Expert Systems with Applications 37 (2010) 4182–4189

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Sea vessel type selection via an integrated VAHP–ANP methodology for high-speed public transportation in Bosphorus

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ARTICLE INFO

Keywords:
Bosphorus
Public transportation
Seaway
VAHP
ANP

ABSTRACT

The transportation planning phases are generally examined in three groups, according to their contents, constant and variable factors, time dimensions, financial costs and decision-making levels: Strategic, tactical and operational levels. Network design and development, terminal capacity and location determination, marketplace selection and vessel fleet and working-power planning are problems of strategic level planning. We are interested in sea vessel type selection to efficient vessel fleet planning in this study. This paper deals with issues related to the selection of right sea vessel type for short and medium distances in Bosphorus and proposes an integrated methodology for this process.

1. Introduction

Transportation via seaway is one of the most important industrial dynamics by following a continuous development trend from the design of the first commercial ship to present. Turkey's surrounded by Aegean, Black and Mediterranean Seas and 40% of all provinces have coastlines. For this reason, in Turkey, sea transportation for passengers and goods is very important, especially in big and crowded cities as İstanbul.

The similar circumstances are valid in İstanbul with Turkey generally and 90% road, 6% railroad and 4% seaway are made use the inner-city transportation (IMM, 2002; SPA, 2001). In such a case, there are major complications in terms of economical and social dimensions because of the little share of seaway in cargo and passenger transportation while Turkey is surrounded by sea on north, west and south. İstanbul, Turkey's largest city, plays a vital role in internal and external trade. It is also the cultural and educational center of the country. One of the fundamental problems of İstanbul is traffic congestion (Ulengin, Topcu, & Sahin, 2001). It is very important and immediate to switch the transportation to seaway in terms of country economy, safety transportation and environmental pollution (IMM, 2002; SPA, 2001).

Making the right decision is always a difficult task for the purchasing manager. The alternatives have varied strengths and weaknesses which require careful assessment by the purchasers before ranking can be given to them. So, every decision needs to be integrated by trading off performances of different alternatives at each stage. Here, the focus of the problem is "alternatives ranking and selecting".

The sea vessel types can be summarized as boats, ships, ocean liners, sea buses, steamships, canoes, cruise ships, steam boats, sailing ships, sail boats, motorboats, and others. We will examine sea buses, steamships, motorboats and boats' efficiencies from these sea vessel types under economic view and choose the most suitable sea vessels in different transportation distances for high-speed passenger transportation in Bosphorus. Turkish Maritime Corp. (TMC) (is bought by ISB at the year of 2005), İstanbul Sea Buses Corp. (ISB), and several private and public organisations are responsible from passenger and vehicle transportation in Bosphorus. Our research comprises and concerns all these organisations.

2. VAHP and ANP integration

In this section, firstly VAHP and ANP methods are defined and the decision-making steps of these methods are presented. Then the integration need between these two methods is emphasized and the proposed VAHP–ANP integrated methodology is introduced.

2.1. VAHP

There are several papers using ranked voting system in the literature (e.g. Andersen and Petersen, 1993; Bouyssou, 1999; Charnes, Cooper, and Rhodes, 1978; Cook and Kress, 1990; Cooper, Seiford, and Tone, 2000; Foroughi and Tamiz, 2005; Green, Doyle, and Cook, 1996; Hashimoto, 1997; Liu and Hai, 2005; Noguchi, Ogawa, and Ishii, 2002; Obata and Ishii, 2003; Stein, Mizzi, and Pfaffenberger, 1994; Thompson, Singleton, Thrall, and Smith, 1986; Yahya and Kingsman, 1999, etc.). Ranked voting data arise when voters select and rank more than one candidate with order of preference (Obata & Ishii, 2003).

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doi:10.1016/j.eswa.2009.11.005

Yahya and Kingsman (1999) illustrate a new approach based on the use of Saaty's analytic hierarchy process (AHP) method that was developed to assist in multi-criteria decision-making problems. In order to decide the total ranking of the suppliers, Liu and Hai (2005) compare the weighted sum of the selection number of rank vote, after determining the weights in a selected rank. This investigation presents a novel weighting procedure in place of AHP's paired comparison for selecting suppliers. It provides a simpler method than AHP that is called voting analytic hierarchy process (VAHP), but which does not lose the systematic approach of deriving the weights to be used and for scoring the performance of suppliers.

