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Route Prioritization by Using Fuzzy Analytic Hierarchy Process Extended Dijkstra Algorithm

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Abstract

Voyage planning is of significance considering the oil consumption, time and safety factors. Determining the proper route after considering multiple convergent factors synchronously is one of the most important subjects in ship management that requires special expertise. The purpose of this paper is to develop a fuzzy analytic hierarchy process (FAHP) extended version of Dijkstra algorithm, and investigate the most prior routing problem in maritime environment. In the literature, there exist many Dijkstra applications but these studies lack of multiple decision makers, consistency control of decision matrices and multiple criteria, which can either be cost or benefit. In this model, subjective judgments and personal experience directly involve in the decision-making process. The proposed FAHP extended Dijkstra algorithm (hereafter FAHP-Dijkstra) improves the capabilities of handling the vague criteria in the presence of fuzziness. This study aims to provide some benefits of oil consumption, time and safety to manned or unmanned ships by presenting a novel route optimization algorithm.

Keywords: *Dijkstra Algorithm, Fuzzy AHP, Route Prioritization, Navigation, Maritime Transportation.*

Bulanık Analitik Hiyerarşi Süreci ile Genişletilmiş Dijkstra Algoritmasını Kullanarak Rota Önceliklendirme

Öz

Seyir planlaması, yakıt tüketimi, zaman ve emniyet faktörleri açısından önem arz etmektedir. Uygun rotanın belirlenmesi, birçok kriterin aynı anda gözden geçirilmesini gerektirdiği için gemi yönetiminde uzmanlık gerektiren konulardan biridir. Bu çalışmanın amacı, bulanık analitik hiyerarşi süreci (BAHS) ile genişletilmiş Dijsktra algoritması geliştirmek ve deniz çevresinde en öncelikli rotalama problemini araştırmaktır. Literatürde Dijsktra algoritması ile ilgili birçok çalışma bulunmaktadır fakat bu çalışmalar çoklu karar vericiler, karar matrislerinin tutarlılık kontrolü ve fayda ya da masraf şeklinde olabilecek çoklu kriterlerden yoksundur. Bu modelde, öznel yargılamalar ve kişisel tecrübeler karar verme sürecine doğrudan dahil olmaktadır. Amaçlanan BAHS ile genişletilmiş Dijsktra algoritması (bundan sonra BAHS-Dijsktra), belirsiz kıstasları ele alma yeteneklerini, bulanıklığın varlığında geliştirmektedir. Bu çalışma, insanlı yada insansız gemilere yeni bir rota optimizasyon algoritması sunarak yakıt tüketimi, zaman ve emniyet faydası sağlanması amaçlanmıştır.

Anahtar Kelimeler: *Dijkstra Algoritması, Bulanık AHS, Rota Önceliklendirme, Seyir, Deniz Taşımacılığı.*

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1. Introduction

Design, development, and improvement of the shortest path algorithms have great potential in the literature [1-4]. Shortest path applications mostly depend on the specific cases and some parameters of the problem. Such cases may vary based on the physical constraints, limitations, purpose, characteristics of the moving object, etc. There exist many studies in the literature considering the graph theory, routing and optimal path selection. Dijkstra algorithm is firstly proposed by Edsger W. Dijkstra as a tool for finding the shortest path between nodes in a graph [5]. It is highly studied by many scholars based on diverse perspectives considering the deterministic, stochastic or fuzzy nature of the fields such as routing for emergency relief distribution, optimal design of management areas, optical network design, optimization of layouts for refueling stations, recovery robust optimization, multiple-path selection for new highway alignments [6-13].

