Journal of Environmental Management 90 (2009) 1469–1475

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

A hybrid design methodology for structuring an Integrated Environmental Management System (IEMS) for shipping business

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ARTICLE INFO

Article history:
Received 6 December 2007
Received in revised form
9 September 2008
Accepted 6 October 2008
Available online 28 November 2008

Keywords:
ISO 14001:2004
International Safety Management Code
Integrated Environmental Management System
Maritime transportation industry
Fuzzy Axiomatic Design
Analytic Hierarchy Process

ABSTRACT

The International Safety Management (ISM) Code defines a broad framework for the safe management and operation of merchant ships, maintaining high standards of safety and environmental protection. On the other hand, ISO 14001:2004 provides a generic, worldwide environmental management standard that has been utilized by several industries. Both the ISM Code and ISO 14001:2004 have the practical goal of establishing a sustainable Integrated Environmental Management System (IEMS) for shipping businesses. This paper presents a hybrid design methodology that shows how requirements from both standards can be combined into a single execution scheme. Specifically, the Analytic Hierarchy Process (AHP) and Fuzzy Axiomatic Design (FAD) are used to structure an IEMS for ship management companies. This research provides decision aid to maritime executives in order to enhance the environmental performance in the shipping industry.

1. Introduction

Although new technologies and recent innovations have been integrated into many different transportation systems, ongoing efforts to reach environmental targets and manage global requirements are too often frustrated (Tsamboulas and Mikroudis, 2000; Toffoli et al., 2005; Giannouli et al., 2006; Vieira et al., 2007). The environmental impact of merchant ships is of particular importance, through both routine operations (Hyvattinen and Hilden, 2004) and catastrophic maritime casualties (Hofer, 2003; Renner, 2006; Loureiro et al., 2006; Ernst et al., 2006; Wirtz et al., 2007). This fact has motivated a global effort towards enhancing the Environmental Management Systems (EMS) used in the shipping business.

To this end, the ISO 14000 series of generic environmental standards has been integrated into the management systems of professional shipping organizations worldwide (Magerholm Fet, 1998). The International Safety Management (ISM) Code, adopted by the International Maritime Organization (IMO) by resolution *A.741(18)*, defines additional performance standards specifically tailored for the maritime industry. The ISM Code also encourages continuous improvement in the safety-related and environmental aspects of ship management. Briefly, the ISM Code aims to ensure safety at sea, prevent human injury or loss of life, and avoid damage to the marine environment (Glazar, 1998). However, recent researches on marine casualties and their significant environmental impact (Derraik, 2002; Burgherr, 2007) have highlighted the urgent need to redesign the procedures followed for implementing these diverse regulations and standards. Recalling the catastrophic impacts of previous famous marine casualties *(i.e., the M/T vessels Torrey Canyon in 1967, Exxon Valdez in 1989, Erika in 1999, and Prestige in 2002)* has also increased the motivation on needs for improving the current EMS practice in shipping industry. Ongoing maritime casualties and their associated environmental threats can be reduced by designing an Integrated Environmental Management System (IEMS) that includes both safety-related requirements and environmental aspects of shipping operations.

The goal of this paper is to develop one such system, using a hybrid methodology that ensures compliance with requirements of the ISM Code and ISO 14001:2004. Section 2 of this paper introduces the implementation and regulatory concepts behind EMS currently used in the maritime transportation industry. Our methodology for designing an IEMS specific to be implemented in ship management companies is described in Section 3. The outcome of the requirements analysis and a proposed IEMS model are discussed in Section 4. In addition to serving as a decision aid, implementing the proposed IEMS would reduce the environmental impact of marine disasters.

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doi:10.1016/j.jenvman.2008.10.005

2. A brief overview of current EMS applications

The requirements of an EMS include organizational procedures, responsibilities, processes, and other necessities for systematically implementing corporate environmental policies (Begley, 1996; Bergeron, 1997; Fresner, 1998). Existing statutory procedures, pressure from international authorities, and increasing environmental threats have forced most organizations to adopt some forms of EMS as an integral part of their strategies to reduce environmental risks. This trend can be seen through organizational behaviors of several global industries (Chen, 1997). To investigate current EMS implementations, Hui et al. (2001) carried out an industry-based survey of manufacturing companies using the Analytic Hierarchy Process (AHP). Based on these results, *environmental conservation* was cited as the prevailing motivator used in EMS implementations.

