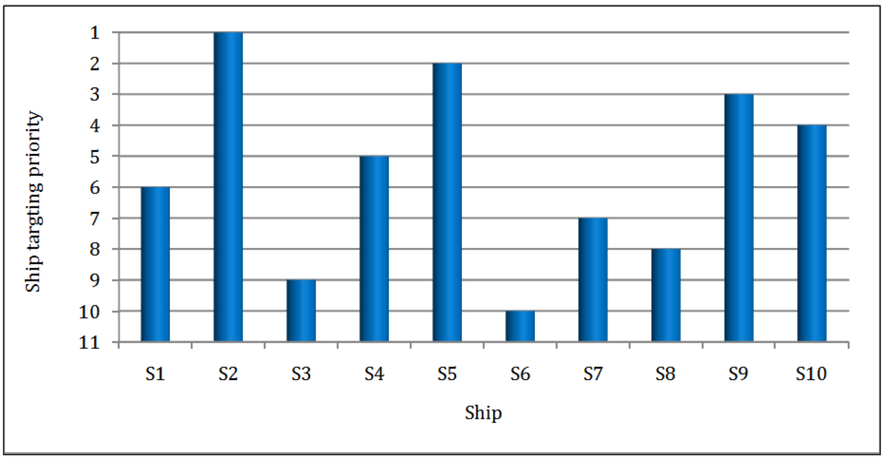

Figure 2: Ship Targeting Priorities Based on WSM Approach

The TOPSIS approach was used to rank the ten ships in respect to the same eight factors considered. The Excel software tool was used for applying the TOPSIS approach according to the procedure outlined in Section 3-2. At first, the PSC decision matrix was constructed by using the Med MOU targeting system, as shown on the left-hand side of Table 3. The normalized decision matrix was obtained by using Equation (3), as shown in Table 4.The weighted normalized decision matrix was obtained by using Equation (4), assuming that the factors are of equal weights, i.e. w_i= (0.125). The results obtained are shown in Table 5. Both Positive Ideal Solution PIS (A^+) and Negative Ideal Solution NIS (A^-) are obtained by using Equations (5) and (6), respectively. Then, the distance from PIS (D^+) and the distance from NIS (D^-) are calculated by using Equations (7) and (8), respectively. The relative closeness to the ideal solution (D^*) was calculated using Equation (9). The results obtained are shown in Table 6.

Table 4: Normalized Decision Matrix

Factor / Ship	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8
S_1	0.3412	0.0000	0.0000	0.1161	0.0000	0.0000	0.1072	0.2535
S_2	0.5939	0.3333	0.3659	0.6192	0.0000	0.5000	0.7505	0.1690
S_3	0.0000	0.3333	0.0000	0.1032	0.0000	0.0000	0.1072	0.1690
S_4	0.1769	0.3333	0.5031	0.2967	0.3536	0.5000	0.0000	0.2535
S_5	0.5181	0.3333	0.7776	0.2709	0.3536	0.5000	0.1072	0.5071
S_6	0.0632	0.3333	0.0000	0.0387	0.0000	0.0000	0.1072	0.0845
S_7	0.1643	0.3333	0.0000	0.0645	0.3536	0.0000	0.0000	0.0845
S_8	0.1264	0.3333	0.0000	0.1032	0.0000	0.0000	0.0000	0.1690
S_9	0.2906	0.3333	0.0000	0.5418	0.3536	0.5000	0.3216	0.5071
S_{10}	0.3159	0.3333	0.0915	0.3483	0.7071	0.0000	0.5361	0.5071

Table 5: Weighted Normalized Decision Matrix

Factor / Ship	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8
S_1	0.0426	0.0000	0.0000	0.0145	0.0000	0.0000	0.0134	0.0317
S_2	0.0742	0.0417	0.0457	0.0774	0.0000	0.0625	0.0938	0.0211
S_3	0.0000	0.0417	0.0000	0.0129	0.0000	0.0000	0.0134	0.0211
S_4	0.0221	0.0417	0.0629	0.0371	0.0442	0.0625	0.0000	0.0317
S_5	0.0648	0.0417	0.0972	0.0339	0.0442	0.0625	0.0134	0.0634
S_6	0.0079	0.0417	0.0000	0.0048	0.0000	0.0000	0.0134	0.0106
S_7	0.0205	0.0417	0.0000	0.0081	0.0442	0.0000	0.0000	0.0106
S_8	0.0158	0.0417	0.0000	0.0129	0.0000	0.0000	0.0000	0.0211
S_9	0.0363	0.0417	0.0000	0.0677	0.0442	0.0625	0.0402	0.0634
S_{10}	0.0395	0.0417	0.0114	0.0435	0.0884	0.0000	0.0670	0.0634

