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Multi-Layer, Multi-Segment Iterative Optimization for Maritime Supply Chain Operations in a Dynamic Fuzzy Environment

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ABSTRACT This study aims to develop a multi-layer, multi-segment iterative optimization algorithm for the operations of a single agent, which can be either a container in a distribution system, an automated guided vessel in a transport network or a vessel in a maritime environment with obstacles. It can be applied to several kinds of problems such as route optimization, path planning, project management, port operations, efficiency of an automated guided vessel, and unmanned vessels. All required qualitative and quantitative concerns (length, energy consumption, economic factors, safety issues, etc.) can be embedded to the system. Relevant data are based on crisp and/or fuzzy values. This model works well in an environment with different sectors. Each sector has its unique characteristics such as different number of options and multiple factors that can be cost and/or benefit.

INDEX TERMS Fuzzy sets, MCDM, operations research, optimization algorithm, supply chain network.

I. INTRODUCTION

The inevitability of change is present in all sectors, including the maritime sector. Almost everything in the world is in a change. With the development of technology and changes in environmental conditions, new routes, new ports, new vehicles are emerging, and new methods are developed for changing needs. In the maritime sector, weather conditions, financial conditions, exchange rate difference, traffic situation, supply and demand, risks and uncertainties are constantly changing dynamically. The literature presented below proves the need for a model to cover all these fractions and dynamic changes.

As a part of global supply chain, maritime supply chain can be defined as a network that includes all actors (ports, ships, waterways, etc.) for transporting a cargo [1], [2]. The literature regarding to maritime supply chain can be categorized and analyzed into several topics as environmental concerns, resilience, risk assessment, inventory routing, network optimization, sustainability and so on. Maritime supply chains are investigated in several perspectives such as slot capacity [3], forward and inverse flow [4], [5], financial considerations [6], etc. The maritime sector is a complex sector that is intertwined or associated with many supply chains, such as transportation, shipbuilding, cold chain [7] or ship repair [8].

The problem of maritime inventory routing is being studied by many scientists [9], [10]. Jiang and Grossmann [11] present a mixed-integer linear programming to explore the maritime scheduling and inventory routing for maritime transportation. Liner shipping service networks with different service routes are analyzed in [12]. A number of approaches have been developed for logistics operations to ensure minimum transport costs, not only long distances, but also short distances [13]. Short sea inventory routing problem with multi-product and heterogeneous fleet is studied in [14]. A comprehensive delivery program for LNG supply chains with large number of vessels and customers is investigated by implementing a mixed integer programming [15]. The routing problem from domestic to overseas with empty or laden containers is studied in [16]. Inventory routing with multiple products is studied in [17]. Fleet deployment optimization at the time-space network for maritime supply chain is conducted under some constraints [18]. In the above-mentioned articles, the problems are addressed in only one dimensional manner.

Not only the removal of some existing routes or the addition of new routes, but also the changes in the nodes or agents

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can affect a supply chain network. For example, increasing the port capacities, vessel capacity utilization, supply chain integration or terminal operating systems will affect the decision process in the transportation systems [19]–[22]. Decision-making models may be required for the capacity expansion requirements of each node in a supply chain network [23]. For instance, Mar-Ortiz *et al.* [24] point out container terminal capacity management problem and propose a decision support system. Impacts of inland ports on supply chain systems are discussed in [25]. Port performance is also an important indicator in the decision-making process of the parties in the maritime supply chain [26], [27]. Dry ports and rural river ports are another components of global supply chain [28]–[30]. The competition of actors or nodes (i.e. sea ports) on the maritime supply chain can lead to changes in alternatives and decision shifts [31], [32]. The existing works show that there is a requirement of a model that handles dynamic changes in a network.

There are many decision making levels in the maritime industry such as strategic, tactical and operational processes [33]–[35]. The environmental criterion such as greenhouse gas is also considered in any nodes (e.g. sea ports) or edges (e.g. waterways) that make up the network [36]. Behavioral differences of shipping industries affect the greenhouse gas emissions [37]. For the environmental management of risks in maritime supply chain, Grant and Elliott [38] propose a risk assessment framework involving ten significant criteria as society, ecology, economy, technology, legal, administration, politics, ethics, culture, and communication [39], [40]. Environmental policies on maritime supply chain are discussed in [41] and [42]. Bektaş *et al.* [43] discuss the decision parameters and roles of operations research methods for green fright transportation. For example, the Ref. [44] studies the effect of reusing empty containers in a supply chain. Panayides *et al.* [45] emphasize the importance of optimization in the transport of different types of cargo, different ship designs, transport systems efficiency and financial improvements. In [46], green practices and drivers are investigated for supply chain in maritime environment. In [47], containerized freight on transportation in the global maritime supply chain is evaluated based on environmental and greening concerns.

There exist a relationship between energy efficiency and emissions [48], [49]. Energy efficiency can be addressed through a holistic approach throughout the supply chain, or it can be calculated on a case-by-case basis. For example energy efficiency of cranes and tractor are computed in [50]. Performance of each element (i.e. rubber tired or electric rubber tired gantries) in green supply chain is another analysis metrics [51]. The existing works highlight that there exist different layers and segments in the supply chains.

Supply chains are always facing expected or unexpected changes. In [52], marine accidents caused by factors such as ship characteristics and geographical conditions are explained and thus distortions in the logistics chain are analyzed. Li *et al.* [53] draw attention of readers by proposing methods for the last minute job arrivals which can disrupt routine container terminal operations. The continuity of the change is also observed in ports [54]. Anomaly detection systems have been developed for the analysis of changes in the maritime supply chain network [55]. Resilience and vulnerability in a supply chain is of significance for a safe and efficient transportation network [56]–[59]. Failures and disruption vulnerability in the maritime transportation system are given in [60]. Mokhtari *et al.* [61] discuss the operational risks and propose a decision framework for risk management. Transportation systems might involve in risks such as natural disasters, cyber-attacks and errors including technology, organization, economy or human factors [62]. Polatidis *et al.* [63] propose a cyber-attack path discovery method for maritime risk management system. Barnes and Oloruntoba [64] express that complexity of interaction between agents in a network create vulnerability and discuss the crisis management. Increasing risk of possible interruptions in supply chain is mentioned in [65], and the relationships between resilience capability concept, security management practices and cargo operations performance are questioned. External or systemic network perturbations are modelled and classified by providing real examples in [66].

