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

Metin Celik*

Department of Maritime Transportation and Management Engineering, Istanbul Technical University, Tuzla 34940, Istanbul, Turkey

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.

* Tel.: +90 216 395 1064; fax: +90 216 395 4500.
E-mail address: celikmet@itu.edu.tr

0301-4797/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
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:

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

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 λ_{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. λ_{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