Table 6: Positive Ideal Solution (A^+) and Negative Ideal Solution (A^-) Results

Factor / Ship	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8
S_1	0.0426	0.0000^-	0.0000^-	0.0145	0.0000^-	0.0000^-	0.0134	0.0317
S_2	0.0742^*	0.0417^*	0.0457	0.0774^*	0.0000	0.0625	0.0938^*	0.0211
S_3	0.0000^-	0.0417	0.0000	0.0129	0.0000	0.0000	0.0134	0.0211
S_4	0.0221	0.0417	0.0629	0.0371	0.0442	0.0625^*	0.0000^-	0.0317
S_5	0.0648	0.0417	0.0972^*	0.0339	0.0442	0.0625	0.0134	0.0634^*
S_6	0.0079	0.0417	0.0000	0.0048^-	0.0000	0.0000	0.0134	0.0106^-
S_7	0.0205	0.0417	0.0000	0.0081	0.0442	0.0000	0.0000	0.0106
S_8	0.0158	0.0417	0.0000	0.0129	0.0000	0.0000	0.0000	0.0211
S_9	0.0363	0.0417	0.0000	0.0677	0.0442	0.0625	0.0402	0.0634
S_{10}	0.0395	0.0417	0.0114	0.0435	0.0884^*	0.0000	0.0670	0.0634
A^+	0.0742	0.0417	0.0972	0.0774	0.0884	0.0625	0.0938	0.0634
A^-	0.0000	0.0000	0.0000	0.0048	0.0000	0.0000	0.0000	0.0106

According to these values, the ten ships were ranked, as listed in Table 7 and depicted in Figure 3. The results of the TOPSIS approach show that shipS_5ranks first, while ship S_2ranks second. Ship S_{10} and shipS_9rank third and fourth, respectively.

Table 7: Distance from PIS (D^+), Distance from NIS (D^-), Relative Closeness to the Ideal Solution (D^*), and Rank

Ship	D^+	D^-	D^*	Rank
S_1	0.1879	0.0504	0.2114	7
S_2	0.1107	0.1656	0.5994	2
S_3	0.1977	0.0457	0.1879	9
S_4	0.1314	0.1163	0.4694	5
S_5	0.1020	0.1583	0.6081	1
S_6	0.2002	0.0445	0.1818	10
S_7	0.1860	0.0642	0.2566	6
S_8	0.1983	0.0465	0.1899	8
S_9	0.1257	0.1314	0.5111	4
S_{10}	0.1197	0.1415	0.5416	3

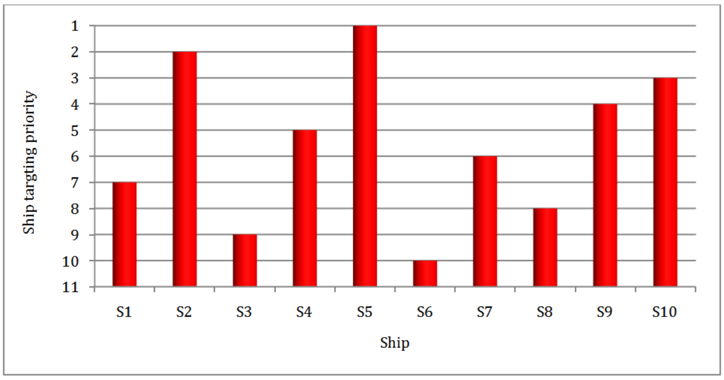

Figure 3: Ship Targeting Priorities Based on TOPSIS Approach

The third approach applied for ranking the same ships is the proposed hybrid approach, which combines AHP and TOPSIS approaches. Three main phases to rank the ships are involved as follows:

Phase 1: Construct a hierarchy structure for the problem and design the expert judgment form,

Phase 2: Use AHP approach to weigh factors, and

Phase 3: Use TOPSIS to rank the alternative ships to be inspected.

In Figure 1, the hierarchy structure has already been built. More specifically, the goal was to calculate the weight for each targeting factor, the factors were identified and the alternative ships specified. Then, the pair-wise comparisons were carried out by each expert. A group of twelve experts with individual minimum experience of 10 years in different positions in PSC field participated in the evaluation process. The consistency check was carried out by using Equations (11) to (13). The results obtained are listed in Table 8.