Numerous modeling and simulation studies are conducted for risk assessment of maritime transport systems. For instance, Faghih-Rooh *et al.* [67] implement Markov modelling and Markov Chain Monte Carlo simulation to assess the risks in transportation systems. Risks of multi-modal supply chains are introduced in [68] and [69]. Risk assessment factors for maritime supply chain security are introduced and analysed in [70]. Wan *et al.* [71] present a Bayesian based the failure mode, effect analysis approach for risk assessment of maritime supply chains. In that study, significant risk factors are determined as dangerous cargo transportation, turbulent prices of fuel, non-attracting market and exchange rate differences, respectively. Dynamic changes in port area capacity, workforce or docks and policy variables affect port efficiency and therefore supply chains in different ways [72]. In [73], quality function deployment method is proposed to improve the resilience of maritime supply chain after definition of maritime risks, customer requirements and required resilience measures. Nguyen *et al.* [74] describe uncertainty as a risk and propose a fuzzy based Bayesian network model for container shipping operational risks. Maritime choke-points are defined as risks in [75], and it is expressed that extreme weather conditions, infrastructural failure and congestion interrupt the traffic and flow of the cargo in the global trade network. Extreme climates and cyclone risk model for container ports are studied in [76]. Kwesi-Buor *et al.* [77] studied means for taking precautions against risks in maritime supply chain.

Sustainability concept for maritime supply chain and design requirements for sustainability are studied in [78] and [79]. According to the authors, objective and subjective design requirements such as integration in the workflow, cooperation with all parties, route optimization, green designs, renewable energy and accident prevention should be

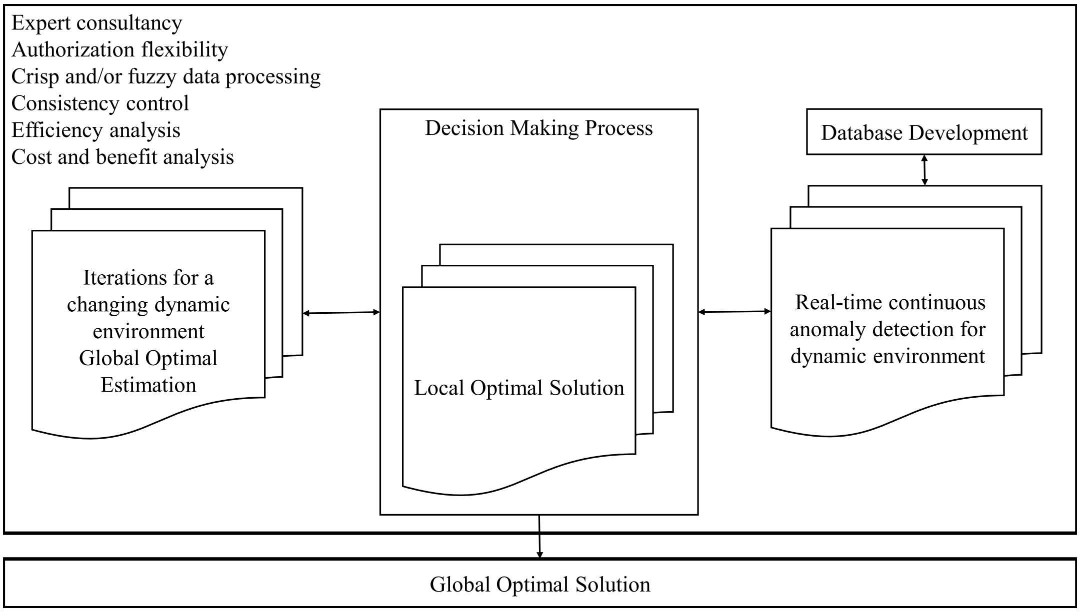

FIGURE 1. General framework of proposed model for supply chain operations in a dynamic fuzzy environment.

present for a sustainable supply chain. Decision support systems are proposed to improve the sustainability in maritime supply chains [80]. Sustainability initiatives are introduced in [81]. Sustainability investment is discussed in [82]. Sustainability criteria for port evaluations are expressed in [83].

As can be seen in the literature given above, many factors and parameters play a significant role during the maritime supply chain operations. In this study, the dynamic change in supply chains is stressed. This study contributes to the literature by proposing a general framework of proposed model for supply chain operations in a dynamic fuzzy environment and a comprehensive iterative optimization algorithm for multi-layer multi-segment supply chains where the algorithm processes all concerns and concepts regarding the supply chain. An empirical example is applied for maritime transportation. The algorithm is comprehensive, inclusive, flexible and can be applied to all multi-layer multi-segment systems in a dynamic environment.

II. METHODOLOGY

This study presents a multi-layer, multi-segment iterative optimization for supply chain operations in a dynamic environment. Optimized parameters can be either length of the network, time spent in the network, or the cost of the network. For the application in this study, any optimization techniques suitable for the problem may be preferred such as any shortest path algorithms along with any of the multi-criteria decision-making techniques [84].

In this study, it is aimed to optimize risk, cost and performance layers in the network for maritime supply chain. For this study, fuzzy analytical hierarchy process [85]–[88] as a multi-criteria decision-making technique is preferred to obtain the weights, and Dijsktra algorithm is used to optimize the lowest cost, minimum risk and highest performance for the optimal estimation [89].

The fuzzy analytic hierarchy process method [90], [91] is capable of multiple experts [92], [93], fuzzy extension [94]–[96], aggregation [97]–[99], extent analysis [100], [101], consistency control [102], and expert consistency prioritization [103]. General framework is provided in Figure 1. This framework is capable of expert consultancy, authorization flexibility, crisp or fuzzy data processing, consistency check and cost-benefit analysis. The data collection phase constitutes the process of gathering the opinions of many experts. Authorization flexibility allows the use of the system to be transferred to others. Cost-benefit analysis, intuitions or subjective views of experts can be expressed as fuzzy numbers, but some of the inputs or statistics might be based on crisp data. The feedback mechanism is formed with the consistency of the matrices in which expert opinions are formed, and more accurate outputs are obtained. All data can be stored in a database to ensure better results. As the abnormalities occurring during the iterations of the system are improved, the decision-making process will operate more effectively.