Integrating an analytical model into an EMS has been shown to increase its consistency of implementation. For example, Lozano and Valles (2007) proposed the SWOT (Strengths, Weaknesses, Opportunities, and Threats) methodology to analyze the strategic consequences of EMS implementations used by local public administrations. The integration of an Environmental Impact Assessment (EIA) report can be cited as another integrated mechanism (Sebastiani et al., 2001) to increase EMS performance. In practice, the design, development, and implementation of Integrated Management Systems (IMS) with respect to quality, risk, safety, health, and environmental concerns require great know-how, professional human resources (Jabbour and Santos, 2008), and a systematic approach (Holdsworth, 2003) to be successful.

Despite the high level of motivation behind researches on EMS implementations in land-based industries, the academic literature on exploring the EMS practices in maritime transportation is scant. Environmental management in the shipping business requires the significant use of information technology (IT) (Smith, 1996) to be effective, in addition to competent human resources in both managerial (Celik and Er, 2006) and operational (Celik et al., 2007a) activities. Recently, prestigious maritime classification societies have published technical guidelines for shipping management companies to help them establish an IMS. The guidelines of ABS (American Bureau of Shipping) for *Marine Health, Safety, Quality, and Environmental Management* (HSQE) can be cited as an example. The HSQE guidelines are based on coupling the ISM Code and the standards ISO 9001, ISO 14001, and OHSAS 18001.

The shipping companies have been forced by regulations to improve operational standards and enhance environmental protection (Mathiesen, 1994). Coupling the ISM Code with ISO 14001:2004, the latest generic environmental management standards, provides additional challenges to shipping operators. At this point, many of the professional company have failed to establish sustainable IEMS. As mentioned earlier, the goal of this paper is to design an IEMS for the shipping business that combines the ISO 14001:2004 standard with the ISM Code. The most relevant previous research is that of Thomas (1998), who proposed a framework for maximizing ISM compliance with ISO 14001. However, to be fully effective such research must be capable of quantifying the degree of compliance with ISO 14001:2004 and ISM Code requirements. The methodology proposed within this paper serves this purpose.

3. Designing an IEMS

Our hybrid methodology is designed to measure the degree of conformity between ISO 14001:2004 requirements and the ISM Code clauses. The latter set of requirements, being mandatory, will serve as the foundation of the proposed IEMS. The Analytic Hierarchy Process (AHP) and Fuzzy Axiomatic Design (FAD) are both used to increase the utility and consistency of the model.

3.1. Theory of AHP

The AHP is a tool for quantifying decision-making processes with multiple criteria (Saaty, 1980, 1988, 1991). It is based on computing a set of normalized eigenvectors, also called priority vectors, of the decision matrix (Saaty, 1994). Table 1 illustrates Saaty's scale of measurement, which is used to quantify the relative importance of each pair of decision elements within the hierarchy.

Golden et al. (1989) represent the mathematical concept of AHP as follows. First of all, a Decision Matrix (DM) is constructed using pairwise comparisons of n relevant criteria. The positive, reciprocal matrix DM = (a_{ij}) is thus defined as

$$DM = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}, \text{ where } a_{ij} = 1/a_{ji} \text{ for all } i,j = 1,2,\ldots,n. \quad (1)$$

The goal is to compute the vector of priorities $w = (w_1, w_2, \ldots, w_n)$ that maximizes some predetermined goal. If the judgments were perfectly consistent, meaning that $a_{ik}a_{kj} = a_{ij}$ for all $i, j, k = 1, 2, \ldots, n$, then the elements of the matrix could be expressed as $a_{ij} = w_i/w_j$. This can be demonstrated with the following formula:

$$a_{ik}a_{kj} = w_i w_k / w_k w_j = w_i/w_j = a_{ij} \quad \text{for all } i,j,k = 1,2,\ldots,n. \quad (2)$$

Normalizing any column j of the matrix DM thus yields the final weights:

$$w_i = a_{ij} / \left(\sum_{k=1}^{n} a_{kj} \right) \quad \text{for all } i = 1,2,\ldots,n. \quad (3)$$

