A MULTICRITERIA DECISION MAKING APPROACH TO THE ANALYSIS OF SHIP LENGTH FACTOR IN THE STRAIT OF ISTANBUL

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ABSTRACT

The Strait of Istanbul is an 'S' shaped narrow channel of difficult nature with heavy currents, which is complex and irregular, and with sharp turns. Due to these characteristics, it is considered one of the most critical waterways in the world. The density of maritime traffic has increased from around 4500 ships passing annually in 1936, when Montreux Convention was signed to regulate navigation in the Straits, to an average of 54000 vessels per year recently. The increase of traffic density has leaded to rise in the number of maritime casualties.
In order to cope with that problem Maritime Traffic Regulations in the Turkish Straits was established in 1994 and revised in 1998. In the regulation the concept of large vessel came to the fore and it is defined in the definitions & abbreviations: Article 2. When considering the increase in length of vessels passing through the Strait of Istanbul, the question 'What is a large vessel?' becomes intriguing. This paper investigates what a large vessel is in terms of length factor in the Strait of Istanbul. In this study experts from VTS, pilot captains of the Strait of Istanbul and experienced captains are consulted. AHP method is utilized to identify the quantitative importance of each efficient and some future works are suggested due to findings.

Keywords: maritime traffic management criteria, decision making, AHP model, the Strait of Istanbul

INTRODUCTION

The Strait of Istanbul, which is one of the world's densest regions in terms of maritime traffic, has for centuries assumed the duty of being a door serving the international shipping market. Since it links The Black Sea to the Mediterranean it has a great strategic importance not just for trade but for the political aspects.

The Strait of Istanbul lies between 41° 01 N and 41° 13´ N and approximately 31 km long, with an average width of 1.5 km. It is only 698m at its narrowest point between Rumelihisarı and Anadoluhisarı. A ship navigating through the Strait of Istanbul must change course at least twelve times. The biggest course alteration, 80 degree, is required at Yeniköy point. The main parameters such as headlands which limit to have an extended sight for a proper lookout, narrowness, sharp turns, day to day changing currents and unpredictable climate makes it difficult and dangerous to navigate through the Strait of Istanbul. Not surprisingly, all these factors can quite easily cause vessels to collide or run aground.

Passage through the Turkish Straits is governed by the 1936 Montreux Convention. When the convention put in place, approximately 4700 ships used to pass through the Strait annually. However the present number of transit vessel has increased 54.396 per year. Due to the technological developments in shipping industry and the opening of the Main- Danube channel which has linked the Rhine to Danube have led to a considerable increase in transit traffic. The Strait of Istanbul is about 4 times heavier than the maritime traffic in Panama Canal. Number of vessels passing through the Strait of Istanbul between 1982 and 2008 are presented in Table 1.

Table 1 Number of vessels passing through the Strait of Istanbul (Birpınar et.all., 2009)

Year	Number of Transit Vessels
1982	12983
1983	12767
1984	11006
1985	14271
1986	12103
1987	11557
1988	12092
1989	11805
1990	11445
1991	12085
1993	20260
1994	18720
1995	46954
1996	49952
1997	50952
1998	49304
1999	47906
2000	48079
2001	42637
2002	47283
2003	46939
2004	54564
2005	54797
2006	54880
2007	56606
2008	54396

It must be noticed that the principle dimension and the cargo capacities of ships grew larger, the severity of accidents have risen, too. In order to ensure the safety of navigation, Maritime Traffic Regulations for the Turkish Straits and Marmara Region was adopted in 1994. Four years later, the rules were reviewed and Maritime Traffic Regulations in the Turkish Straits is accepted. The regulation includes extensive provisions for safe navigation in the Straits.