Limited number of the shortest path applications include decision support systems in which the shortest path application process is complex, hard and complicated meaning that multiple decision makers consider multiple criteria and alternatives. In [14], the similarity value of vague sets and TOPSIS as a multi-criteria decision-making method are preferred. Two values are assigned for each metric after the constraints are determined the best and the worst cases are found based on TOPSIS algorithm. AHP enhanced Dijkstra algorithm is studied in [15]. In that study, conventional AHP is applied with the weak consistency check method, and the routing is conducted by considering the weights of impedance factors. The weights of each route are not obtained by using AHP method. Moreover, it does not mention the number and consistency of decision makers. Fuzzy Dijkstra algorithm for shortest path problem is studied by [16]. In their study, the addition of two edges and the comparison of the distance between two different paths are analyzed. The edge lengths themselves are assigned as fuzzy numbers. Moreover, each length between nodes are assigned only one fuzzy value which means that they depend on only one parameter. In this study, multiple criteria (route length, weather conditions, etc.) are embedded in the decision-making process, and each criterion is assigned as fuzzy numbers by multiple decision makers. Other studies in the literature are [17] and [18], which use generic FAHP and TOPSIS methods without processing the most route prioritization. These studies only select the best option among alternatives under the given criteria.

This study introduces the concept of route prioritization that means the shortest path in a graph is computed by the Dijkstra algorithm in which the weights of each alternative are found by FAHP method. The proposed model improves the pure Dijkstra algorithm by combining with FAHP method of which it has many advantages such as flexibility in route geometry. For instance, the maritime environment does not necessarily be a planar straight-line graph. Multiple decision-makers might involve evaluating multiple criteria (cost or benefit) and alternatives to determine the weights of all edges. Consistency control of the expert judgments, expert consistency prioritization, and linguistic expressions are also processed.

Ship navigation is conducted under several complex decision situations (International Convention for the Safety of Life at Sea (SOLAS), Chapter V, Annex 24). There exist more than hundred parameters that require judgments for voyage planning. In general, the voyage planning is done by the navigation officer of the ship after receiving the master's approval (SOLAS, Regulation 34). The routes are determined after considering all factors related to safety, economy, time, ship, traffic, etc. In order to complete an optimal navigation in terms of safety and economy, decision makers must have knowledge and experience on the atlases, charts, ocean passages of the world, distance tables, light lists, routing, climatic, electronic navigational systems and radio signal information, port regulations, characteristics of the own vessel, notice to mariners, radio and local warnings, pilot charts, current/tidal stream atlases, and so on (SOLAS, Chapter V, Annex 25). Furthermore, available route options should be planned after the hazards identified. The risks such as (1) shallow waters limiting navigable waterways, (2) prohibited, restricted and danger areas, (3) limited safety distance of the ship (4) harsh currents and weather conditions (5) abrupt speed changes (6) traffic conditions (7) unexpected changes are always possible for the ship navigation [19]. Based on the complex and subjective nature of the dynamic environment, ship navigation is not only conducted by continuous visual observation along with the help of the electronic navigational systems and communication devices. Bridge team bring together all knowledge, discuss all probabilities considering the own ship, then route planning is managed based on the local and global experiences obtained from the bridge team and the directions from representatives of the shipping company (designated person ashore, company security officer, etc.), if necessary.

Optimal combination of safe, short and economic navigation requires a perfect voyage planning. Human capacity is limited to process the large information that contains several trade-offs. Multiple convergent factors directly involve in decision making for ship navigation. The proposed algorithm finds the optimal route for ship management team. Route prioritization is a multi-criteria decision-making process that derives priority vector of criteria and alternatives. The most prior route is found through the weighted directed graph. The empirical study with the eleven vertices (waypoints) and twenty-two edges (alternatives) proves the applicability of the proposed approach. In the future, enhanced versions of this algorithm might be employed in unmanned ships.

The rest of the paper is designed as follows: Section 2 explains the proposed FAHP-Dijkstra methodology. Section 3 gives the empirical study, Section 4 discusses the results and Section 5 concludes the paper.

2. Methodology

The proposed model is the FAHP extended version of the Dijkstra algorithm. In this model, the edge weights are priority values rather than distance. The edge weights are the combination of seven quantitative and qualitative criteria. Priority values are found by using FAHP method and maximum priority is searched and computed by the Dijkstra algorithm [20-35]. The proposed model is given in the following algorithm.