All decision matrices were aggregated using Equation (10) and weight of each factor was calculated using Equation (14). The results obtained are listed in Table 9 and depicted in Figure 4.

Finally, the TOPSIS approach was applied in order to rank the ships. The weights of factors which were calculated by the AHP approach were used as input to the TOPSIS approach. According to these values, the ten ships were ranked, as depicted in Figure 5.

Table 8: Consistency Check of Judgments

Expert	Consistency Index (CI)	Consistency Ratio (CR)
D_1	0.0262	0.0186
D_2	0.0089	0.0063
D_3	0.0033	0.0024
D_4	0.0000	0.0000
D_5	0.0751	0.0533
D_6	0.0336	0.0238
D_7	0.0248	0.0176
D_8	0.0203	0.0144
D_9	0.0088	0.0062
D_{10}	0.1194	0.0847
D_{11}	0.0000	0.0000
D_{12}	0.0027	0.0019

Note: Random Consistency Index (RCI) = 1.41, for n = 8

Table 9: Factor Weights

Factor	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	Geometric Mean	Weight
f_1	1.0000	1.4628	0.3337	2.5671	1.3807	0.6674	2.7198	3.2170	1.3353	0.1322
f_2	0.6836	1.0000	0.2430	1.7994	1.1225	0.4306	1.9064	2.3221	0.9457	0.0936
f_3	2.9966	4.1153	1.0000	5.4381	3.5794	1.7994	5.5700	5.9012	3.3039	0.3270
f_4	0.3895	0.5557	0.1839	1.0000	0.5000	0.2476	1.0595	1.3348	0.5375	0.0532
f_5	0.7243	0.8909	0.2794	2.0000	1.0000	0.3536	1.9064	2.3450	0.9321	0.0923
f_6	1.4983	2.3221	0.5557	4.0395	2.8284	1.0000	3.8843	4.2096	2.0880	0.2067
f_7	0.3677	0.5246	0.1795	0.9439	0.5246	0.2574	1.0000	1.2599	0.5226	0.0517
f_8	0.3108	0.4306	0.1695	0.7492	0.4264	0.2376	0.7937	1.0000	0.4385	0.0434

