

# Economic Analysis on Substitution of paper chart with ECDIS Onboard for Turkish Flag Ships

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**ABSTRACT:** ECDIS as a real-time navigation system integrating variety of charts and navigation-related information that replaces the usage of paper chart. Nowadays, ECDIS usage is getting more recognized as being used for both navigation and collision avoidance tasks. In this consideration, Turkish ship management companies are at the right cornerstone to take a decision for the substitution of paper chart with ECDIS. Cost factor has a significant role during the selection process and it needs to be optimized with cost-benefit ratios of each alternative. This study originally tends to describe decision making process with alternative solutions that could be applied to ship's bridge operations. By utilizing multi-criteria decision making model, it is aimed to facilitate the selection of two alternatives with "Analytic Hierarchy Process (AHP)". Consequently quantifying the influence of related factors to the selection of two alternatives for Turkish management companies, a hierarchical analysis framework is developed and applied by AHP method.

## 1 INTRODUCTION

Electronic charts have been under active development since 1981 and appeared as a commercial product from early 1983. They are, as the name implies, an electronic version of a nautical chart, reproducing those items on the chart intended to promote navigation safety at sea. Electronic chart is rapidly gaining acceptance as the preferred means of displaying ship's position, especially since GPS can be used to accurately place its location on the chart. The ability to see the ship's position relative to dangers on the bottom and the course to its destination is what makes the use of the electronic chart so compelling. When radar is added to the display, the picture is complete: the whole tactical situation is displayed. GPS by itself is not very useful until its measured ship's position is placed on the chart. When radar is added the display combines a view of ship's position with objects on the surface and with a portrayal of the bottom that is essential for safe navigation. (Shea & Grady 1998)

The introduction and use of electronic charts in marine service has taken an odd path compared to the many new marine electronic devices. (Er & Celik, 2005) There is a complication that sets it apart from virtually every other advance in marine navigation. (Akten, 2004) The nautical chart is a legal document, and ocean-going ships are required to carry them under a combination of rules laid down by the International Maritime Organization. Besides this if ECDIS fulfil the performance

requirements that are defined by International Hydrographic Organization (IHO) and International Electro technical Commission (IEC), is equivalent to an up to date paper chart. In this consideration, Turkish ship management companies need to take a decision for the substitution of paper chart with ECDIS. (Rodriguez & Dauer, 2006) Making a decision implies that there are alternative choices to be considered, and in such a case we want not only to identify as many of these alternatives as possible but to choose the one that best fits with our goals. (Yang 2006) In this multi criteria decision making process, to facilitate the selection of two alternatives Analytic Hierarchy Process (AHP) model is being used. In order to quantify the influence of related factors to the selection of two alternatives of Turkish ship management companies, this study developed a hierarchical analysis framework being applied by AHP method. (May 1999, Smeaton 1995)

## 2 THE ANALYTIC HIERARCHY PROCESS METHODOLOGY

The main purpose of this paper is to solve the selection of route planning equipment by employing AHP method. As it is well-known, the AHP consists of decomposing a complex problem into its components, organizing the components, organizing the components, organizing the components into sets and locating the sets into levels to generate a hierarchical structure. The aim of constructing such

a hierarchy is to determine the impact of lower level elements on an upper level criterion, which is achieved by pair wise comparisons provided by the decision maker. The AHP is a simple decision making tool to deal with complex, unstructured and multi attribute problems which has been developed by Saaty. (Saaty, 1980) The most creative part of decision making, that has an important effect on the outcome, is modeling the problem. Identification of the decision hierarchy is the key to success in using AHP. AHP is essentially the formalization of a complex problem using a hierarchical structure and it is a multi criteria decision making approach that employs pair wise comparisons. The AHP consists of three basic steps;

- Design of the decision hierarchy,
- The prioritization procedure,
- Calculation of results.