Errors in judgment are generally expected, however, so the weights obtained by column normalization may vary with the selected column. Saaty's eigenvector method is an approach to estimating the weights when there are errors in the judgment matrix. It computes w as the principal eigenvector of DM: $\mathrm{DM}_w = \lambda_{\max} w$, where $\lambda_{\max}$ is the maximum eigenvalue of DM. This is equivalent to the following formula:

$$w_i = \frac{\sum_{j=1}^{n} a_{ij} w_j}{\lambda_{\max}} \quad \text{for all } i = 1,2,\ldots,n. \quad (4)$$

The degree of inconsistency in the judgments can also be measured using the eigenvector method. $\lambda_{\max}$ is always greater than or equal to n for a positive, reciprocal matrix; furthermore, it is equal to n if and only if the a_{ij} are perfectly consistent (as defined above). The difference $\lambda_{\max} - n$ thus provides a useful measure of internal consistency. Specifically, Saaty defines the consistency index as

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}. \quad (5)$$

Table 1
Saaty's scale of measurement.

Intensity of importance	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

Table 2
Evaluation scale for conformity assessment.

Linguistic terms on conformity degree	Corresponding fuzzy numbers	Abbreviation
Clauses at least *fully* conforming	0.8, 1, 1	F
Clauses at least *substantially* conforming	0.6, 1, 1	S
Clauses at least *partially* conforming	0.4, 1, 1	P
Clauses at least *low* conforming	0.1, 1, 1	L
Closes at least *very low* conforming	0, 1, 1	VL

For a matrix of size n, one can compute a large number of random matrices; their mean CI value is named the random index (RI). The Consistency Ratio (CR) is

$$CR = CI/RI. \tag{6}$$

Values of $CR \leq 0.1$ are typically considered acceptable. If a decision matrix has a CR larger than 0.1, its judgments should be revised.

The AHP is a common decision-making tool in several disciplines and industries, including energy, manufacturing, and education (Steuer, 2003; Kumar and Vaidya, 2006). It also frequently appears in integrated models (Ho, 2008). In this study, AHP is used to prioritize the inclusion of ISO 14001:2004 requirements (i.e. planning, management review, etc.) in the IEMS.

3.2. Fundamentals of Fuzzy Axiomatic Design

The theory of FAD establishes a scientific foundation for improving design activities by applying a set of axioms (Suh, 2001). One critical aspect of FAD is determining the minimum set of *functional requirements*: mutually independent requirements that characterize the design goals (Kulak et al., 2005). The Information Content (I) of the design based on FAD methodology is another important parameter. According to FAD theory, if several designs meet the predetermined goal then the alternative with the smallest I is determined as the best. In the computation stages of FAD applications, decision parameters are represented by triangular fuzzy numbers (TFNs). This allows decision-makers to quantify expert judgments on decision parameters and incorporate multiple criteria consistently. Table 2 collects linguistic terms on conformity assessment and fuzzy numbers that will be used later in this paper.

The *common area* of a model is defined as the intersection of (a) the decision ranges for each attribute and (b) the system ranges of alternatives. The information content of the ith attribute is computed by calculating the ratio of the common range to the system:

$$I_i = \log\left(\frac{1}{p_i}\right), \tag{7}$$

$$p_i = \frac{\text{common range}}{\text{system range}}, \tag{8}$$

$$I_i = \log_2\left(\frac{\text{system range}}{\text{common range}}\right). \tag{9}$$

FAD is a relatively new tool in decision-making and its applications in different fields are to become widespread. Initially, Kulak and Kahraman (2005) proposed using a hybrid of FAD and AHP methodologies for modeling transportation company selection problem under multiple criteria. The FAD can be applied to

Table 3
Fundamental clauses of ISM Code.

Fundamental clauses	Clause numbers
General	Clause 1
Safety and environmental protection policy	Clause 2
Company responsibilities and authority	Clause 3
Designated person(s)	Clause 4
Master's responsibility and authority	Clause 5
Resources and personnel	Clause 6
Development of plans for shipboard operations	Clause 7
Emergency preparedness	Clause 8
Reports and analysis of nonconformities and accidents	Clause 9
Maintenance of the ship and equipment	Clause 10
Documentation	Clause 11
Company verification, review, and evaluation	Clause 12
Certification and periodical verification	Clause 13
Interim certification	Clause 14
Verification	Clause 15
Forms of certificates	Clause 16

Table 4
Hierarchic structure on the EMS requirements of ISO 14001:2004.