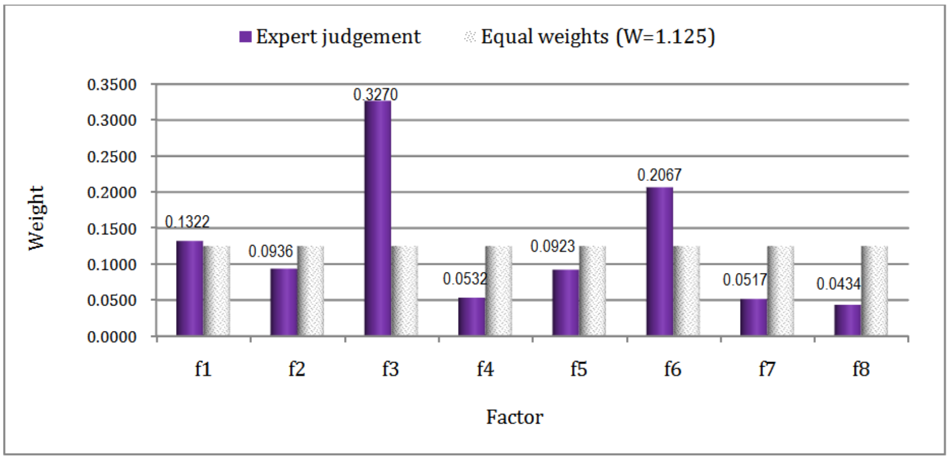

Figure 4: Weight of Factors using AHP approach

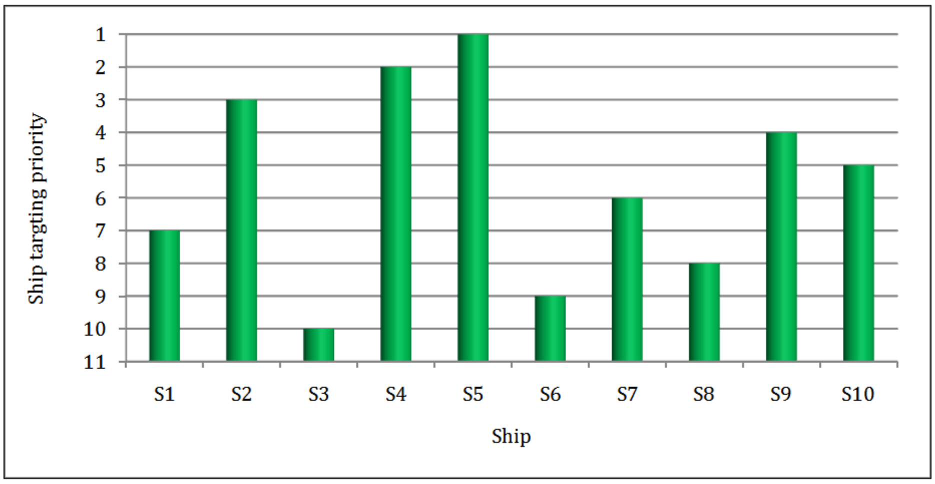

Figure 5: Ship Targeting Priorities Based on the Hybrid Approach

The results of the hybrid approach show that shipS_5 ranks first, while ship S_4 ranks second. Ship S_2 and shipS_9 rank third and fourth, respectively. The results obtained from the hybrid approach reflect the importance of weights of the factors and its impact on selecting the four ships. For instance, ship S_5 comes on top of all ships, due to its high TFVs: f_3 (ship flag), f_6 (classification society) and f_1(ship age); so were the cases of ship S_4, S_2 and S_9.

Results obtained from the different approaches applied, namely: WSM, TOPSIS and the hybrid approaches were compared and ranks of the ten ships using the three approaches are illustrated in Figure 6.

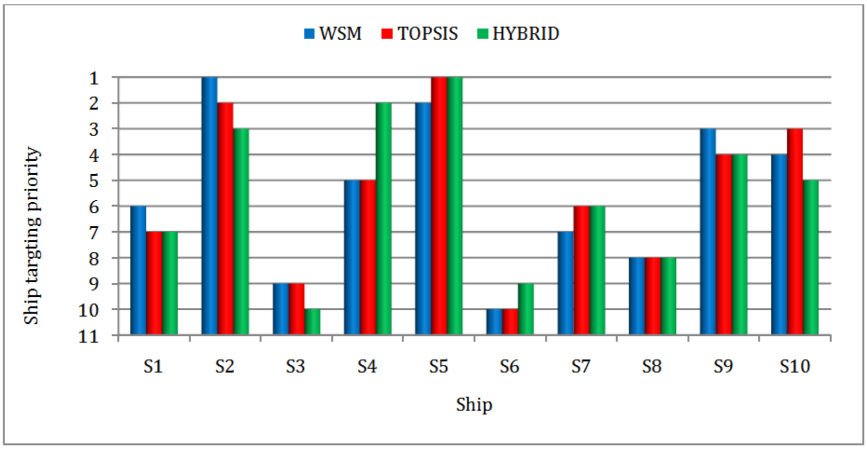

Figure 6: Comparison of WSM, TOPSIS and Hybrid Approaches Results

The Results Obtained from the Three Approaches Were Presented and it was Found that:

- Ship S_5 was targeted, as first ship to be inspected according to the hybrid and TOPSIS approaches, in disagreement with the WSM approach, which ranks ship S_5 second to ship S_2.
- Relatively large variations were found among the approaches results. Especially, for the case of ship S_4, where it ranks second according to the hybrid approach, and fifth according to both the WSM and TOPSIS approaches.
- Likewise, ship S_2 ranks third according to the hybrid approach, in disagreement with the WSM and TOPSIS approaches, which rank ship S_2 first and second, respectively.
- Ship S_9ranksfourth according to the hybrid approach in agreement with the TOPSIS approach and disagreement with WSM approach, which ranks ship S_9third.
- Ships S_1, S_3, S_6, S_7 and S_{10} rank in the hybrid approach up or down by one level to their ranking in the WSM and TOPSIS approaches, whereas ship S_8 ranks eighth in the three approaches.

CONCLUSIONS AND SUGGESTIONS

To improve the effectiveness of the PSC programme, the TOPSIS approach was introduced. Comparison between the TOPSIS and WSM approaches, lead to two main conclusions. Firstly, the TOPSIS approach can accommodate more information among factors than the WSM approach. The values and the potential relations among factors are considered in TOPSIS, while WSM considers the values only. So, WSM is easily affected by some bigger values and loses the right direction, which, in turn, causes uncertainty in its results. Secondly, TOPSIS is more efficient in taking advantage of the given information than WSM. Under the same limitation of information, TOPSIS is more powerful in finding the substandard ships than WSM.