AHP initially breaks down a complex multi criteria decision making problem into a hierarchy of interrelated decision elements (criteria, decision alternatives). With The AHP, the objectives, criteria and alternatives are arranged in a hierarchical structure similar to a family tree. A hierarchy has at least three levels: overall goal of the problem at the top, multiple criteria that define alternatives in the middle, and competing alternatives at the bottom. The process of building this structure not only helps to identify all the elements of the decision more accurately, but also to recognize the inter-relationships between them. The AHP process involves defining the various alternatives, organizing the objectives and goals, developing the decision hierarchy, synthesizing the result, examining how modifying the variables affects the results. The top level of hierarchy consists of only one element, which is the overall objective. The elements that affect the decision are called attributes or criteria. The lowest level of hierarchy is referred to as alternatives, which are decision options. (Forman & Selly, 2000)

Once the problem has been decomposed and the hierarchy constructed, prioritization procedure starts in order to determine the relative importance of the elements within each level. The pair-wise judgment starts from the second level (first level of criteria) and finishes in the lowest level, alternatives. In each level the elements are compared pair-wise according to their levels of influence and based on the specified element in the higher level. The decision maker must express his preference between each pair elements (collecting input data of decision elements). (Golden & Wasil & Harker 1989, Zahedi, 1986)

After forming the preference matrices, the mathematical process commences in order to normalize and find the priority weights for each matrix (using the eigenvalue method to estimate the relative weights of the decision elements and rating the decision alternatives). (Chin & Chiu & Tummala, 1999)

It should be noted that the quality of the output of the AHP is strictly related to the consistency of the pair wise comparison judgments given by managers. Saaty (Wind & Saaty, 1980) suggests a simple procedure for checking on consistency. Then the AHP process determines the consistency ratio (CR) for all matrices. If the CR value is larger than 0.10 (which is the acceptable upper limit for CR, it implies that there is a 10% chance that the elements have not been properly compared. In this case the decision maker must review the comparisons made. In using the AHP to model this problem, we developed a hierarchic structure to represent the problem of selecting route planning equipment and made pair wise comparisons. The factors, which affect this problem, are analyzed in a hierarchy having 5 levels. (Kuruuzum & Atsan 2001)

### 3 AHP APPLICATION ON SELECTING ROUTE PLANNING EQUIPMENT

#### 3.1 Structuring the decision hierarchy

The first step of the AHP consists of developing a hierarchical structure of the assessment problem. In order to determine the best alternative, a four level hierarchical model is devised. The first level, objective, here is referred to as the selection of route planning equipment (SRPE). (Hadley 1997) The goal is divided into two main criteria, which are economical (E), navigational safety (NS) factors. The third level of hierarchy includes sub-criteria;

- Economical factors: Installation costs (IC), maintenance and update costs (MUC), training expenses (TE), navigational efficiency (NE).
- Navigational safety factors: Human factor (HF), Technical factors (TF), emergency situations (ES).
- (Sullivan & Alexander 1997, Shaw & Pettus 2000,)
- The fourth level of hierarchy includes sub-criteria;
- Human factor: Ease of use (Eu), workload (Wl), error chain (Ec), training needs (Tn).
- Technical factors: Integration (I), reliance and sensitivity (Rs), situational awareness (Sa).
- Emergency situations: Electrical breakdown (Eb), meteorological factors (Mf), abandons ship (As).

(Gillard & Heim 2002, Devogel & Baccei & Shaw 2001)

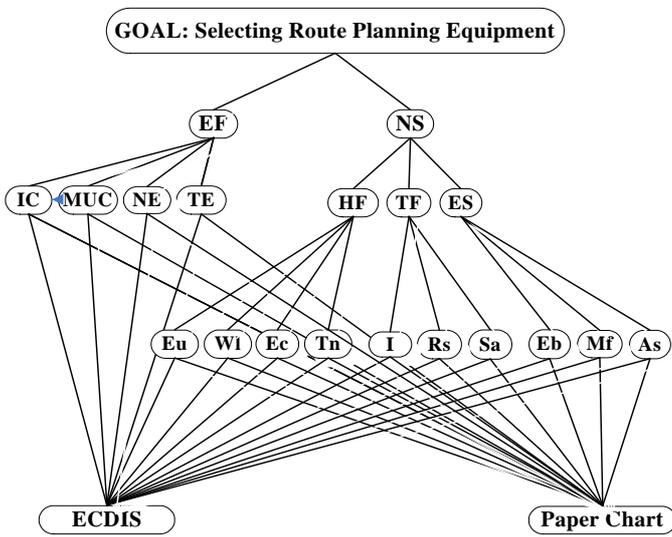


Fig. 1. Hierarchy structure

Finally, the fifth and the last level consists of two decision alternatives of route planning equipment that the ship management companies want to compare; ECDIS (E), paper chart (PC).