One of the changes in new regulation is the description of large ships. In the second article of definitions & abbreviations, the description of a large ship is stated as follows:
'big ship: ships have a total length of 200 m or more' (Maritime Traffic Regulations in the Turkish Straits,1998).
Some provisions of the regulation states the rules that large ships must comply with. For instance; when the strength of current speed is more than 4 mile/ hour large ships cannot enter the Straits due to the reverse currents if they cannot provide the necessary manoeuvring speed. Also ships have a length of 150m or more are defined as the ships have difficulty in navigating in the traffic separation lane.
As seen from the above statements about the ship length, there is a length-interval at which the danger become apparent but cannot be expressed for the ships navigating through the Straits.
Risk always exists for ships navigation through the Strait of Istanbul . In this study, the size interval at which the danger shows an increase is tried to find.

METHODOLOGY

Analytic Hierarchy Process (AHP), since its invention, has been a tool at the hands of decision makers and researchers; and it is one of the most widely used multiple criteria decision-making tools (Vaidya & Kumar,2006). It is a theory of measurement through pair wise comparisons and the judgements of experts are used to construct priority scales which measure intangibles in relative terms. The form of matrix of the pair-wise comparisons is as follows:

$$A=\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_n \end{array}\begin{array}{c} \begin{array}{cccc} A_1 & A_2 & A_3 & A_n \end{array} \\ \begin{pmatrix} w_1/w_1 & w_1/w_2 & w_1/w_3 \cdots w_1/w_n \\ w_2/w_1 & w_2/w_2 & w_2/w_3 \cdots w_2/w_n \\ w_3/w_1 & w_3/w_2 & w_3/w_3 \cdots w_3/w_n \\ \vdots & \vdots & \vdots \quad\quad \vdots \\ w_n/w_1 & w_n/w_2 & w_n/w_3 \cdots w_n/w_n \end{pmatrix} \end{array} \quad (1)$$

The comparisons are made using a scale that indicates how many times more important one element is over another element with respect to a given attribute. The scale ranges from 1 for 'least valued than' to 9 for 'definitely more important than'.

Table 2: Saaty's 1-9 Scale for the pair wise comparison

	Preference number
Equally important / preferred	1
Weakly more important / preferred	3
Strongly more important / preferred	5
Very strong important / preferred	7
Absolutely more important / preferred	9
Intermediate values	2,4,6,8

In the basic structure of Analytic Hierarchy presented in Fig.1, the goal is specified at the top, all the objectives or criteria are listed below the goal and all alternatives are presented at the last level.
Some key and basic steps involved in this methodology are:

- Step 1. Determine the problem
- Step 2. Structure the decision hierarchy of different levels constituting goal, criteria, sub-criteria and alternatives
- Step 3. Compare each element in the related level and establish priorities.
- Step 4. Perform calculations to find the normalized values for each Criteria / alternatives. Calculate the maximum Eigen value, CI (Consistency Index) and CR (Consistency Ratio)
- Step 5. If the maximum Eigen value, CR and CI are satisfactory then the decision is made based on the normalized values; if not the procedure is repeated until the values lie in the desired range.