In spite of the aforementioned advantage of TOPSIS, it has its own shortcomings. One of these shortcomings is the method weight of individual factors is determined. AHP provides a suitable technique to solve this type of shortcoming, where weights can be obtained using the pair-wise comparison of factors. The experts are asked to use their experience to compare the factors in pairs subjectively, but the consistency of judgments provided is checked. Data which are highly inconsistent are either waived or returned to the expert for reconsideration, thus reducing uncertainties in results to the minimum level possible. The main criticism of AHP approach is that it requires many time-consuming calculations, depending upon the number of the factors. As the number of factors increases, the dimension of the problem expands. This could lead to a great number of mathematical operations. Under such circumstances, it is preferable to use the TOPSIS approach, for ranking the alternatives, where no recourse to pair-wise comparisons of alternatives is called upon.

The AHP-TOPSIS hybrid approach overcomes the difficulties found when applying the TOPSIS and AHP approaches individuality. The AHP approach is first used to determine the weight of individual factors. Then TOPSIS is used to complete the analysis until alternative ships are ranked. It can be concluded that the proposed hybrid approach, which is the main contribution of this endeavor, solves the selection problem associated with the three approaches used herein, and has a direct impact on the effectiveness of PSC inspections.

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APPENDIX A

Table A1: Targeting System used by the Mediterranean MOU

Target Factor	Target Factor Value (TFV)
Ship age	0 Point: 0-5 years; 5 Points: 6-10 years; 10 Points: 11-15 years; 10+1 points for each year exceeding 15 years; 16-20 years; 15+2 points for each year exceeding 20 years.
Ship type	4 Points: A ship with code 13, 30, 40, 55, 60, 61, 70, or 71; 0 Point: All others.
Ship flag	1 Point for each percentage point in excess (decimal number rounded up) based upon 3 year rolling average detention figure.
Number of deficiencies	0.6 Point for each deficiency found in last 4 initial inspections or follow ups with new deficiency (decimal number rounded up).
Number of detentions	Depending on number of detentions in last 4 inspections: 15 Points: 1 detention; 30 Points: 2 detentions; 60 Points: 3 detentions; 100 Points: 4 detentions.
Classification society	10 Points: Non IACS* (The members of IACS are ABS, BV, CCS, DNV, GL, KR, LR, NK, RS, and RINA); 0 Point: IACS.
Number of outstanding deficiencies	2 Points for each outstanding deficiency: A deficiency recorded in the Med targeting system in the last initial inspection or associated follow ups and not marked as rectified.
Time since last inspection	3 Points: 6-12 months; 6 Points: 12-24 months; 50 Points: Over 24 months or never inspected in the region (including new ships).
Target Factor Value (TFV)	Sum of points corresponding to each target factor.

Source: Med MOU Manual, 2017 ***IACS:** International Association of Classification Societies

Table A.2: Ship Targeting Priority used by the Med MOU

Priority level	Total TFV
Priority I (very high)	points> 100
Priority II (high)	41 - 100 points
Priority III (medium)	11 - 40 points
Priority □ (low)	0 - 10 points

APPENDIX B

Table B.1: Ship Particulars Recorded by PSC

Factor / Ship	Ship age (year) (f_1)	Ship Type (f_2)	Ship Flag (f_3)	Number of Deficiencies (f_4)	Number of Detentions (f_5)	Classification Society (f_6)	Number of Outstanding Deficiencies (f_7)	Time Since Last Inspection (Month) (f_8)
S_1	26	Container	China	15	0	IACS	1	06
S_2	36	Oil tanker	Malta	79	0	Non IACS	7	04
S_3	05	Chemical tanker	Cyprus	12	0	IACS	1	04
S_4	19	Oil tanker	Algeria	37	1	Non IACS	0	06
S_5	33	General cargo	Ecuador	35	1	Non IACS	1	12
S_6	08	Refrigerated cargo	Turkey	05	0	IACS	1	02
S_7	18	Ro/Ro ship	Lebanon	07	1	IACS	0	02
S_8	11	Gas carrier	Cyprus	12	0	IACS	0	04
S_9	24	Multi-purpose	Togo	69	1	Non IACS	3	12
S_{10}	25	Bulk carrier	Kenya	44	2	IACS	5	12

Source: Med MOU, Annual reports on PSC inspections, 2017