Figure 1 shows the performance hierarchy we have designed for this problem.

### 3.2 Pair wise comparison of criteria and calculating the relative weights

After developing the performance hierarchy, we have to determine the relative weights of the factors. In the AHP, weights are determined using pair wise comparison between each pair of criteria. To determine the relative weights, managers are asked to make pair wise comparisons using a 1-9 preference scale on Table 1. Each comparison is then transformed to a numerical value. For instance, if economical criteria is judged to be "very strongly more important" than navigational safety for selecting the route planning equipment, a score 7 is given.

The pair wise comparison data are organized in the form of a matrix and are summarized on the basis of eigenvector procedure. AHP method computes  $w$  as the principal right eigenvector of the matrix  $A$ . The pair wise comparison data are translated into the absolute values and the normalized weight vector  $w = (w_1, w_2, \dots, w_n)$  is obtained by solving the following matrix equation;

$$Aw = \lambda_{\max} w \quad (1)$$

Where  $A$  is the pair wise comparisons matrix,  $w$  is the normalized weight vector and  $\lambda_{\max}$  is the maximum eigenvalue of the matrix  $A$  (used to calculate the consistency index).

$$\lambda_{\max} w = \sum_{j=1}^n a_{ij} \frac{w_j}{w_i} \quad (2)$$

The result is a positive reciprocal matrix  $A = \{a_{ij}\}$  with  $a_{ji} = 1/a_{ij}$ , where  $a_{ij}$  is the numerical equivalent of the comparison between criteria  $i$  and  $j$ .

A judgment or comparison is the numerical representation of a relationship between two elements that share a common parent. (Saaty, 1991) Each judgment represents the dominance (relative importance) of an element in the column over an element in the row. (Millet, 1998)

After this point experts were asked to compare the relative importance of the three criteria on a pair wise scheme by questionnaire. From these data, a square pair wise comparison matrix was constructed. Each judgment represents the dominance (relative importance) of an element in the column (Rangone, 1996).

In order to help the pair wise comparisons, Saaty created a nine-point scale of importance between two elements. (Saaty, 1999) The suggested numbers to express degrees of preference between the two elements are shown in Table 1.

Table 1. Importance scale

Definition	Intensity of importance
Equally importance	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9

Intermediate values (2, 4, 6 and 8) can be used to represent compromises between the preferences. The relative priorities can be considered the results of using the geometric mean of the pair wise relative importance obtained from a set of participants. AHP's results are obtained with the software, the Super Decisions (Decision Support Software) software package (Creative Decision Foundation, 2006)

### 3.3 Results of AHP Application

After setting up the hierarchy and pair wise comparisons of the criteria and alternatives, it is necessary to calculate the global value of priority of the alternatives. The optimal set of scores is the principal eigenvector of the pair wise comparison matrix.

The principal vector is the relative ranking of the evaluation criteria with respect to the goal. Applying eigenvector method to these data, estimates of the weights are calculated for each pair wise comparison matrix for each level of the hierarchy. To synthesize the results over all levels, the priorities at each level are weighted by the priority of the higher level criterion with respect to which the comparison was made. The eigenvector scaling technique of AHP then modeled the relative weights for each category

(priorities) and for each ratio (local weights). Global weights for each ratio were calculated as the product of its local weight and its category's priority. Once the matrices in each level are completed, the relative importance of the elements in that level is given by the principal right eigenvector of the matrix of judgments. The number of eigenvectors is therefore equal to the number of criteria. The results quantify the decision maker's preference for each alternative and provide a means for solving the problem.