Noguchi et al. (2002) examine the application of Green's method and show that different weights among objects give rise to different results in ranking. Moreover, Liu and Hai (2005) apply Noguchi's strong ordering not only to single-purpose problems, but also to multi-purpose problems such as the supplier-selection problem in a business corporation. "Noguchi's strong ordering" is defined as follows (For the details of Green's method and Noguchi's strong ordering, please look at Green et al. (1996), Noguchi et al. (2002) and Liu and Hai (2005)):

$$\theta_{rr} = \max \sum_{(s=1\sim S)} u_{rs}x_{rs}, \tag{1}$$

$$\text{s.t.} \quad \theta_{rp} = \sum_{(s=1\sim S)} u_{rs}x_{ps} \le 1 \quad (p = 1,2,\ldots,R), \tag{2}$$

$$u_{r1} \ge 2u_{r2} \ge 3u_{r3} \ge \cdots \ge Su_{rs}, \tag{3}$$

$$u_{rs} \ge \varepsilon = 1/((1+2+\cdots+S)^{*}n) = 2/(n^{*}S(S+1)). \tag{4}$$

Here, n is the number of voters, S is the number of places, and R is the number of criteria. u_{rs} denotes the weight of the s_{th} place with respect to the r_{th} criteria. Every candidate wishes to assign each weight u_{rs} so as to maximize the weighted sum of votes to the r_{th} criteria, that is, the score $y\theta_{rr}$ becomes the largest. Also, x_{rs} is the total votes of the r_{th} criteria for the s_{th} place by n voters. u_{rs} should be positive in order not to lose information about last place. Therefore, the condition $u_{rs} \geqslant \varepsilon$ is added (Liu & Hai, 2005).

Liu and Hai (2005) propose a six-step procedure for selecting suppliers with a numerical example in their paper. According to their VAHP methodology, firstly they structure the problem into a hierarchy. Then they follow the six-step below:

Step 1. *Select suppliers' criteria:* Use several respondents and obtain the criteria from group decision. Use the criteria that must be satisfied in order to fulfill the goals of the selection process.

Step 2. *Structure the hierarchy of the criteria:* Use the AHP here to identify subcriteria under each criterion, and to investigate each level of the hierarchy separately.

Step 3. *Prioritize the order of criteria or subcriteria:* The voters will select different orders of criteria or subcriteria for the candidates. Everyone votes 1 to S ($S \leqslant R$).The voters get the order of criteria/subcriteria but not the weights. The weight of each ranking is determined automatically by the total votes each candidate obtains.

Step 4. *Calculate the weights of criteria or subcriteria:* Use Noguchi's voting and ranking to develop criteria varied level from hierarchy analysis process (so, this methodology is called voting analytic hierarchy process (VAHP)). Then find the weights of subcriteria and normalize them. Finally, multiply the subcriteria weight by the criterion weight.

Step 5. *Measure supplier performance:* This step requires the voters to assess the performance of all suppliers on the subfactors identified as important for supplier scores. It is agreed that all performance scores would be based on an 11-point grade scale.

Step 6. *Identify supplier priority:* Mathematically, the supplier rating is equivalent to the sum of the product of each factor weight and the supplier performance score on that factor. The supplier with the highest supplier rating value should be regarded as the best performing supplier and the rest can be ranked accordingly (Liu & Hai, 2005).

2.2. ANP

Analytic network process (ANP) method was proposed by Saaty (1996) in 1975. It is an extension of analytic hierarchy process (AHP). In reality, the elements within the hierarchy of various rules are often interdependent. Low-level elements also dominate high-level elements. There is a feedback relationship. In such instances, the structure of a system resembles that of a network. ANP method is stemmed from this type of network system structure (Lin, Tsai, Shiang, Kuo, & Tsai, 2009; Wang, 2005).

ANP are not detailed here because of being a well-known application (for details and mathematical equations of ANP please look at Saaty (1980, 1996, 2005). ANP decision-making steps can be summarized as below (Lin et al., 2009; Meade & Sarkis, 1999):

Step 1. *Definition of policy issues and establishment of policy-making members:* A body of decision makers should be established in order to collate the opinions of the experts in the relevant fields for purpose of determination the factors that affect policy issues. The decision-making group probably should not be too large, i.e. a minimum of five to a maximum of about 50 (Robbins, 1994; Taskin Gumus, 2009).

Step 2. *Construction of the network hierarchy layer structure of the problems:* In the structure, there exists interdependency within each layer and loop arcs are used to indicate feedback relationships.

Step 3. *Questionnaire surveys and expert preference integration:* According to the network hierarchy layer valuation model structured for the decision issues, weightings are given to each element according to their corresponding upper elements via questionnaires issued to experts to gather opinions regarding the relative importance of different elements.

Step 4. *Establishment of comparison matrixes:* Now, it is possible to construct a comparison matrix of multiple valuation criteria and options. ANP method applies a measurement of 1–9 and derives relative weightings based on this measurement. These weightings then are entered as values of the super matrix structure so as to reflect the interdependency and relative importance of each valuation criteria and option.

Step 5. *Consistency test:* The consistency tests are conducted based on the consistency ratios (CR) of the comparison matrixes. The CR of a pairwise comparison matrix is the ratio of its consistency index to the corresponding random value. The details can be found in Saaty's (2005).

Step 6. *Computations of super matrixes:* A super matrix lists down all the sub-matrixes consisting of all the clusters and necessary elements in the order on the left and upper sides of the matrix (Saaty, 1996).

Step 7. *Selection of most optimal options:* Desirability index (DI) is used to determine the most optimal options. The formula is as follows:

$$DI_i = \sum_{j=1}^{r} S_{ij} = \sum_{j=1}^{r} R_j W_{ij}, \quad \forall i,\ j = 1,2,\ldots,r, \tag{5}$$