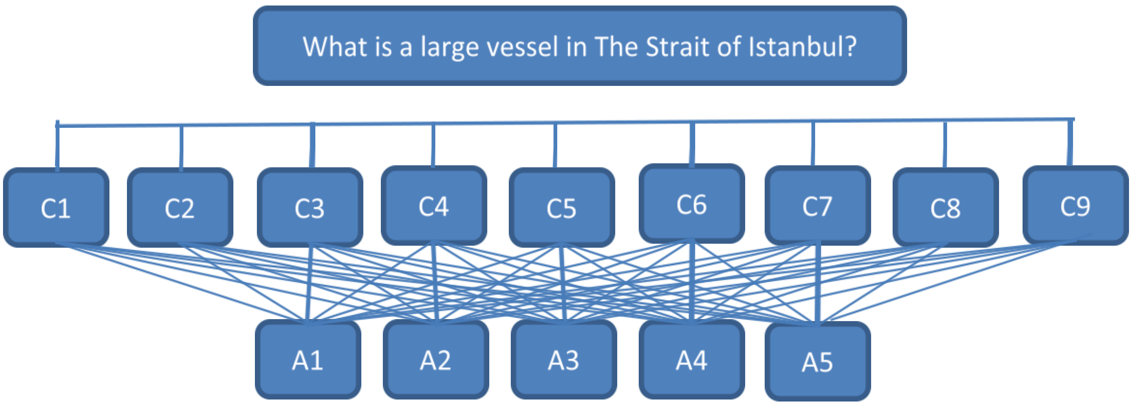

Figure 1 - Basic structure of AHP

Calculating the consistency

The consistency analysis is a part of AHP method. It is applied in order to assure a certain quality level of decision. The formula 2 and 3 is generated to determine the convenience of the numerical judgment. In this respect, we calculated the CR confirming Saaty, which is defined as a ratio between the consistency of a given evaluation matrix (consistency index CI) and the consistency of a random matrix. The consistency ratio (CR) should be less than 0.1 for a matrix larger than 4 by 4.

$$CI = \frac{\lambda - n}{n-1} \qquad \textbf{(2)}$$

$$CR = \frac{CI}{RI} \leq 0.1 \qquad \textbf{(3)}$$

where *RI* is the average index of randomly generated weights and *n* is number of criteria or alternatives.
In this study, consistency results for all criteria and alternatives based on each criterion are less than 0.1.
The 1-10 ranks matrix's RI is as the following table;

Table 3- The averagely random consistent indicator RI of 1-10 judging matrix

N	RI	N	RI
1	0	8	1,41
2	0	9	1,45
3	0,58	10	1,49
4	0,90	11	1,51
5	1,12	12	1,48
6	1,24	13	1,56

DETERMINING CRITERIA AND ALTERNATIVES

There are many factors that have negative effect on navigation in the Strait of Istanbul. The factors put into practice according to expert advice and statistical search are mentioned in this section.
Firstly, 50m- 100m (A_1), 101m- 150m (A_2), 151m- 200m (A_3), 201m- 250m (A_4), 251m- 300m (A_5) ship length intervals are selected as the alternatives of the problem.
After determining the alternatives, criteria affect casualties are categorised. There are 9 criteria such as; ship speed (C_1), loading condition of ship (C_2), wind effect (C_3), current effect (C_4), narrowness of the area (C_5), restricted visibility (C_6), the effect of pilot existence on board (C_7), local traffic (C_8) and turning circle of ship(C_9).

Ship speed

As the size of ship increases, the time and distance required to reduce speed also increases. If a vessel is obliged to stop engine or reduce speed in case of a failure or dangerous situation in the Strait of Istanbul, the increase in ship length becomes important.

Loading Condition of ship

Loading condition of ship is important in terms of maneuvering ability. Turning ability and maneuvering abilities of large vessels deteriorate in full- load condition relative to ballast condition (A Guide to Ship Handling, 2000) .

Dominant winds in the region

The wind effect on the superstructure above water limits the maneuvering performance of ships. The larger the ship, the wider the wind-exposed area is. Large ships are more vulnerable to danger because of increasing force affecting the maneuverability.
Moreover, the 6-7 knot north easterly winds are able to increase the current strength to 7- 8 knots in the narrow parts of the Strait of Istanbul. The increase of the current flow is a negative factor for navigation in the area.

Current

Surface currents, which can increase up to 6-8 knots in speed, are one of the most important handicaps for navigation through the Straits. Vessels navigating with the current lose the ability to steer (İstikbal C., 2006).
Fig.2 shows the impact of current on a vessel at Yenikoy point where an 80 degree course alteration is required.