In order to determine which route planning equipment to select, AHP was applied to determine the priority values for two alternatives (Figs. 2-3). The priority rankings for each alternative were determined from a hierarchy that was based upon 2 criteria, 17 sub-criteria and 2 alternatives. The criteria and sub-criteria were compared on a pair wise basis.

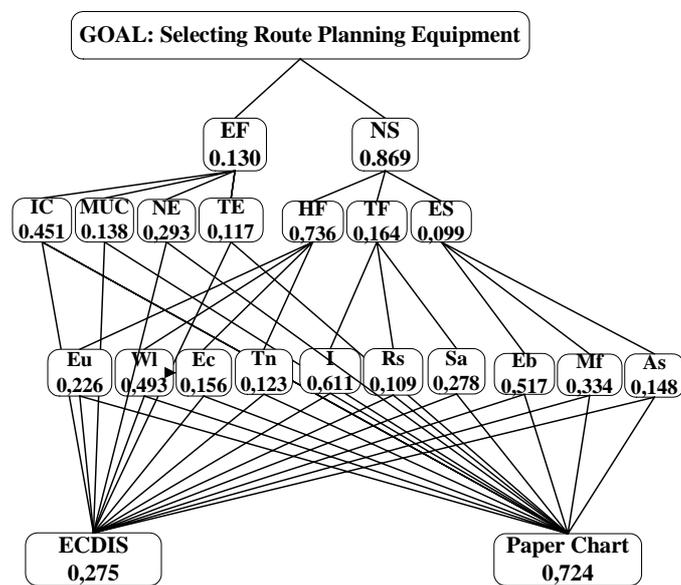


Fig. 2. Hierarchy structure

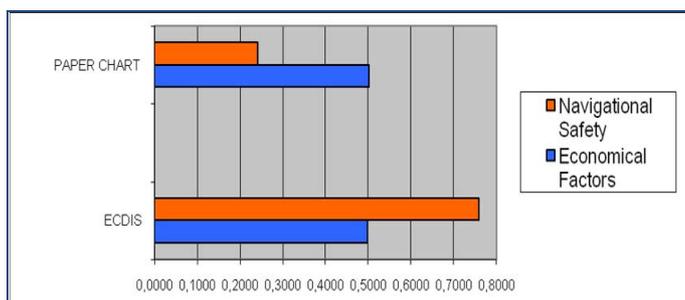


Fig. 3. Alternative weights with respect to navigational safety and economical factors

#### 4 MODEL EXTENSION ON COST BENEFIT ANALYSIS

To find out cost benefit ratio, we need to change the decision hierarchy. Firstly, it is considered to structuring problem on benefit criteria only, hence

the relevant attributes on cost are neglected. The new structure has shown on figure 4.

The first level, objective, here is referred to as the selection of route planning equipment (SRPE). The goal is divided into two main criteria, which are Navigational efficiency (NE), navigational safety (NS) factors. The third level of hierarchy includes sub-criteria;

- Navigational safety factors: Human factor (HF), Technical factors (TF), emergency situations (ES).

The fourth level of hierarchy includes sub-criteria;

- Human factor: Ease of use (Eu), workload (Wl), error chain (Ec), training needs (Tn).
- Technical factors: Integration (I), reliance and sensitivity (Rs), situational awareness (Sa).
- Emergency situations: Electrical breakdowns (Eb), meteorological factors (Mf), abandon ship (As).