The algorithm of multi-layer, multi-segment iterative optimization for maritime supply chain operations in a dynamic fuzzy environment is provided in Figure 2. Decision making process can be conducted under any multi-criteria decision making methods, and optimal estimation can be completed considering any graph-based optimization techniques.

This algorithm is capable of any number of layers/phases, segments/processes, criteria/factors, alternatives/options and decision makers/experts for both criteria and alternatives (Table 1).

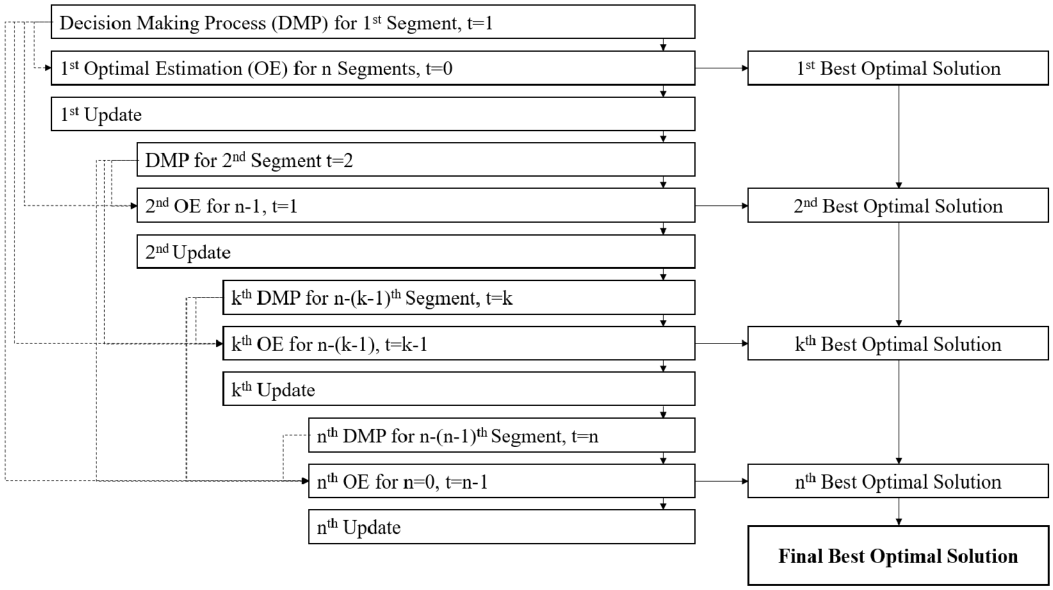

FIGURE 2. Algorithm of a multi-layer, multi-segment iterative optimization model in a dynamic fuzzy environment.

TABLE 1. The model's numerical capabilities.

Phases	Processes	Number of Criteria	Number of decision makers for evaluating criteria	Number of Alternatives	Number of decision makers for evaluating alternatives
1,2,...,n	a,b,...n	Any			

III. EMPIRICAL STUDY

The presence of different segments in the maritime industry necessitates dynamic optimization. The segment concept represents steps or structures independent of others in terms of their internal parameters. The concept of segment can be determined by time, space or category. The distance between segments on a network may be short or at very long intervals. For example, for a navigating ship, wind, rain, or wave size as weather conditions constitute an effective segment within itself. Similarly, financial factors such as return on investment, loss probability and exchange rate refer to another segment which is integral in itself. Depending on characteristics of the problem, segments can be composed of parts or can be completely separate from each other. Segments can be complementary, if one is not available, the other cannot be realized. For example, there is a flow in the shipbuilding industry, and construction process cannot be moved to the next step if one previous step is not performed. The second segment type is not connected to each other in any order and can be observed in networks formed by the combination of independent parts. It can be given an example of a single agent, such as AGV acting on a network, evaluating the technical characteristics, weather or conditions in different environments into different segments. The main texture, theme or targeted goal that makes up a network can be all kinds of parameters such as distance, cost, risk, flexibility, etc. thus, the concept of layer comes to the fore. This study provides a global result by optimizing different layers of different segments in a dynamic environment.

In this study, while many layers can be handled in the proposed approach, we prefer the supply chain network to have three layers as an example. These layers are cost, risk and performance. Cost and risk are the loss layers which are inversely proportional to the resulting values. Performance is the benefit layer which is directly proportional to the results. The empirical region for the Layer 1 with four segments is illustrated in Figure 4. The agent moves from node 1 to node 14. In [84], prioritization concept is introduced. In the layers of cost, risk and performance, route prioritization phenomena (route importance or preferability) is considered. As the values of cost and risk increase, their priority decrease, and as opposed to this, the priority increase as performance increases. Segment concept might be a time interval, region (i.e. ports, navigational areas), category or steps such as ship construction, etc.

In this experimental study, criteria and alternatives are introduced to the maritime professionals in detail. Since there are many criteria and alternatives, the criteria and alternatives are harmonized at the segments, combined in various ways and presented to the experts. For example, operation costs, insurance costs, attendance fee, communication expenses, personnel salary, facility, anchor dues, extras,

TABLE 2. Pairwise comparison of criteria for the 1^{st} segment of layers at the 1^{st} iteration.

	C_{1111} C_{1112}	C_{1111} C_{1113}	C_{1112} C_{1113}			
E_{1111}	1/vl	m	e			
E_{1112}	l	1/l	e			
E_{1113}	1/h	1/h	vl			
E_{1114}	1/vh	1/vh	e			
	C_{1211} C_{1212}	C_{1211} C_{1213}	C_{1211} C_{1213}	C_{1212} C_{1213}	C_{1212} C_{1213}	C_{1212} C_{1213}
E_{1211}	e	e	1/l	1/l	1/l	1/l
E_{1212}	1/vl	e	1/vl	1/vl	1/vl	e
E_{1213}	l	m	m	e	m	e
E_{1214}	e	1/vl	1/vl	e	1/vl	e
	C_{1311} C_{1312}	C_{1311} C_{1313}	C_{1312} C_{1313}			
E_{1311}	e	e	1/l			
E_{1312}	1/l	e	1/l			
E_{1313}	l	m	e			
E_{1314}	1/l	1/l	e			

capital, safety costs, trailer, garbage, maintenance, port, sanitary dues, customs, etc. are put forward as some of the costs for cost layer. Similarly, environmental considerations, ecological concerns, geographical risks, risks of structural design, risks related to weather conditions, piracy attacks, fire risks, technical risks, stability risks, falling asleep, abusive alcohol usage, personnel related problems etc. are some of the risk examples for risk layer. Examples of performance layer criteria can be summarized as capacity, efficiency, reliability, sustainability, speed, organizational effectiveness, employee or customer satisfaction, ability to learn, technology capability, service quality, functionality, accuracy, human resource capability, profitability, etc. To determine the criteria, a literature review is conducted as some are mentioned in the introduction section and expert opinions are utilized.