This pseudocode briefly describes Dijkstra algorithm for the intended route selection problem. Suppose it is given a graph $G=(W,C)$, a starting point $a \in W$, a final waypoint $t \in W$, and a nonnegative priority function $\beta := C \longleftarrow R$. The ship goes from a to t on route R of the highest priority function $\beta(R) = \sum_{c \in C(R)} \beta(c)$. The algorithm generates a set of N navigated waypoints by queuing the all waypoints and also tunes priority weight labels for all $w: W \longleftarrow R \geq 0$, $p(w)$ is the most prior a-u route when these routes are restricted to the waypoints $N \cup \{u\}$. Moreover, if $u \in N$, such the most prior route is also global most prior a-u route. For all $w \in W$, *pred(w)* is used as a predecessor of w on the present a-u route with the priority p(w). Finally, the most prior route from a to t is found as a, ..., pred(pred(t)), pred(t), t and has priority p(t).

```
Algorithm: DIRECTEDGRAPH G(W,C)
Input: A weighted connected graph with non-negative weights
Output: The shortest path from a to t
Begin
        PriorityWeight[a] ⟵0
        For all w∈W – {a}, Do PriorityWeight[w] ⟵ -∞
        N⟵∅
        Q⟵W
        While Q≠∅, t ∉ N
                Do Find the weights of each alternative ⟵FAHP
                Select u ∈ arg max$_{w∈N}$c (Q, PriorityWeight)
                N⟵N ∪ {u}
                For all w ∈ Neighbors[u]

                                If PriorityWeight[w] < PriorityWeight[u] + β(u,w)
                        Do      then  PriorityWeight[w]⟵PriorityWeight[u] + β(u,w)
                                End if
                        Set Pred(w) := u
                        End for
                End while
        Return PriorityWeight
End
```

3. Empirical Study

This study provides a holistic perspective to the criteria and alternatives and finds the most prior route. The empirical study is designed in the five phases of the decision process. Particulars of all alternatives are determined for each phase. The route prioritization is conducted for each waypoint. For instance, waypoint 2 (WP_2) has six alternatives, WP_3 has three alternatives and so on. Table 1 provides the alternative routes between the corresponding waypoints (Figure 1).

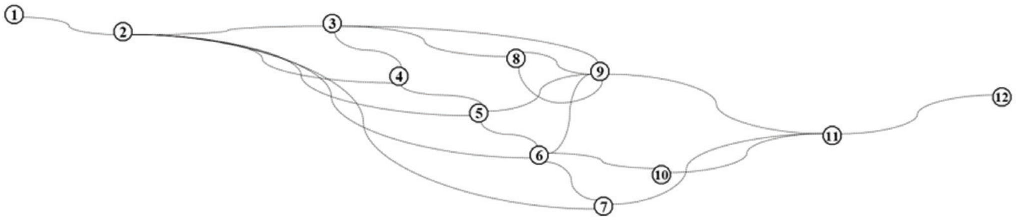

Figure 1. *The Proposed Region to Navigate*

Table 1. *The Alternatives for Each Phase*

Phases	For	Waypoints	Number of Alternatives	Alternatives
1.Phase	WP_1	WP_1-WP_2	1	r_1
2.Phase	WP_2	WP_2-WP_3	6	r_2
		WP_2-WP_4		r_3
		WP_2-WP_5		r_4
		WP_2-WP_6		r_5
		WP_2-WP_7		r_6
		WP_2-WP_7		r_7

Table 1. *The Alternatives for Each Phase (cont')*

Phases	For	Waypoints	Number of Alternatives	Alternatives
3.Phase	WP_3	WP_3-WP_9	3	r_{12}
		WP_3-WP_4		r_8
		WP_3-WP_8		r_{13}
	WP_4	WP_4-WP_3	2	r_8
		WP_4-WP_5		r_9
	WP_5	WP_5-WP_9	3	r_{14}
		WP_5-WP_6		r_{10}
		WP_5-WP_4		r_9
	WP_6	WP_6-WP_{10}	4	r_{16}
		WP_6-WP_7		r_{11}
		WP_6-WP_5		r_{10}
		WP_6-WP_9		r_{15}
	WP_7	WP_7-WP_{11}	2	r_{17}
		WP_7-WP_6		r_{11}
4.Phase	WP_8	WP_8-WP_9	2	r_{18}
		WP_8-WP_9		r_{19}
	WP_{10}	WP_{10}-WP_{11}	1	r_{21}
5.Phase	WP_9	WP_9-WP_{11}	1	r_{20}
	WP_{11}	WP_{11}-WP_{12}	1	r_{22}