Main requirements	Code	Sub-requirements	Code
EMS requirements of ISO 14001:2004			
General requirements (4.1)	R_1	–	–
Environmental policy (4.2)	R_2	–	–
Planning (4.3)	R_3	Environmental aspects (4.3.1)	R_{31}
		Legal and other requirements (4.3.2)	R_{32}
		Objectives, targets, programs (4.3.3)	R_{33}
Implementation and operation (4.4)	R_4	Resources, roles, responsibility and authority (4.4.1)	R_{41}
		Competence, training, awareness (4.4.2)	R_{42}
		Communication (4.4.3)	R_{43}
		Documentation (4.4.4)	R_{44}
		Control of document (4.4.5)	R_{45}
		Operational control (4.4.6)	R_{46}
		Emergency preparedness and response (4.4.7)	R_{47}
Checking and corrective action (4.5)	R_5	Monitoring and measurement (4.5.1)	R_{51}
		Evaluation of compliance (4.5.2)	R_{52}
		Nonconformity, corrective and preventive action (4.5.3)	R_{53}
		Control of records (4.5.4)	R_{54}
		Internal audit (4.5.5)	R_{55}
Management review (4.6)	R_6	Management review	–

Table 5
Priority weights on EMS requirements of ISO 14001:2004.

Level of hierarchy	Assessment factors	Limiting values	Normalized values
1st level	R_1	0.123	0.176
	R_2	0.170	0.244
	R_3	0.078	0.112
	R_4	0.146	0.210
	R_5	0.079	0.114
	R_6	0.101	0.145
2nd level	R_{31}	0.036	0.464
	R_{32}	0.022	0.281
	R_{33}	0.020	0.255
	R_{41}	0.026	0.175
	R_{42}	0.031	0.211
	R_{43}	0.016	0.110
	R_{44}	0.016	0.107
	R_{45}	0.015	0.105
	R_{46}	0.019	0.133
	R_{47}	0.023	0.160
	R_{51}	0.016	0.197
	R_{52}	0.014	0.182
	R_{53}	0.018	0.222
	R_{54}	0.016	0.207
	R_{55}	0.015	0.192

Table 6
Definition of FRs in fuzzy linguistic terms.

Maritime expert groups	EMS requirements (ISO 14001:2004)																
	R_1	R_2	R_3						R_4						R_5		R_6
			R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{44}	R_{45}	R_{46}	R_{47}	R_{51}	R_{52}	R_{53}	R_{54}	R_{55}	
Group I: ship managers	P	P	F	F	S	S	P	P	L	VL	S	F	P	P	L	L	S	P
Group II: environmental experts	L	F	F	F	F	F	S	S	P	L	F	F	S	F	S	L	P	S
Group III: administrative organizations	L	P	S	F	F	S	P	P	P	L	S	F	S	P	S	P	P	P

many different domains, including system architecture (Hirani and Suh, 2005), software design (Chen et al., 2001), product design (Thielman et al., 2005), and decision-making (Celik et al., 2007b, 2008).

Furthermore, the nature of focused problem is suitable to apply FAD in order to take the advantage of information axioms on system redesign process. Therefore, this paper uses FAD to measure the level of conformity between clauses of the ISM Code and ISO 14001:2004 standard. On the other hand, the AHP is used to weight and prioritize the requirements of ISO 14001:2004. System design of IEMS is targeted using the design synergy of FAD and prioritization ability of AHP which is coupled under a hybrid approach. The methodological foundation of hybrid approach is structured in order to ensure the transformation of judgments (in TFNs form) into useful knowledge via information content values.

3.3. *Structuring evaluation framework of hybrid approach*

The ISM Code was created in the late 1980s, a time of growing concerns about poor management standards in the shipping industry. Initially, the IMO simply adopted a few technical guidelines on ensuring safety and preventing pollution. After a great many revisions and amendments, however, the ISM Code became a mandatory international standard for the operation of ships (Glazar, 1998; Santos-Reyes and Beard, 2002). Table 3 lists the fundamental clauses of the ISM Code.

Environmental management in the shipping industry is another significant issue especially in operational level. In practice, the ISO 14001 standard has been adopted by limited numbers of professional shipping firms worldwide. In a broader context, the ISO 14001:2004 standard is applicable to any organization wishing to establish, implement, and improve an EMS. However, it requires greater effort in shipping industry to fulfill the expectations of international maritime authorities on regulation basis. Therefore, both the EMS requirements and ISM Code clauses need to be taken into account while establishing an IEMS in shipping business. Table 4 lists the hierarchy of ISO 14001:2004 EMS requirements.