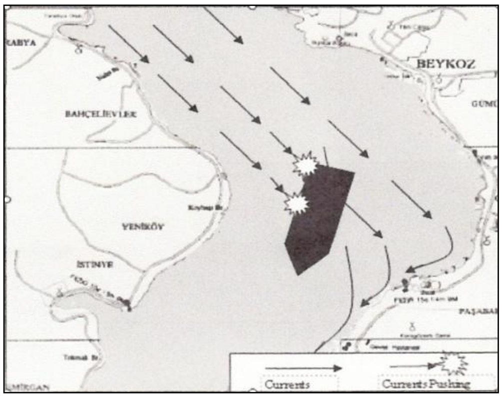

Figure 2 - Current effect in the Strait of Istanbul (İstikbal C., 2006)

According to the Maritime Traffic Regulations in the Turkish Straits , when the surface current speed exceeds 4 knots, then large vessels which can not provide safe maneuvering speed will not enter the strait and wait until current speed is 4 knots or less. If the current speed is 6-7 knots or more then, large vessels will not enter the Straits.
In case of a failure, the distance required to stop is getting longer as the vessel increase in size. As well as being a factor leading accident , current cause an increase in danger due to the increase in vessel length.

Narrowness of the area

The Strait of Istanbul has a risky structure in terms of geographical features and the narrowest part of it is situated between Anadolu Hisarı and Rumeli Hisarı with 698 m.
A vessel navigating through the Strait of Istanbul must change course at least 12 times. During the significant course alterations, especially at Kandilli and Yeniköy point, the rear and forward sights of ships are totally blocked.
Another problem for large ships is the lack of adequate space during side by side transition of vessels at Kandilli point.

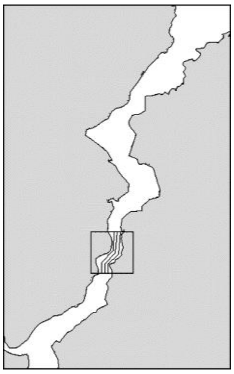

Figure 3 – Narrowest point of the Strait of Istanbul (Sarıöz K. & Narlı E., 2003)

Restricted Visibility

Another factor greatly affects navigation in the Strait of Istanbul is restricted visibility. It is known that many casualties occurred when the visibility drops to 1/2 mile or less in the strait. Low visibility causes casualties especially in the winter (Akten N.2004).
At the moment a vessel proceeding at a safe speed incur a danger, it immediately starts maneuvering to avoid trouble. Reducing distance causes limited maneuvering area.
A late realization of danger by the reason of restricted visibility causes reduction of maneuvering area and as the distance reducing, the increase in ship length triggers decrease in time to escape from danger.

Existence of pilot on board

The pilot is entirely familiar with the special regulatory requirements and unique conditions that exist in his specific pilotage area, and with which the Master of the vessel cannot be expected to be fully conversant. The pilot is wholly familiar with all the local factors that might affect the navigation of the ship. These may include strong tidal flows, recent shoaling, ferry activity, dredging operations and other hazards (URL 1, 03.12.2009).

Existence of pilot on board has a risk reducing effect on transit vessels not familiar with other hazards related to ship length.

Local traffic

The density of local traffic is an important factor has a negative effect on navigation in the Strait of Istanbul. Routes cause traffic density between Anatolian side and European side of the Strait are; conventional ferry transportation, seabuses, private passenger vessels, sports-fishing boats, yachts and military boats (T.C. Undersecretariat for Maritime Affairs Publications, 2000).

When we consider each floating vehicle forms a safe maneuvering area around itself, it is obvious that the size of the area is a positive function of ship length. In dense local traffic areas it is much more difficult to maneuver for large vessels.

Turning circle

Due to the winding shape of the Strait of Istanbul, big course alterations are required at Kandilli point (45 degree), Yenikoy point (80 degree) and Umur bankı (70 degree) **(**Güngör S., 1999).

Fig.4 is an example of the turning circle of a 6000 unit PCC at the narrowest point of the Strait.