3.1. Design of the Problem

The hierarchy of the shortest path planning is given in the Figure 2. Seven criteria are considered for ship navigation in this region (Table 2).

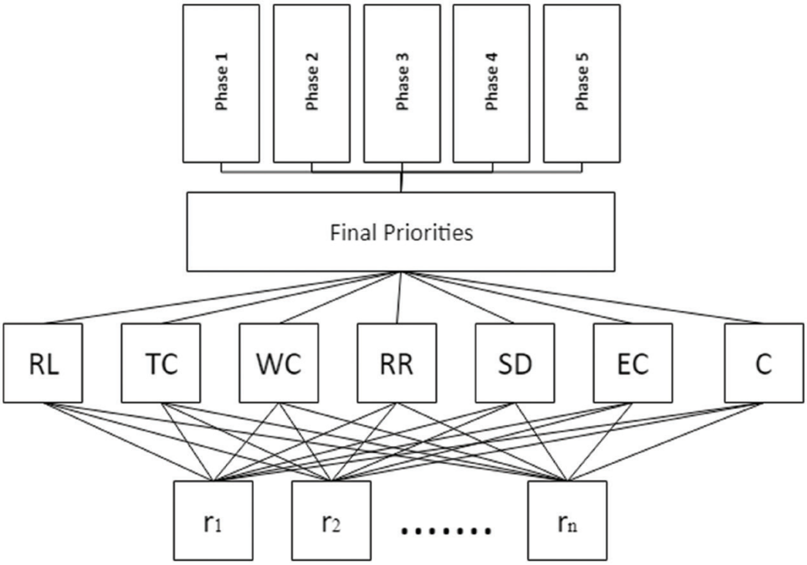

Figure 2. *The Hierarchy of the Shortest Path Planning*

Table 2. *The Criteria for the Shortest Path Planning and Their Symbols*

Criteria	The symbols of each criterion
Route Length	RL
Traffic Congestion	TC
Weather and Sea Conditions	WC
Regulations and Restrictions	RR
Sea Depth	SD
Environmental Constraints	EC
Charges	C

After determining all probable routes, the optimal route is selected. Optimal route does not always mean the shortest one. In this study, optimal route is selected after taking into consideration the situations such as route length (RL), traffic congestion (TC), weather and sea conditions (WC), regulations and restrictions (RR), sea depth (SD), environmental constraints (EC) and charges (C). These criteria are determined after several expert consultations. These three anonymous experts are ship masters whom each one has more than ten-year field experience. Although experts agreed that these are the suitable criteria for ship navigation in this region, it is important here to express that number of criteria might vary and the criteria might be different for other regions. In this study, a static route prioritization is proposed, and the empirical study is projected under these criteria. In practice, ship navigation is conducted under hundreds of criteria and the relevant data are obtained in a real-time manner. Master's previous experience in that region is the most significant factor for safe ship navigation.

The unit of the RL is taken as a knot, which is a nautical mile per hour. TC may cause maritime accidents (collision, etc.) so that it is represented by risk parameters as minimum, low, moderate, high and extreme risks. Wind speed/direction, wave height and currents are used as the sub-criteria of WC. Drift and set are characteristics of the current. Ship masters should check the RR in the navigated region after considering the admiralty sailing directions. All or part of the navigated region may be restricted because of several reasons such as fishing, mining, firing, search and rescue, submarine operating, offshore drilling, holidays, etc. Availability of a restriction is enough, but numbers of RR is also provided. Metric unit is used for SD, which is related to the technical terms of under keel clearance and ship squat. EC is about the visual observation of the ship's navigation officers. Charges may be on ships, goods, pilotage, towage, tolls, environmental levy, waste reception levy, etc. In this study, empirical amounts in dollars are assigned to each route.