3.4. *Initial inputs and outputs of proposed methodology*

This section describes the data used and results generated at each stage of the hybrid methodology.

3.4.1. *Computing priorities for the ISO 14001:2004 EMS requirements*

The appropriate weights for the EMS requirements are computed using AHP. First, a decision matrix containing all pairwise comparisons of the criteria must be created for each level of hierarchy. Various industry experts (*administrative organizations, marine environmental managers, and shipping managers*) were contacted through maritime societies to provide the judgments on required pairwise comparisons. Aggregated results of the expert judgments from different groups are taken into account. These data were inserted into the *Super Decisions* software package to compute the priority weights, which are listed in Table 5. According to these findings, the most significant requirements of ISO 14001:2004 are *Clauses* 4.2 and 4.4 within the first level and *Clauses* 4.3.1, 4.4.2, and 4.5.3 in the second level. An effective IEMS for the shipping business must focus on these standards to maintain a high level of compliance.

3.4.2. *Definition of FRs*

The next step is to represent the design intervals as functional requirements (FRs) using TFNs. Table 6 repeats the expert judgments in linguistic terms, and Table 7 describes the group consensus for FRs in TFNs form based on the aggregation algorithm of Chen (1998).

3.4.3. *Assigning the linguistic judgments on conformity levels of ISM Code clauses*

The same expert groups, mentioned within previous section in detail, helped define linguistic judgments on the level of conformity over ISM Code clauses, as indicated in Table 8.

For clarifying the calculation procedure, the weighted information content value for the *ISM Code – Clauses* 3 with respect to R_1 requirements of ISO 14001:2004 is illustrated as follows: System Range (0.1,1,1); $\mathrm{FR}_{R_1}(0.197,\ 1,\ 1)$

$$I(\text{ISM Code—Clause 3})_{R_1} = \log_2\left(\frac{\frac{(1-0.1)*1}{2}}{\frac{(1-0.197)*1}{2}}\right) = 0.165,$$

$$Iw(\text{ISM Code—Clause 3})_{R_1} = 0.165*0.176 = 0.029.$$

3.5. *Final results*

The FAD algorithm provides the relative information content of each clause within the ISM Code. The weighted information content of the ISM Code clauses is given in Table 9.

Table 7
Aggregated TFNs on EMS requirements of ISO 14001:2004.

R_1	R_2	R_3						R_4						R_5			R_6
		R_{31}	R_{32}	R_{33}	R_{41}	R_{42}	R_{43}	R_{44}	R_{45}	R_{46}	R_{47}	R_{51}	R_{52}	R_{53}	R_{54}	R_{55}	
(0.197, 1.000, 1.000)	(0.529, 1.000, 1.000)	(0.734, 1.000, 1.000)	(0.800, 1.000, 1.000)	(0.734, 1.000, 1.000)	(0.666, 1.000, 1.000)	(0.466, 1.000, 1.000)	(0.466, 1.000, 1.000)	(0.303, 1.000, 1.000)	(0.067, 1.000, 1.000)	(0.666, 1.000, 1.000)	(0.800, 1.000, 1.000)	(0.535, 1.000, 1.000)	(0.529, 1.000, 1.000)	(0.441, 1.000, 1.000)	(0.197, 1.000, 1.000)	(0.466, 1.000, 1.000)	(0.466; 1.000, 1.000)

Table 8
Linguistic judgments on conformity levels of ISM Code clauses.