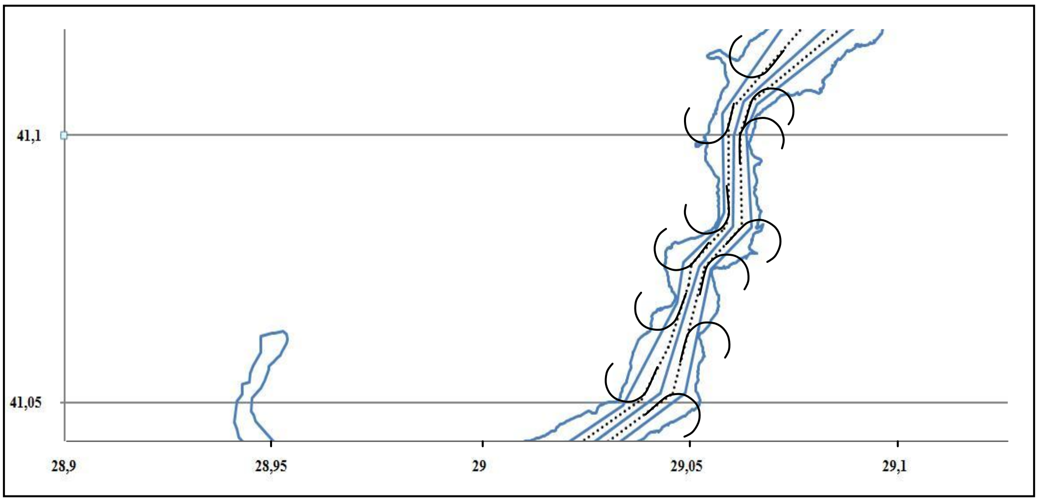

Figure 4 – Turning circle tracks of a 199.93 meter- long –vessel in the Strait of Istanbul (Kececi T., 2010)

The length of the vessel affects the rate of turn and the size of turning circle (URL 2., 11.03.2010). The increase in length is of vital importance to safe navigation in narrow channel.

EMPRICAL STUDY AND RESULTS

Analytic hierarchy process is a method helps a group of decision makers evaluate complex judgemental problems. In the first stage of this study, a questionnaire is applied to VTS operators, Pilot Captains and experienced Captains in order to collect opinions on risk factors. In this way, the judgements of experts about ship length related criteria and the weights of the alternatives are stated.

Characteristics of the experts are listed below:

1. The number of people participated in the survey is 37,
2. % 49 of the experts is Pilot captains who serves in the Strait of Istanbul,
3. %46 of the experts is VTS operators,
4. %5 of the experts is oceangoing captains who passed through the strait at least 15 times.

It is doubtless that all participated experts have opinion about criteria and risk varying depending on ship length. It is requested the experts not to be interested in other criteria when evaluating one criterion. In other words, all ratings should be done independently from each other.

In order to analyse the data obtained by survey in AHP , 15 days trial version of expert choice 2000 software is used.

In the first step, in order to assess the relative importance of criteria a pairwise comparison matrix is constructed. Priorities and inconsistency value derived from matrix are shown in Table 4.

Table 4 – Pair wise comparisons and ratings of criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	Priorities
C_1	1	1	3	1	3	3	5	2	1	.173
C_2	1	1	3	1	3	3	5	2	1	.173
C_3	1/3	1/3	1	1/ 3	1	1	3	1/2	1/3	.060
C_4	1	1	3	1	3	3	5	2	1	.173
C_5	1/3	1/3	1	1/3	1	1	3	1/2	1/3	.060
C_6	1/3	1/3	1	1/3	1	1	3	1/2	1/3	.060
C_7	1/5	1/5	1/3	1/5	1/3	1/3	1	1/4	1/5	.028
C_8	1/2	1/2	2	1/2	2	2	4	1	1/2	.101
C_9	1	1	3	1	3	3	5	2	1	.173
Incon.	0.01									

The next step is to compare alternatives two by two under each criterion. Priorities and inconsistency value are as below:

Table 5 – Pair wise comparisons and priorities of alternatives for C1

	A_1	A_2	A_3	A_4	A_5	Priorities
A_1	1	1/4	1/5	1/6	1/5	.044
A_2	4	1	1/2	1/4	174	.102
A_3	5	2	1	1/3	1/3	.156
A_4	6	4	3	1	1	.353
A_5	5	4	3	1	1	.345
Incon.	0.05					