For navigation, waypoints are preferred as a reference point. All alternative routes contain waypoints including the start and final points. When a ship reaches the waypoint, there might exist some options. The next alternatives are evaluated for each waypoint. Soon after the analysis, the most feasible route is selected, and ship navigation is maintained until the following waypoint. The optimal alternatives are always checked considering the given updated criteria for the corresponding route.

3.1. Application and Results

Three field decision makers consider the criteria and the alternatives as given in Table 3 in which the data are based on the assumptions. The pairwise comparison

Table 3. *Particulars of the Navigation Field*

				WC									
	Waypoints	Routes	RL (nm)	TC (hours)	Wind Speed (knots)	Wind Direction	Wave Height (m)	Drift (knots)	Set (degrees)	RR	SD (m)	EC	C ($)
1	WP_1-WP_2	r_1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	WP_2-WP_3	r_2	202	High risk	<1	North	0.5	1.5	150	No	85	Moderate fog	2650
	WP_2-WP_4	r_3	252	Extreme risk	1-2	North-Northeast	0.75	1.25	125	1	60	Mist or thin fog	4320
	WP_2-WP_5	r_4	255	Extreme risk	1-2	East-Northeast	0.75	1.25	135	1	55	Poor visibility	4320
	WP_2-WP_6	r_5	307	Extreme risk	2	Northeast	1	1.35	110	1	70	Moderate fog	4320
	WP_2-WP_7	r_6	313	Extreme risk	1-2	Northeast	0.75	1.45	125	1	70	Mist or thin fog	4480
	WP_2-WP_7	r_7	183	High risk	<1	Northeast	0.5	1.55	135	No	100	Poor visibility	2200
3	WP_3-WP_9	r_{12}	178	High risk	2	Northeast	1	1.15	90	2	90	Moderate visibility	3230
	WP_3-WP_4	r_8	112	Low risk	1	Southeast	0.75	1.25	100	No	110	Good visibility	890
	WP_3-WP_8	r_{13}	96	Moderate risk	1-2	Southeast	1	1.05	95	1	100	Very good visibility	1210
4	WP_4-WP_3	r_8	65	Minimum risk	<1	East-Southeast	<0.5	1.5	90	1	110	Good visibility	640
	WP_4-WP_5	r_9	76	Low risk	<1	East	0.5	1.25	95	1	100	Very good visibility	1400
5	WP_5-WP_9	r_{14}	113	Low risk	2-3	Northwest	1.25	1.25	85	2	90	Dense fog	2100
	WP_5-WP_6	r_{10}	84	Minimum risk	1	Southeast	0.5	1.35	90	No	110	Thick fog	No
	WP_5-WP_4	r_9	69	Low risk	1-2	Southeast	1	1.45	90	1	100	Fog	1350
6	WP_6-WP_5	r_{10}	105	Low risk	3	East-Southeast	1.5	1.55	95	2	90	Good visibility	1700
	WP_6-WP_7	r_{11}	98	Low risk	2	South	1	1.15	90	No	105	Very good visibility	1430
	WP_6-WP_9	r_{15}	182	Minimum risk	<1	West-Northwest	<0.5	1.15	100	1	100	Good visibility	850
	WP_6-WP_{10}	r_{16}	176	Low risk	3	West	1.25	1	90	2	95	Very good visibility	2300
7	WP_7-WP_{11}	r_{17}	48	Minimum risk	2	Southeast	1	1	90	No	85	Good visibility	No
	WP_7-WP_6	r_{11}	53	Minimum risk	2	South	1.25	1	90	No	85	Very good visibility	No
8	WP_8-WP_9	r_{18}	44	Minimum risk	1	South-Southwest	0.5	1	90	No	90	Good visibility	No
	WP_8-WP_9	r_{19}	86	Minimum risk	<1	East	0.75	1	95	No	90	Very good visibility	Yes
9	WP_9-WP_{11}	r_{20}	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10	WP_{10}-WP_{11}	r_{21}	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11	WP_{11}-WP_{12}	r22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

is completed for the five phases of the decision process and is reported. Linguistic terms and fuzzy numbers used for the pairwise comparison matrices are based on the fuzzy extended version of Saaty's 1–9 scale [23]. The individual fuzzy judgment matrix for inter-criteria assessment of route prioritization and aggregated weight vector for criteria of route prioritization are calculated as the weight of criteria.