Clause number (ISM Code)	EMS requirements and priorities of ISO 14001:2004																	
	R_1 0.176	R_2 0.244	R_3 0.112			R_4 0.210							R_5 0.114					R_6 0.145
			R_{31} 0.464	R_{32} 0.281	R_{33} 0.255	R_{41} 0.175	R_{42} 0.211	R_{43} 0.110	R_{44} 0.107	R_{45} 0.105	R_{46} 0.133	R_{47} 0.160	R_{51} 0.197	R_{52} 0.182	R_{53} 0.222	R_{54} 0.207	R_{55} 0.192	
Clause 1	P	S	P	L	P	L	L	L	VL	VL	L	L	P	L	L	VL	VL	VL
Clause 2	P	S	P	P	P	L	L	P	VL	VL	P	P	L	L	L	VL	VL	VL
Clause 3	L	P	S	P	S	F	F	S	P	P	S	F	S	S	S	P	S	S
Clause 4	L	L	P	L	P	F	S	P	L	VL	S	P	P	P	P	L	P	P
Clause 5	L	L	P	L	P	F	S	S	S	P	S	F	S	S	S	P	P	P
Clause 6	L	P	L	P	P	S	F	S	L	VL	S	S	P	L	L	VL	L	L
Clause 7	L	L	S	P	S	S	S	S	P	P	F	F	S	S	P	L	L	L
Clause 8	L	L	L	P	L	P	S	P	L	P	F	P	L	L	L	L	P	P
Clause 9	L	L	L	P	P	P	L	L	L	L	P	P	P	L	F	L	P	P
Clause 10	L	L	P	L	S	P	S	P	L	P	P	F	P	L	P	L	P	P
Clause 11	L	L	P	P	P	L	L	P	F	F	P	P	P	P	L	F	L	L
Clause 12	L	L	L	P	L	P	P	L	L	L	P	P	P	L	P	L	F	F
Clause 13	L	L	L	P	L	L	L	P	P	P	L	L	VL	VL	VL	L	VL	L
Clause 14	VL	VL	VL	P	L	VL	P	P	L	VL	L	P	VL	VL	L	VL	VL	VL
Clause 15	L	L	P	P	VL	L	L	L	VL	VL	L	P	L	L	L	VL	L	VL
Clause 16	L	L	VL	L	VL	VL	L	VL	L	VL	VL	VL	L	VL	VL	P	VL	VL

Finally, Table 10 presents the targeted results of this paper: the ISM Code clauses are ranked with respect to their overall compliance with the ISO 14001:2004 requirements. The relation between the assigned ranks of ISM Code clauses and corresponding information contents lay to the transformation of fuzzy linguistic judgments based on FAD algorithm. The quantitative outcomes are planned to be utilized during system design process of IEMS in advance.

4. Decision aid to structure an effective IEMS implementation in ship management

The hybrid model in this paper targets to represent quantitative outcomes in order to aid the state-art-of the IEMS in shipping business cycle. Despite the expected benefits of IEMS, the execution procedure should be avoided from excessive bureaucracy in practice. Therefore, the AHP gives an opportunity for system designer or executive managers about understanding the priorities of requirements within ISO 14001 standard when it is integrated with current ISM Code procedure. At this point of research, motivating on the ISO 14001 as a hierarchic viewpoint gives the shipping managers or management system designers (maritime consultants) to prioritize the requirements of standards during IEMS design. As the mandatory requirements of the ISM Code that are continuously monitored by maritime authorities, maintaining the minimum requirements of ISM Code within originally designed IEMS has a vital importance. That's why the ISM Codes which have higher information contents (worst design conditions) require additional efforts & attention by relevant shipping managers. For managing this kinds of incompliance, a couple of ISM Code clauses can be maintain separately from the main procedure of IEMS. On the other hand, the lower information contents for the ISM Code clauses mean that the high level of integration can be achieved on IEMS basis to reduce the probable environmental risks in shipping business cycle.

Hence, the results of the proposed methodology clearly indicate that *Clause* 3 of the ISM Code, with a total information content of 0.219, can easily be integrated into an IEMS. Moreover, we find that *Clauses* 5, 7, 6, 10, 2, 4, and 1 conform with ISO 14001:2004 standards well enough for shipping organizations to include them in a hybrid IEMS without any major conflict. Nevertheless, there may be problems implementing *Clauses* 11, 15, 13, 14, and 16 into the proposed IEMS as these requirements have higher information contents (0.726, 0.845, 0.852, 0.916, and 0.940 respectively). To aid shipping organizations in managing compliance with the ISM Code and ISO 14001:2004 standards, Fig. 1

Table 9
Distribution of weighted information contents over main requirements of ISO 14001:2004.