Table 6 – Pair wise comparisons and priorities of alternatives for C2

	A_1	A_2	A_3	A_4	A_5	Priorities
A_1	1	1/2	1/4	1/5	1/5	.055
A_2	2	1	1/2	1/4	1/4	.088
A_3	4	2	1	1/3	1/3	.154
A_4	5	4	3	1	1	.352
A_5	5	4	3	1	1	.352
Incon.	0.02					

Table 7 – Pair wise comparisons and priorities of alternatives for C3

	A_1	A_2	A_3	A_4	A_5	Priorities
A_1	1	1/4	1/5	1/5	1/6	.044
A_2	4	1	1/2	1/3	1/4	.109
A_3	5	2	1	1/2	1/3	.170
A_4	5	3	2	1	1/2	.262
A_5	6	4	3	2	1	.416
Incon.	0.04					

Table 8 – Pair wise comparisons and priorities of alternatives for C4

	A_1	A_2	A_3	A_4	A_5	Priorities
A_1	1	1/4	1/5	1/6	1/6	.043
A_2	4	1	1/2	1/3	1/2	.119
A_3	5	2	1	1/2	1/2	.191
A_4	6	3	2	1	1	.324
A_5	6	3	2	1	1	.324
Incon.	0.02					

Table 9 – Pair wise comparisons and priorities of alternatives for C5

	A_1	A_2	A_3	A_4	A_5	Priorities
A_1	1	2	1/6	1/5	1/6	.057
A_2	1/2	1	1/8	1/7	1/8	.036
A_3	6	8	1	2	1	.346
A_4	5	7	1/2	1	1/2	.216
A_5	6	8	1	2	1	.346
Incon.	0.01					

Table 10 – Pair wise comparisons and priorities of alternatives for C6

	A_1	A_2	A_3	A_4	A_5	Priorities
A_1	1	1/2	1/3	1/3	1/3	.082
A_2	2	1	1/2	1/2	1/2	.138
A_3	3	2	1	1	1	.260
A_4	3	2	1	1	1	.260
A_5	3	2	1	1	1	.260
Incon.	0.00					

Table 11 – Pair wise comparisons and priorities of alternatives for C7

	A_1	A_2	A_3	A_4	A_5	Priorities
A_1	1	1/7	1/7	1/8	1/8	.030
A_2	7	1	1/2	1/4	1/4	.109
A_3	7	2	1	1/3	1/3	.156
A_4	8	4	3	1	1	.353
A_5	8	4	3	1	1	.353
Incon.	0.05					

Table 12 – Pair wise comparisons and priorities of alternatives for C8

	A_1	A_2	A_3	A_4	A_5	Priorities
A_1	1	1/5	1/4	1/5	1/6	.044
A_2	5	1	2	1/2	1/3	.170
A_3	4	1/2	1	1/3	1/4	.109
A_4	5	2	3	1	1/2	.262
A_5	5	3	4	2	1	.416
Incon.	0.04					

Table 13 – Pair wise comparisons and priorities of alternatives for C9

	A_1	A_2	A_3	A_4	A_5	Priorities
A_1	1	1/2	1/3	1/5	1/5	.058
A_2	2	1	2	1/4	1/4	.090
A_3	3	2	1	1/3	1/3	.145
A_4	5	4	3	1	1	.354
A_5	5	4	3	1	1	.354
Incon.	0.01					

The last step for the AHP method is calculation of ranking scores. Ranking scores are calculated by summation of each row.