Aggregated weight coefficients show that the WC has the major contribution with its 0.25 value (midpoint) and RL is the second as its 0.20 selectivity power. Regulations and restrictions, traffic congestion, charges, sea depth, environmental constraints have the posterior weights of 0.17, 0.16, 0.10, 0.08 and 0,04 respectively. Aggregated fuzzy judgment matrix is found consistent since CCI is 0.03 less than the threshold of 0.37. the extent synthesis is performed for the shortest path planning.

As an example, calculation results for WP5 based on the weather and sea conditions (WC) criterion) are given in this study. In Tables 4, 5 and 6, individual fuzzy judgment matrix, the individual fuzzy priority vector of DMs and aggregated weight, the aggregated fuzzy judgment matrix for weather and sea conditions criterion are calculated. Then the extent synthesis is conducted.

Table 4. *The Individual Fuzzy Judgment Matrix for Weather and Sea Conditions Criterion on* WP_5 *(Alternatives* r_9*,* r_{10} *and* r_{14}*)*

DM_1	**λ=0.01**	**r_9**	**r_{10}**	**r_{14}**
	r_9	(1.00 1.00 1.00)	(0.20 0.33 1.00)	(0.33 1.00 1.00)
	r_{10}	(1.00 3.00 5.00)	(1.00 1.00 1.00)	(1.00 1.00 3.00)
	r_{14}	(1.00 1.00 3.00)	(0.33 1.00 1.00)	(1.00 1.00 1.00)
DM_2	λ=0.08	r_9	r_{10}	r_{14}
	r_9	(1.00 1.00 1.00)	(0.14 0.2 0.33)	(0.14 0.2 0.33)
	r_{10}	(3.00 5.00 7.00)	(1.00 1.00 1.00)	(1.00 3.00 5.00)
	r_{14}	(3.00 5.00 7.00)	(0.20 0.33 1.00)	(1.00 1.00 1.00)
DM_3	λ=0.24	r_9	r_{10}	r_{14}
	r_9	(1.00 1.00 1.00)	(1.00 3.00 5.00)	(0.14 0.20 0.33)
	r_{10}	(0.20 0.33 1.00)	(1.00 1.00 1.00)	(0.20 0.33 1.00)
	r_{14}	(3.00 5.00 7.00)	(1.00 3.00 5.00)	(1.00 1.00 1.00)

Table 5. *The Individual Fuzzy Priority Vector of DMs and Aggregated Weight Vector for Weather and Sea Conditions Criterion*

	r_9	**r_{10}**	**r_{14}**
DM_1	(0.19 0.2 0.22)	(0.45 0.47 0.5)	(0.29 0.31 0.33)
DM_2	(0.08 0.08 0.1)	(0.56 0.57 0.61)	(0.29 0.32 0.33)
DM_3	(0.21 0.22 0.22)	(0.12 0.14 0.18)	(0.59 0.62 0.65)
Aggregated Weight	(0.18 0.19 0.20)	(0.46 0.47 0.50)	(0.31 0.33 0.35)

Table 6. *The Aggregated Fuzzy Judgment Matrix for Weather and Sea Conditions Criterion*

	r_9	r_{10}	r_{14}
r_9	(1.00 1.00 1.00)	(0.20 0.34 0.93)	(0.28 0.75 0.82)
r_{10}	(1.07 2.90 4.86)	(1.00 1.00 1.00)	(0.93 1.09 3.05)
r_{14}	(1.20 1.31 3.47)	(0.32 0.91 1.07)	(1.00 1.00 1.00)
CCI=0.02			