After considering all the information regarding the regions, experts express their opinions based on pairwise comparisons. In this study, the symbols for iterations, layers, segments, experts, criteria and alternatives are indicated by I, L, S, E, C and A respectively. E_{ILSe}, C_{ILSc} and A_{ILSa} form the general structure. As an example, C_{1234} represents forth criterion at the third segment of the second layer for the first iteration. Similarly, A_{1111} is the first alternative at the first segment of the first layer for the first iteration, $n_1 - n_2$, which is equal to l_1 (Figure 4). Each segment of a layer has a certain number of criteria which are evaluated by a certain number of experts. Similarly, there are a number of alternatives at the nodes in each segment, and alternatives are evaluated by a certain number of experts in terms of each criterion of that segment. The numbers of experts, criteria and alternatives might vary because of time-dependent situations, conditions and conjuncture. Pairwise comparisons are conducted in accordance with the decision-making technique, first comparison of the criteria and then the alternatives for each criterion. The experts made their judgments based on fuzzy expressions where e, vl, l, m, h, vh stand for equal importance, very low, low, medium, high and very high, respectively.

A. FIRST ITERATION

Table 2 provides expert judgment evaluations of criteria at the 1^{st} segment of the layers for the 1^{st} iteration. Experts evaluate a total of three criteria in the first and third segments, and four criteria in the second segment by performing pairwise comparisons.

Individual expert judgments of alternatives based on criteria for the 1^{st} segment of layers at the 1^{st} iteration are given in Table 3. As can be seen, each layer-specific experts evaluate the alternatives of each layer according to the criteria of each layer using a pairwise comparison method. Thus, all the components of the system can be completely independent and unique. New alternatives may emerge according to developing and changing conditions, and some criteria may lose their importance and reason for existence. In accordance with real-life examples, the number of experts, criteria or alternative numbers in layers can be as many as desired. For example, at t = 4, the number of alternatives in segment 3 can be 5, while at t = 2, 3, and at t = 0, 3. This flexibility of the model applies to all other layer segments in the network.

Similar data collection processes are run for each node at each layer. Firstly criteria are evaluated and then alternative weights for each criterion are obtained. Consistency of each expert's decision matrices for criteria and alternatives is calculated. Individual and aggregated consistency values of expert judgment matrices are given in Tables 4 and 5. In Table 2, at the 1^{st} segment of the Layer 1, three criteria (C_{1111}, C_{1112} and C_{1113}) are evaluated by four experts. As it is seen at Table 3, there are four alternatives, and at the 1^{st} segment of the Layer 1, number of experts involving the evaluation of alternatives based on C_{1111}, C_{1112} and C_{1113} are 3, 4 and 3, respectively. Consistency values are not expected to be greater than 0.37 according to [102]. If the consistency value is greater than 0.37, the experts are asked to review their decisions again.

Weights of alternatives at each node are provided in Table 6. Since Layer 1 and Layer 2 are the cost (negative) layer, Layer 3 is the benefit (positive) layer and inverse of Layer 3 is taken, normalized and the calculations are designed accordingly. Finding the minimum of the final assessment, which is the average of these three layers, will give the correct result. As it is seen on Table 6, node 5 at Layer 1 has 4 alternatives (Figure 4) and other layers have five alternatives.

Based on the weights given in Table 6, Dijkstra algorithm is implemented to find the optimal paths (optimal estimation process) for Layers 1, 2 and 3 (minimum cost, minimum risk and maximum performance).

The optimal path for the Layer 1 is found as n_1,n_5,n_9,n_{13} and n_{14}. The optimal path for the Layer 2 is found as n_1,n_2,n_9,n_{13} and n_{14}. The optimal path for the Layer 3 is found as n_1,n_5,n_7,n_{10} and n_{14}.

The optimal path for the global solution (Final Assessment) for the first iteration is found as n_1,n_3,n_8,n_{13} and n_{14}.

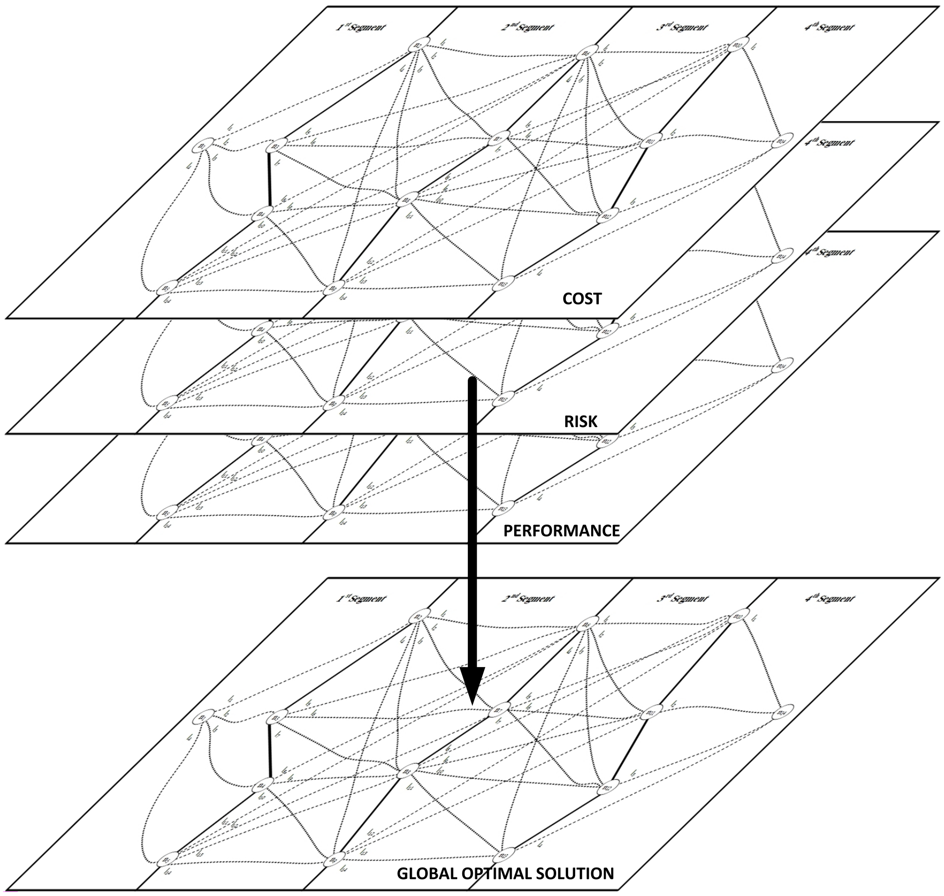

FIGURE 3. The layers.