ISM Code	R_1	R_2	R_3	R_4	R_5	R_6
Clause 1	0.000	0.000	0.163	0.230	0.072	0.131
Clause 2	0.000	0.000	0.145	0.180	0.085	0.131
Clause 3	0.029	0.085	0.097	0.007	0.000	0.000
Clause 4	0.029	0.228	0.163	0.075	0.026	0.024
Clause 5	0.029	0.228	0.163	0.007	0.004	0.024
Clause 6	0.029	0.085	0.175	0.061	0.069	0.109
Clause 7	0.029	0.228	0.097	0.009	0.023	0.109
Clause 8	0.029	0.228	0.192	0.096	0.066	0.024
Clause 9	0.029	0.228	0.175	0.166	0.035	0.024
Clause 10	0.029	0.228	0.146	0.067	0.038	0.024
Clause 11	0.029	0.228	0.145	0.166	0.049	0.109
Clause 12	0.029	0.228	0.192	0.141	0.034	0.000
Clause 13	0.029	0.228	0.192	0.202	0.092	0.109
Clause 14	0.056	0.265	0.200	0.173	0.092	0.131
Clause 15	0.029	0.228	0.166	0.210	0.082	0.131
Clause 16	0.029	0.228	0.222	0.245	0.085	0.131

Table 10
Final results on total information contents and ranking.

Rank	ISM Code	$\sum I$
1	Clause 3	0.219
2	Clause 5	0.455
3	Clause 7	0.496
4	Clause 6	0.528
5	Clause 10	0.532
6	Clause 2	0.541
7	Clause 4	0.544
8	Clause 1	0.596
9	Clause 12	0.623
10	Clause 8	0.634
11	Clause 9	0.658
12	Clause 11	0.726
13	Clause 15	0.845
14	Clause 13	0.852
15	Clause 14	0.916
16	Clause 16	0.940

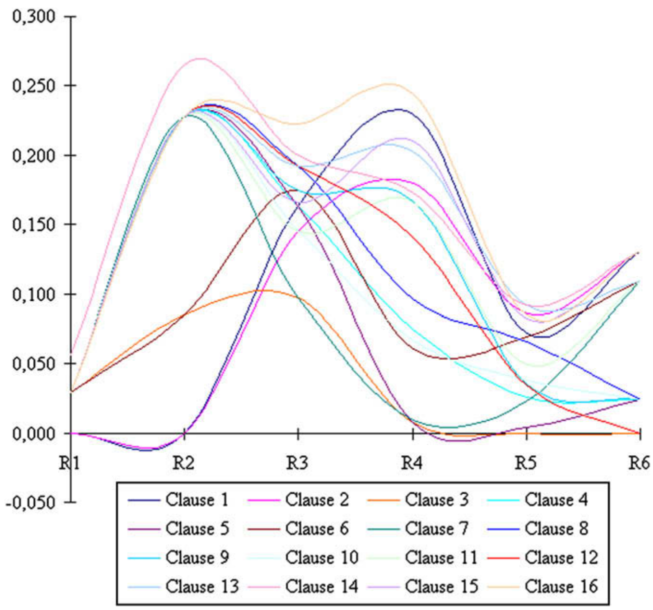

Fig. 1. Weighted information content of the ISM code clauses.

illustrates the weighted information content of the ISM Code clauses graphically.

As the figure indicates, it may require great effort to implement all the requirements of ISO 14001:2004 into a practical IEMS especially with regard to defining the scope of environmental policy, designing new implementation procedures, and improving operational processes. On the other hand, more general requirements and corrective action processes will properly satisfy the expectations of shipping operators. An IEMS following these priorities would integrate some ISO 14001:2004 requirements into the traditional ISM Code implementation. As it represents the mandatory requirements of marine commerce, the ISM Code continues to be the guiding principle of the proposed IEMS. But ISM Code procedures are expected to be enhanced via integrating the requirements of ISO 14001:2004 standard.

Following the compliance levels in Fig. 1 and considering the priorities of ISO 14001 clauses; Fig. 2 illustrates the execution framework of our proposed IEMS, which contains all the ISM Code clauses and some compatible ISO 14001:2004 requirements. Referring Fig. 2 as a guideline in order to encourage the different stakeholders in shipping industry through enhancing the environmental management procedures is recognized as contributions of this research.