The extent synthesis is performed for route prioritization problem as follows:

S_{r9} =(1.49, 2.10, 2.76) $\otimes$ (1/15.96, 1/10.34, 1/8.30) = (0.09, 0.20, 0.33)

S_{r10} =(3.01, 5.01, 8.92) $\otimes$ (1/11.31, 1/10.34, 1/12.95) = (0.27, 0.48, 0.69)

S_{r14} =(2.54, 3.23, 5.54) $\otimes$ (1/14.21, 1/10.34, 1/10.04) = (0.18, 0.31, 0.55)

$V(S_{r9} \geq S_{r10})=(0.27-0.33)/((0.20-0.33)-(0.48-0.27))=0.19$

$V(S_{r9} \geq S_{r14})=(0.18-0.33)/((0.20-0.33)-(0.31-0.18))=0.59$

$V(S_{r10} \geq S_{r9})=1$

$V(S_{r10} \geq S_{r14})=1$

$V(S_{r14} \geq S_{r9})=1$

$V(S_{r14} \geq S_{r10})=(0.27-0.55)/((0.31-0.55)-(0.48-0.27))=0.62$

$d(r_9) = \min(0.19, 0.59)= 0.19$

$d(r_{10}) = \min(1, 1)= 1$

$d(r_{14}) = \min(1, 0.62)= 0.62$

$d(WP_5)= (r_9,r_{10},r_{14}) =(0.11, 0.55, 0.34)$

Final assessment is introduced in Table 7. Alternative priority weights of all routes between the waypoints are used as the edge weights of the directed graph. Then the proposed Dijkstra algorithm is implemented. The results of the FAHP provide the priority values of each routes starting from the corresponding waypoint. Dijkstra algorithm considers these values and find the most prior route with the maximum value. The found route connects the waypoints of WP_1, WP_2, WP_6, WP_{10}, WP_{11} and WP_{12} respectively. At WP_1, WP_{10}, WP_{11} and WP_9, there is only one alternative. Therefore, a priority weight is not assigned for each waypoint. The route of r_1, r_5, r_{16}, r_{21} and r_{22} is the most prior route with priority value 0.14 among all alternatives as shown on Figure 3.

4. Analysis of Results, Discussion and Further Research

FAHP method enables finding the priorities for each route as inputs of Dijkstra algorithm. As it is seen in Table 7, route weights for each criterion are different. If only FAHP method is used to find the most prior route, it would be