Table 14 – Ranking scores of alternatives

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	**Ranking Scores**
A_1	.002	.001	.004	.008	.009	.018	.005	.002	.003	.053
A_2	.005	.002	.010	.021	.006	.031	.018	.008	.005	.106
A_3	.008	.004	.015	.034	.057	.057	.025	.005	.008	.214
A_4	.013	.009	.034	.057	.036	.057	.057	.013	.020	.296
A_5	.020	.009	.033	.057	.057	.057	.057	.020	.020	**.331**
Incon.	0.02									

According to the ranking scores of the alternatives; 250m- 300 m interval has the highest priority. At this stage, it is important to determine the point where the largest rate of change is obtained. In other words, at which point is the abnormal increase in risk? Thus, figure 5 is drawn using analysis results. As seen in the figure, 151m- 200 m interval is the point where there is a maximum increase in risk is seen.

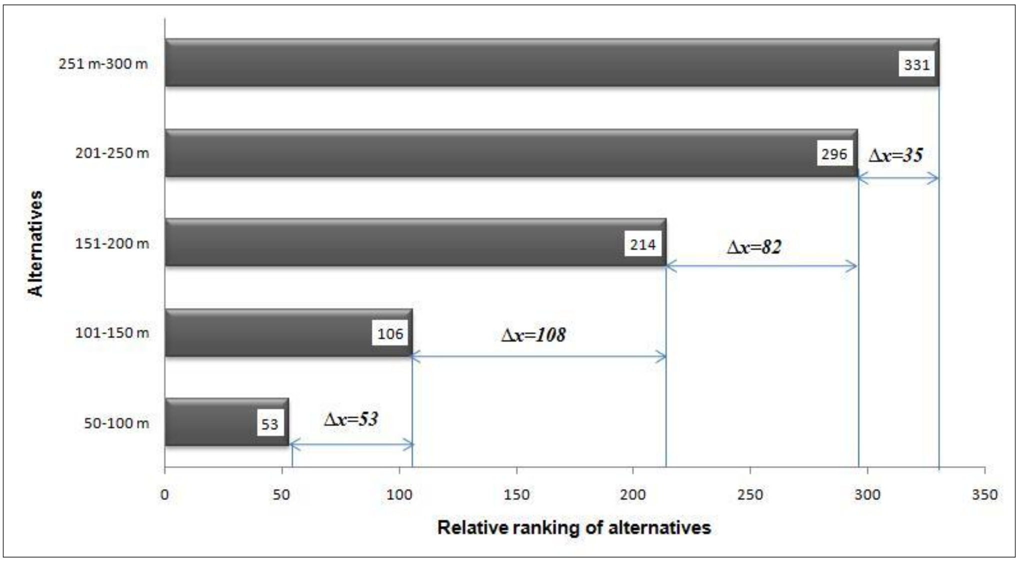

Figure 5 – Rate of increase in ranking scores

Another important issue is the consistency ratio of the selection, which according to Saaty should be less or equal to %10. In the present study the inconsistency ratio of 0.02 is obtained.

Furthermore, the most important criteria are current, restricted visibility, narrowness of the area and existence of pilot on board according to the results.

CONCLUSION

This paper investigates what a large vessel is in terms of ship length factor in the Strait of Istanbul. For this purpose, applicability of a common strategic selection tool, AHP, is investigated. Moreover, factors affect the rate of change in risk due to the increase in ship length are studied.
Criteria put into practice according to expert advice and statistical search are chosen as turning circle of ships, narrowness of the area, loading condition of ships, wind effect, ship speed, restricted visibility, local traffic and the existence of pilot on board. Alternatives are set in five intervals. The intervals are 50-100m, 101-150m, 151-200m, 201-250m, 251-300 m.
After selection of criteria and alternatives for the AHP method application, the Saaty's scale for pair-wise comparison is used to determine the importance of criteria and alternatives which are compared for each criterion. In order to analyse the data in AHP ,15 days trial version of expert choice 2000 program is used. The results of the calculation revealed the global weights of the alternatives.
According to the final ranking scores of alternatives, the point where the largest rate of change is tried to be obtained. 151m- 200 m interval is determined as the point where the maximum increase in risk is seen.

For the further research, the present study should be improved for particular ship size groups by creating a model of the system in order to identify and understand the factors which control the system and/or to predict the future behaviour of the system.

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