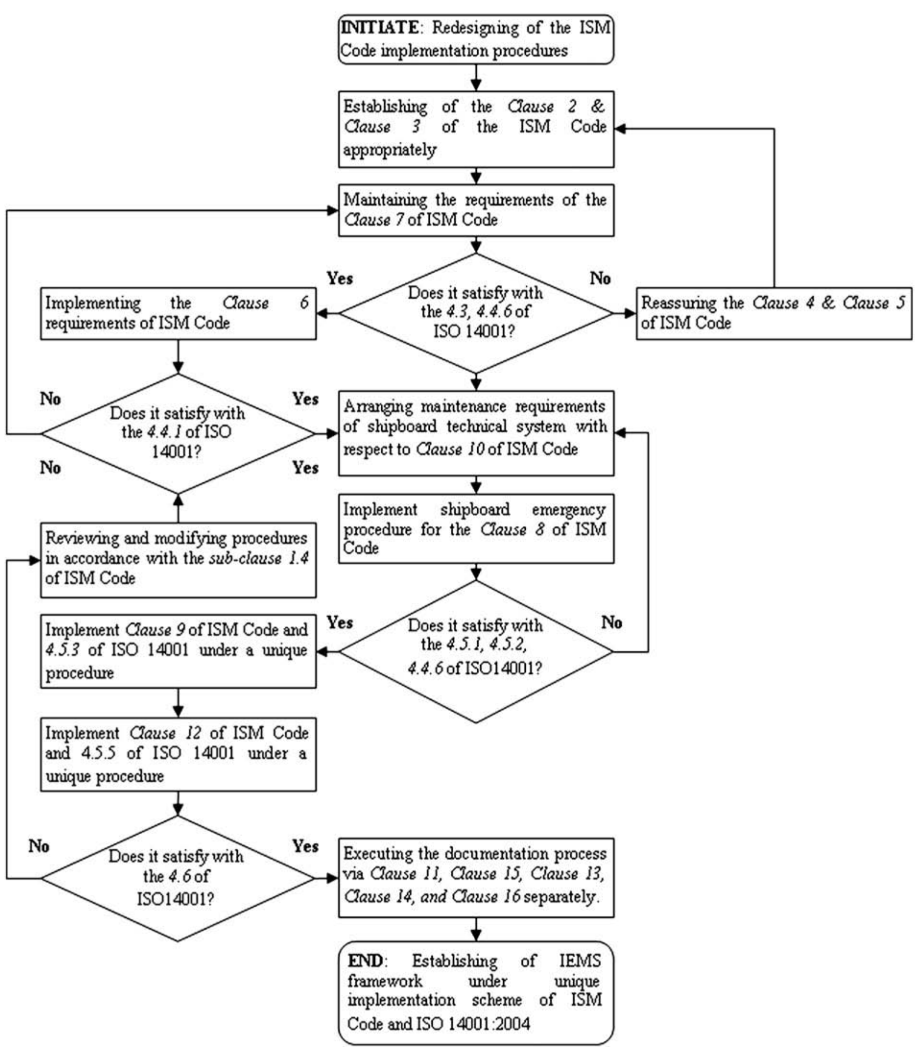

Fig. 2. Information flow within the proposed IEMS.

5. Conclusion and discussion

This paper analyzes the degree of compliance between ISM Code clauses and ISO 14001:2004 requirements on the basis of AHP and FAD methodologies. In particular, FAD is used to quantify the expected problems and shortcomings in a fully IEMS. We complete the analysis by proposing an IEMS that can serve as a pilot application for ship management companies. The proposed IEMS is expected to contribute environmental performance of ship management companies and to prevent environmental disasters in maritime transportation industry subsequently. Hence, the outcomes of this study can satisfy the maritime industry expectations on managing the environmental concerns satisfactorily. However, the concern about the availability of competent managers to execute this kind of environmental tools in shipping industry is a common problem that urgently seeks for a satisfactory solution. However, this paper gives a scientific foundation and genius idea for the further efforts to design IEMS in ship management companies. Despite the complexity of hybrid methodology for relevant shipping managers, the industrial practice of the proposed IEMS can be managed by taking advisory support from maritime consultants. Consequently, it can be expected that execution of the proposed IEMS in shipping business will ensure establishing of managerial and operational interface on maintaining sustainable environmental management satisfactorily.

Our future research will expand the scope of the integrated system to cover issues of occupational health, safety, quality, and environmental management under a unique implementation scheme based on the same hybrid methodology. Moreover, the same methodology can be followed also to enforce the integration of Eco-Management and Audit Scheme (EMAS) with ISM Code.

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