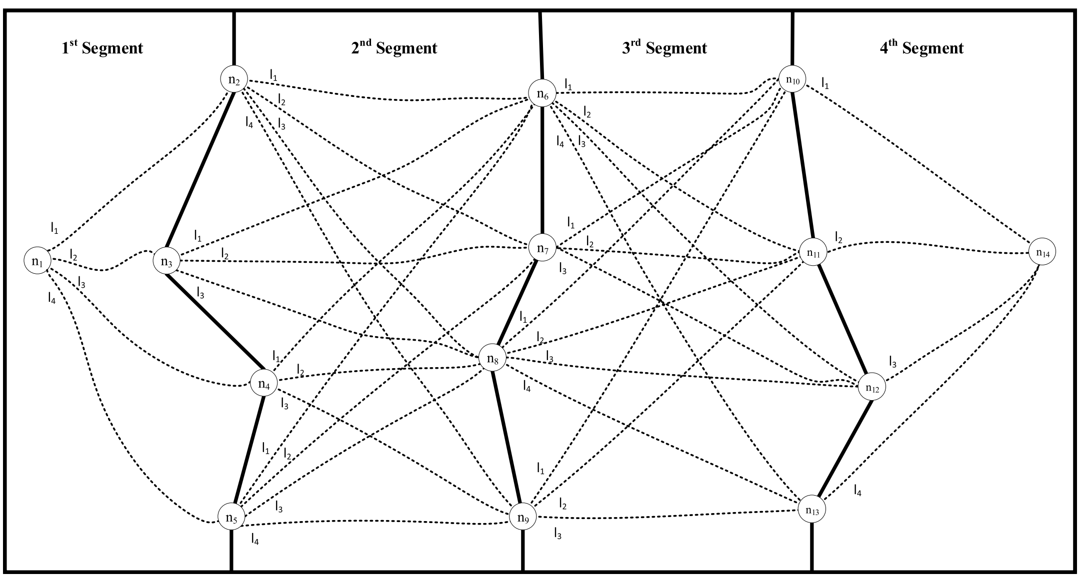

FIGURE 4. The initial region of the Layer 1 with four segments.

We can easily observe the difference when compared to the linear shortest path given at the final assessment (n_1,n_2,n_7,n_{10},n_{14}). This model has the flexibility of choosing the alternatives. The selected route does not necessarily have the highest priority. It is up to the user to decide which path to choose after all considerations. This path can

TABLE 3. Pairwise comparison of alternatives based on criteria for the 1^{st} segment of layers at the 1^{st} iteration.

	C_{1111}						C_{1112}						C_{1113}					
	l_1	l_1	l_1	l_2	l_2	l_3	l_1	l_1	l_1	l_2	l_2	l_3	l_1	l_1	l_1	l_2	l_2	l_3
	l_2	l_3	l_4	l_3	l_4	l_4	l_2	l_3	l_4	l_3	l_4	l_4	l_2	l_3	l_4	l_3	l_4	l_4
E_{1111}	vh	vh	h	e	l	m	vh	vh	vh	e	e	e	m	m	1/l	e	e	e
E_{1112}	h	h	h	e	l	e	h	h	vh	e	e	m	1/vh	1/vh	1/vl	e	l	l
E_{1113}	vh	vh	h	e	e	e	h	h	h	e	e	l	1/vl	1/vh	e	e	l	l
E_{1114}							m	m	m	e	1/l	e						

	C_{1211}						C_{1212}						C_{1213}						C_{1214}					
	l_1	l_1	l_1	l_2	l_2	l_3	l_1	l_1	l_1	l_2	l_2	l_3	l_1	l_1	l_1	l_2	l_2	l_3	l_1	l_1	l_1	l_2	l_2	l_3
	l_2	l_3	l_4	l_3	l_4	l_4	l_2	l_3	l_4	l_3	l_4	l_4	l_2	l_3	l_4	l_3	l_4	l_4	l_2	l_3	l_4	l_3	l_4	l_4
E_{1211}	1/l	1/l	1/l	1/l	1/vl	1/vl	e	1/vl	1/vl	l	l	e	l	1/l	m	l	1/vl	m	l	e	e	l	e	l
E_{1212}	l	1/l	1/vl	l	1/vl	1/vl	l	1/l	1/vl	1/vl	1/vl	1/vl	1/h	1/h	1/h	e	e	e	1/l	1/l	1/l	e	e	e
E_{1213}	l	1/l	m	l	1/vl	1/vl	l	e	l	m	h	l	1/l	1/l	1/l	e	e	e	1/l	1/l	1/l	e	e	e
E_{1214}							1/l	1/l	1/l	e	1/l	1/l												

	C_{1311}						C_{1312}						C_{1313}					
	l_1	l_1	l_1	l_2	l_2	l_3	l_1	l_1	l_1	l_2	l_2	l_3	l_1	l_1	l_1	l_2	l_2	l_3
	l_2	l_3	l_4	l_3	l_4	l_4	l_2	l_3	l_4	l_3	l_4	l_4	l_2	l_3	l_4	l_3	l_4	l_4
E_{1311}	1/l	1/l	1/l	1/l	1/l	1/l	e	1/l	1/l	l	l	e	l	1/l	m	e	e	e
E_{1312}	l	1/l	1/l	l	1/l	1/l	l	1/l	1/l	1/l	1/l	1/l	1/h	1/h	1/h	e	e	e
E_{1313}	l	1/l	m	l	1/l	1/l	l	e	l	m	h	l	1/l	1/l	1/l	e	e	e
E_{1314}							1/l	1/l	1/l	e	1/l	1/l						

TABLE 4. Individual consistency values of expert judgment matrices at each layers.