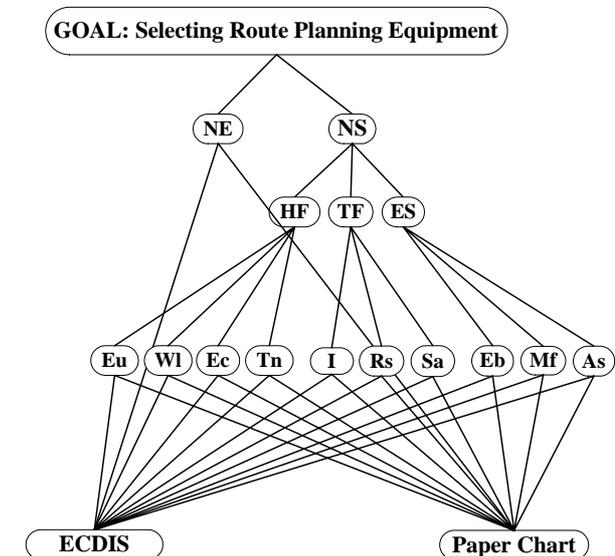


Fig. 4. Hierarchy structure

After the AHP model calculation overall results for the alternatives illustrated on figure 5.

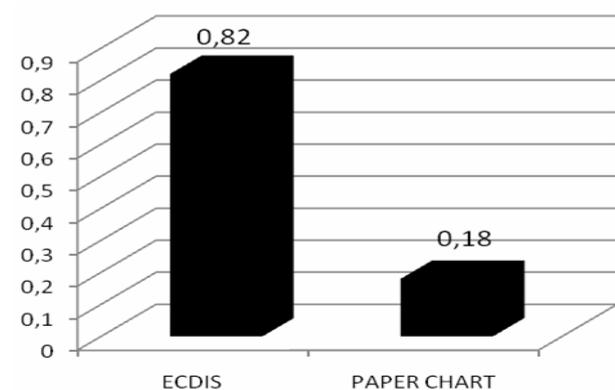


Fig. 5. Overall rank of alternatives

Secondly, we need to calculate total costs for route planning equipment to determine cost benefit ratio. This calculation has implemented based on a bulk carrier tramper ship that trade internationally owned by a Turkish ship owner.

Table 2. Costs of alternatives

	IC	TE	MUC	Total Cost	Normalized values
			Annual	For 5 years	
Paper chart	26500E	-	5923E	56115E	0.29
ECDIS	20000E	9000E	21210E	135050E	0.71

For five year projection, paper chart costs are 56115E on the other hand, ECDIS costs 135050E. Consequently, the ratio of normalized cost values over priority weights of ECDIS and paper chart on benefit attributes are computed. The results are illustrated for each alternative correspondingly in table 2.

Table 3. Cost benefit ratio calculation for alternatives

	Costs	Benefit	Cost/Benefit
ECDIS	0,71	0,82	0,87
Paper Chart	0,29	0,18	1,61

Cost benefit ratio is determined by dividing the projected benefits of the route planning equipment by the projected costs shown on table 3. In general, alternative with a low cost benefit ratio will take priority over other alternatives with lower ratio. Eventually, ECDIS alternative is appropriate selection for route planning.

## 5 CONCLUSION

This paper introduces a model, based on AHP, which determines the global priority weights for selecting route planning equipment alternatives and has examined the critical factors and benefits that affect ship management companies.

Substantial practical experience shows that there are numerous positive benefits from the use of ECDIS, most significantly the increased situation awareness. But also the possibility of savings in fuel, of avoiding damage to ships due to collisions and groundings and of preventing lost sailing days due to repairs is evident. Finally, increased competitiveness due to the ability to operate confidently in adverse weather conditions should be mentioned. Now these benefits are also backed by research results. The findings in casualty investigations are that the human factor accounts for the overwhelming majority of accidents. Hence, schemes that limit the

extent of human errors, for example by means of better education and training, ECDIS systems and other policies are the most likely risk reduction factors.

However, there are several hurdles to overcome in the process of full replacement of paper charts, some legal, some economical, and some technical. ECDIS to become mandatory carriage legislating under current scheme is not realistic because of the inadequate pricing and monopolistic situation. The Maritime community will resist any such attempts. This will result in further delay in implementation.

To overcome economical obstacles, International Hydrographic Organization (IHO) proposes pay-per-use licensing scheme (IHO, 2006). In this solution, A daily amount of \$40 levied for the time during which the vessel was in the national waters of a country. It costs to ship management company approximately 15000 \$/year per ship.

When fully mature, this technology will replace the paper charts and plotting instruments used by navigators since the beginning of sea exploration.

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