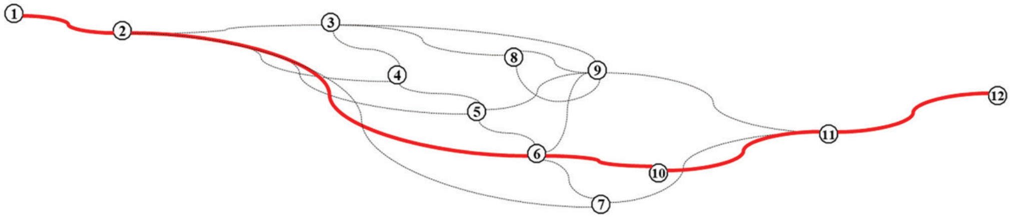

Figure 3. *The Optimal Route*

Table 7. *Final Assessment of Alternatives of Route Prioritization*

Weight	RL 0.20	TC 0.16	WC 0.25	RR 0.17	SD 0.08	EC 0.04	C 0.10	Alt. Priority Weight
r_2	0.38	0.36	0.27	0.30	0.20	0.33	0.34	0.32
r_3	0.10	0.00	0.14	0.08	0.09	0.10	0.08	0.09
r_4	0.00	0.00	0.10	0.04	0.01	0.04	0.01	0.04
r_5	0.00	0.00	0.10	0.09	0.11	0.00	0.00	0.05
r_6	0.00	0.14	0.14	0.10	0.12	0.08	0.09	0.10
r_7	0.52	0.51	0.25	0.39	0.46	0.46	0.48	0.42
r_{10}	0.22	0.14	0.18	0.21	0.19	0.26	0.25	0.20
r_{11}	0.38	0.37	0.39	0.44	0.40	0.27	0.15	0.37
r_{15}	0.27	0.44	0.35	0.26	0.33	0.34	0.51	0.35
r_{16}	0.13	0.04	0.08	0.08	0.08	0.13	0.10	0.09
r_{12}	0.00	0.11	0.12	0.02	0.04	0.17	0.12	0.07
r_8	0.43	0.43	0.55	0.64	0.60	0.49	0.53	0.52
r_{13}	0.57	0.47	0.33	0.34	0.36	0.35	0.35	0.41
r_9	0.00	0.09	0.11	0.04	0.04	0.00	0.06	0.06
r_{10}	0.35	0.56	0.55	0.64	0.57	0.67	0.59	0.54
r_{14}	0.65	0.36	0.34	0.32	0.40	0.33	0.35	0.41
r_8	0.56	1.00	0.68	0.00	0.68	0.42	1.00	0.62
r_9	0.44	0.00	0.32	1.00	0.32	0.58	0.00	0.38
r_{11}	0.56	1.00	0.00	0.51	0.54	0.00	0.56	0.46
r_{17}	0.44	0.00	1.00	0.49	0.46	1.00	0.44	0.54
r_{18}	1.00	0.68	0.56	0.54	0.56	0.42	1.00	0.71
r_{19}	0.00	0.32	0.44	0.46	0.44	0.58	0.00	0.29

misleading. For instance, the alternatives r_7, r_{11}, r_{13}, r_{10}, r_8, r_{17} and r_{18} have relatively higher weights. Combining these alternatives do not guarantee the final most prior route even they sometimes may not constitute a route starting from beginning (WP_1) to the end point (WP_{12}).

By using pure Dijkstra algorithm, the most prior route is always computed in case using weights of only one criterion (route length, traffic congestion, etc.). However, the final route only represents the criterion's priority. For example, if the values of cost weights are used in Dijkstra algorithm, it means that the most prior route is the cheapest route. This study uses alternative priority weights of each alternative. The final route of a criterion might be different than the most prior route is r_1, r_5, r_{16}, r_{21} and r_{22}. In this study, seven criteria (cost or benefit) are evaluated, and subjective judgments of three experts are embedded in decision-making process.

In this study, Chang's synthetic extent method and Wang's approach are compared based on the same problem. When Chang's approach is applied, the most prior route is found as r_1, r_5, r_{15}, r_{20} and r_{22}. We observe that the algorithm finds different routes for each approach that proves the openness to new improvements and applicability of new approaches. For the future research, a convenient way to assign a priority value for waypoints that have only one alternative will be generated. Moreover, dynamic route prioritization will be developed as further research. Different shortest path algorithms can be used, and a detailed comparison of FAHP-Dijkstra with different versions of FAHP method (i,e, Improved Gaussian FAHP, Improved FAHP [33,34]) will be conducted.

5. Conclusions

Ship navigation is a multi-dimensional task that requires comprehensive knowledge and field expertise. Human thinking style is limited for decision making to determine the optimal route among several alternative paths considering multiple convergent criteria. This study proposes an FAHP extended Dijsktra algorithm in order to help the ship management team to determine the optimal route for safe, short and economic navigation. There exist several versions of Dijkstra applications in the literature. Conventional Dijkstra algorithm commonly considers edge values as a distance and finds the shortest path in a graph by assigning predefined crisp values. However, in practice, prioritization is considered as the purpose, one or multiple decision makers involve decision-making process under the multiple parameters in the fuzzy environment. For instance, multiple criteria such as route length, weather and sea conditions, traffic congestion, etc. are the concerns of bridge team of the ships during routing process for maritime transportation. This study improves the capability of handling the conventional Dijkstra algorithm. Consistency control of decision matrices and expert consistency prioritization are conducted in the FAHP-Dijkstra algorithm. The empirical study of route prioritization demonstrates the applicability of the proposed approach. It is also expected in the future that unmanned ships might also be benefited from enhanced versions of the proposed algorithm.

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