Layer 1						Layer 2						Layer 3					
		E_1	E_2	E_3	E_4			E_1	E_2	E_3	E_4			E_1	E_2	E_3	E_4
S_1	Criteria	0.221	0.213	0.019	0.000	S_1	Criteria	0.026	0.008	0.066	0.004	S_1	Criteria	0.035	0.120	0.023	0.017
	C_{1111}	0.082	0.039	0.001			C_{1211}	0.029	0.183	0.266			C_{1311}	0.044	0.190	0.317	
n_1	C_{1112}	0.000	0.074	0.039	0.017	n_1	C_{1212}	0.064	0.071	0.190	0.029	n_1	C_{1312}	0.110	0.068	0.190	0.029
	C_{1113}	0.166	0.026	0.085			C_{1213}	0.290	0.000	0.006			C_{1313}	0.140	0.000	0.006	

TABLE 5. Aggregated consistency values of expert judgment matrices at the 1^{st} layer.

	Layer 1					Layer 2					Layer 3				
	Criteria	C_1	C_2	C_3	C_4	Criteria	C_1	C_2	C_3	C_4	Criteria	C_1	C_2	C_3	C_4
n_1	0.000	0.001	0.000	0.010		0.002	0.017	0.021	0.000	0.006	0.015	0.032	0.024	0.000	

TABLE 6. Weights of each alternative after the 1^{st} iteration.

	Layer 1					Layer 2					Layer 3					Final Assessment				
	l_1	l_2	l_3	l_4	l_5	l_1	l_2	l_3	l_4	l_5	l_1	l_2	l_3	l_4	l_5	l_1	l_2	l_3	l_4	l_5
n_1	0.500	0.204	0.252	0.044		0.123	0.283	0.298	0.296		0.464	0.198	0.177	0.160		0.362	0.228	0.242	0.167	
n_2	0.087	0.288	0.406	0.219		0.383	0.360	0.231	0.026		0.136	0.202	0.136	0.525		0.202	0.284	0.258	0.257	
n_3	0.595	0.285	0.120			0.605	0.289	0.106			0.098	0.552	0.350			0.433	0.375	0.192		
n_4	0.552	0.364	0.083			0.452	0.433	0.115			0.232	0.208	0.560			0.412	0.335	0.253		
n_5	0.427	0.328	0.229	0.016	0.000	0.269	0.142	0.436	0.074	0.079	0.026	0.031	0.163	0.174	0.608	0.241	0.167	0.276	0.088	0.229
n_6	0.437	0.232	0.175	0.155		0.403	0.250	0.187	0.159		0.161	0.200	0.319	0.319		0.334	0.228	0.227	0.211	
n_7	0.657	0.227	0.116			0.579	0.246	0.175			0.123	0.877	0.000			0.453	0.450	0.097		
n_8	0.438	0.325	0.209	0.028		0.410	0.269	0.232	0.089		0.114	0.182	0.252	0.451		0.321	0.259	0.231	0.189	
n_9	0.832	0.168	0.000			0.496	0.310	0.195			0.178	0.260	0.562			0.502	0.246	0.252		
n_{14}	0.290	0.183	0.260	0.268		0.328	0.225	0.251	0.197		0.135	0.228	0.637	0.000		0.251	0.212	0.382	0.155	

change according to the conditions and circumstances of that moment.

Then the experts have decided to use l_1 to move forward. The graph became as shown in Figure 5.

Similar steps are conducted for the input data regarding to criteria and alternatives based on each criterion for 2^{nd}, 3^{rd} and 4^{th} segments at the 1^{st} iteration. It should be considered that this is a time dependent process. Therefore, during the first segment, the conditions at other segments might change. For example, new criteria or alternatives might come into account. The values that the experts express in the first iteration might change in the second iteration.

B. SECOND ITERATION

When the moving agent arrives to the second segment, this environment evokes a whole new situation. Data collection for this new situation is conducted again as done at the first iteration. As it is mentioned experts have evaluated all segments in the first iteration. In the second iteration, they have the chance to evaluate their previous judgments about the segments related to second iteration. Moreover, experts have the chance to consider the findings, optimal result along with expert evaluations and final assessment of the first iteration. For example, experts revise their assessment of 2^{nd}, 3^{rd} and 4^{th} segments conducted at the first iteration with the help of

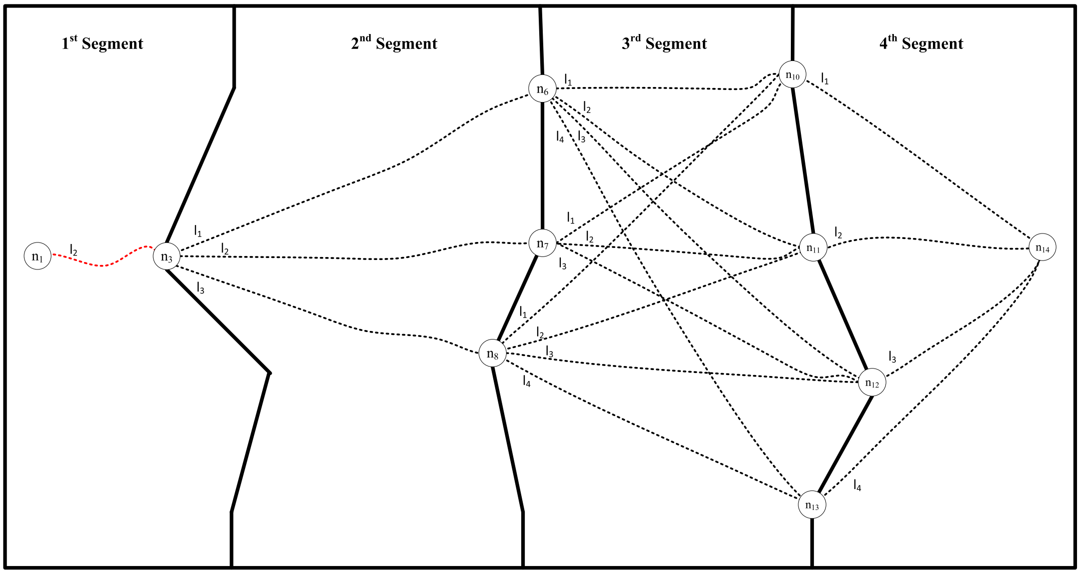

FIGURE 5. The position after first iteration.

TABLE 7. Weights of each alternative after second iteration.

	Layer 1				Layer 2				Layer 3				Final Assessment			
	l_1	l_2	l_3	l_4	l_1	l_2	l_3	l_4	l_1	l_2	l_3	l_4	l_1	l_2	l_3	l_4
n_2	0.228	0.348	0.423		0.691	0.276	0.033		0.141	0.181	0.678		0.354	0.269	0.378	
n_5	0.213	0.210	0.237	0.339	0.429	0.242	0.174	0.154	0.122	0.229	0.304	0.345	0.255	0.227	0.238	0.280
n_6	0.255	0.253	0.492		0.579	0.234	0.187		0.105	0.304	0.592		0.313	0.263	0.424	
n_7	0.308	0.240	0.261	0.191	0.362	0.428	0.168	0.042	0.034	0.038	0.053	0.875	0.235	0.235	0.161	0.369
n_{14}	0.290	0.183	0.260	0.268	0.299	0.278	0.271	0.153	0.209	0.332	0.233	0.226	0.266	0.264	0.255	0.216

more up-to-date data in the second iteration. It is ensured that all individual and aggregated matrices are consistent. The weights of the alternatives for the second iteration is found as given in Table 7.

After implementing the Dijkstra algorithm (optimal estimation process), the optimal path for the Layer 1 is found as n_3,n_6,n_{11} and n_{14}. The optimal path for the Layer 2 is found as n_3,n_8,n_{13} and n_{14}. The optimal path for the Layer 3 is found as n_3,n_6,n_{10} and n_{14}. The optimal path for the global solution (Final Assessment) for the second iteration is found as n_3,n_8,n_{12} and n_{14}. This means that the previous optimal estimation is now updated from n_1,n_3,n_8,n_{13},n_{14} to n_3,n_8,n_{12},n_{14}.

The path found after second iteration is given in Figure 6.

C. THIRD ITERATION

In the third iteration, data are collected for the segments in the remaining region, taking into account the changing conditions and elapsed time. Consistency values for judgment matrices are calculated. Once the criteria and alternatives have been weighed, the new path is determined (Table 8).

After the optimal estimation process, the optimal path for the Layer 1 is found as n_8,n_{10} and n_{14}. The optimal path for the Layer 2 is found as n_8,n_{13} and n_{14}. The optimal path for the Layer 3 is found as n_8,n_{10} and n_{14}.

The optimal path for the global solution (Final Assessment) for the third iteration is found as n_8,n_{13} and n_{14} (Figure 7).

The Figure 7 shows the final best optimal solution. The proposed model has the flexibility of choosing the alternatives. The selected route does not necessarily have the highest priority. It is up to the user (moderator) to decide which path to choose. This path can change according to the conditions and circumstances of that moment, and might require a subjective decision.

IV. DISCUSSIONS

A maritime supply chain can be defined as systems in which ships and ports are involved in the process of moving a cargo from one point to another. The purpose of the maritime supply systems is to ensure that the overall system is successful, outputs are greater than inputs, and the system gains. The design of a supply chain where all parties are satisfied can be considered as successful.

The supply chain can succeed as a result of managing several systems together. These include management issues of fleet, technology, time, strategy, risk, resilience, personnel, transportation, technology, information management, internal and external factors, market recognition, customer recognition, economic, financial management, chance factors.

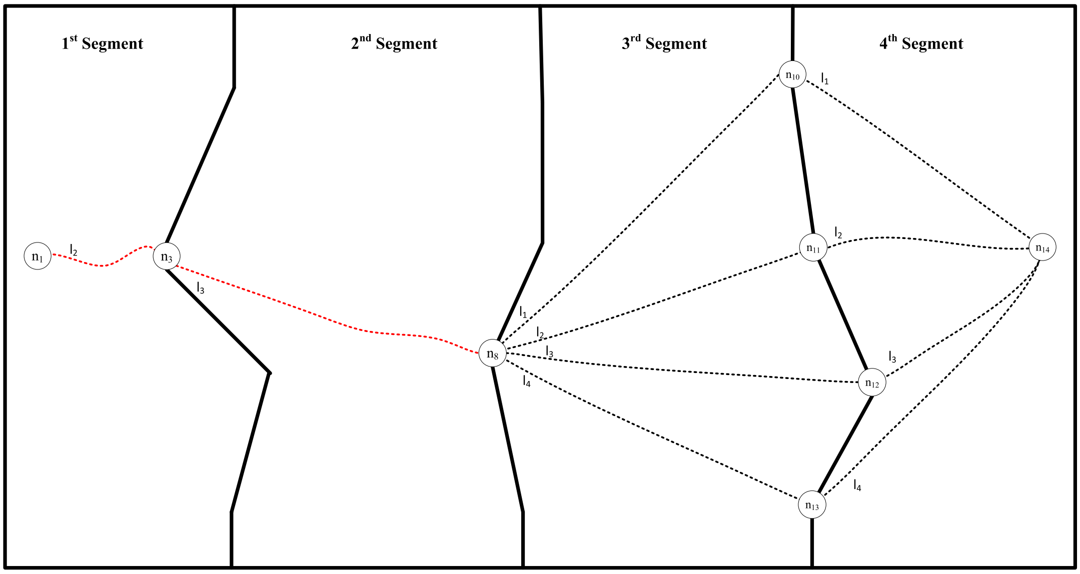

FIGURE 6. The position after second iteration.

TABLE 8. Weights of each alternative after third iteration.

	Layer 1				Layer 2				Layer 3				Final Assessment			
	l_1	l_2	l_3	l_4	l_1	l_2	l_3	l_4	l_1	l_2	l_3	l_4	l_1	l_2	l_3	l_4
n_8	0.324	0.245	0.249	0.182	0.434	0.238	0.212	0.116	0.038	0.131	0.831	0.000	0.265	0.205	0.431	0.099
n_{14}	0.105	0.259	0.294	0.343	0.263	0.254	0.246	0.236	0.128	0.211	0.328	0.333	0.165	0.241	0.289	0.304

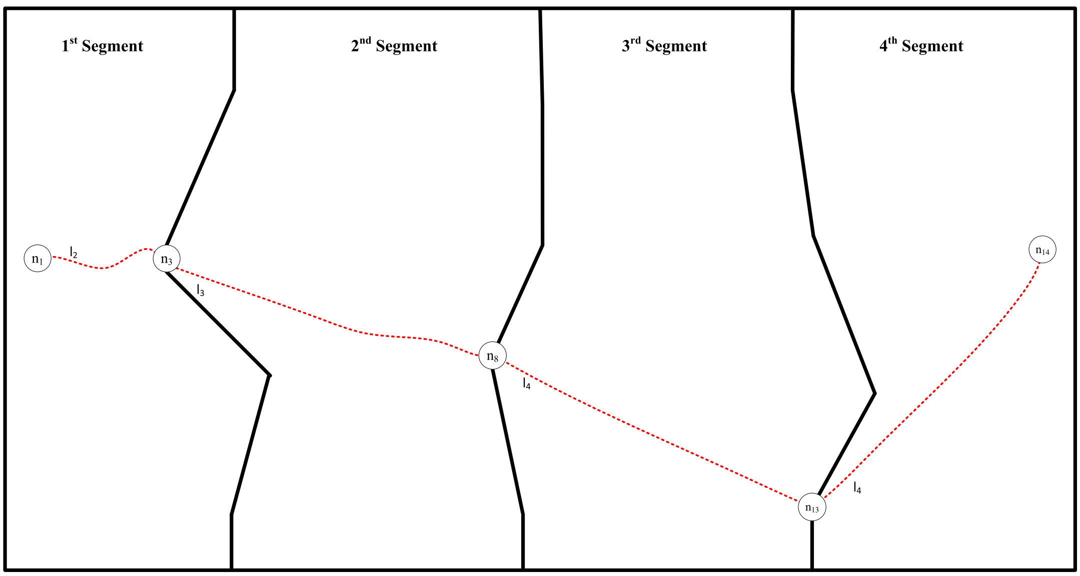

FIGURE 7. The position after third iteration.

In order to include all these factors into the maritime supply chain problem, it is mandatory to propose an appropriate and a comprehensive algorithm. Fleet (or asset) management in the supply chain, age, capacity, capabilities, agility of the fleet are the main structure of maritime supply chain. A fleet is the most essential part and the most important agents of a supply chain. For example, whether a ship has a crane is related to asset management where it is of importance for optimizing the supply chain network.

Fleet management is associated with technology management. The high-tech fleet is more likely to achieve faster and more reliable results. Human factor is important in maritime sector, but since the highest cost items also constitute personnel costs, personnel management, technology management of autonomous ships are given great importance and value. Not only the ships but also the container stacking areas in the ports, all the elements of the global supply chain supporting the maritime supply chain are aiming to become completely independent of human beings in terms of technology. Although the transition process contains many problems and risks, more optimal and high output results can be achieved when fully unmanned ships are reached. In supply chains it is significant to achieve optimal results that the fleet consists of similar quality ships, which means there are no differences in quality, capacity and capability between the ships.

Time management should be done well in terms of customer satisfaction and the circulation of the economy. Efficient time management reduces costs because the ship has continuous cost and expense structure. Time optimization is associated with technology optimization and technology management. Each activity in the supply chain has been defined for a period of time, and the efficient use of that period is important in terms of achieving the objectives.

Strategy management is the most vital activity in the supply chains. Appropriate strategies, system design and activities at the appropriate time are the most promising factors of success. Use of system components and elements in that manner, right action, correct deployment of the fleet, minimum error, stability and trust, confidence in strategy, focus, robustness, acumen, persistence, a good competitive environment strengthen the supply chain, and make it dynamic, agile and sustainable.

Recognizing competitors, determining the way companies behave according to competitors contribute to supply chain. In addition, as the prices decrease in the competitive environment, customer satisfaction increases, and new routes emerge in the competitive environment. The rate of globalization increases, time management becomes more efficient and diversity increases. Although the prices fall, it is aimed to increase the gain from demand. Thus, the total profit margin turns visible.

Financial management is influenced by many factors. Some of them are world economy, global markets, exchange rates, raw material circulation, commodity directly related to production, quantity of raw material in circulation, etc. Financial management affects the supply chain in every sense, such as technology, personnel and time management. As profitability increases, the number of fleets, total tonnage, capacity and supply amount increases. The number of ship demolition increases, ship construction sector slows down.

Risk management in the supply chain includes certain activities or concessions given in a certain period of time in order to increase profit margin or the profit of system under favorable competition conditions or downward trends. This may include increasing or decreasing the number of fleets, as well as reducing the total tonnage, increasing ship capacities, making concessions from certain loads, changing routes, adding new rights and new strategy management. The risk is not directly demanded. However, the global economic crisis emerges with the imposition of taxes, exchange rates, some natural disasters, warfare and similar resilience conditions and time. Risk is expressed as the result of the occurrence of an event multiplied by the likelihood of the occurrence of the event.

The results of this study show that making improvements by updating the estimations in a supply chain network by separating them into layers or segments yields more reliable results than the initial optimization. All possible situations and conditions of a supply chain have been considered and adapted to the system with the proposed model.

One of the disadvantages of the model is that huge amount of data is handled for the several repeating iterations, and the process is time consuming. In the future, additional algorithms can be embedded to the algorithm to work faster and process big data. Different algorithms and priorities for decision making process and optimal estimation can be used to compare the results.

V. CONCLUSION

Supply chains have a dynamic structure like a living organism. Therefore, it may be subject to a change or disruption at any time. Supply chain operations consist of many different layers and many segments. In order to achieve a goal in the supply chain network, there may be multiple decision-makers, multiple criteria and many alternatives for each layer and each segment. Many qualitative and quantitative inputs are involved in decision-making processes as an inevitable requirement. In this study, a transportation problem on a maritime supply chain network consisting of three layers and four segments is optimized with the proposed model. The number of experts varies according to the situation and their fuzzy expressions form inputs. Consistency of both individual and aggregate matrices in each segment is computed. Thus, more reliable and realistic results are obtained.

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