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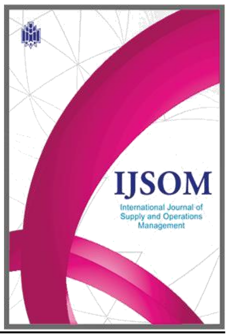


A Review Study: A Conceptual Model of the Maritime Inventory-Routing Problem

Ali Nazemi [a], Sanaz Sheikhtajian [a,*] and Majid Feshari [a]

[a] *Faculty of Economics, Kharazmi University, Tehran, Iran*

Abstract

The main aim of this paper is to present a conceptual structure for the Maritime Inventory-Routing Problem. We have looked at the matter from the supply chain angel and summed up the key comprising elements and major hypotheses in the framework of a conceptual model. We have reviewed the related literature in detail in a classified manner, separated various issues, and eventually in accordance with the identified gaps, presented the grounds for the development of the model in the same particular framework. What we deal with in this article is in fact the zero level of the Maritime Inventory-Routing Problem while for focusing on higher levels it is possible to consider greater details by providing arithmetic models on more comprehensive navigation of naval goods in a more compact and sold manner. According to this review, most researches are deterministic at the tactical level, on the basis of discreet time and in the arc-flow framework, generally solved by exact or heuristic methods.

Keywords: Maritime inventory-rutting Problem; Conceptual model; Supply chain.

1. Introduction

Close relations between the transportation and inventory management field have led many researchers to do solid studies on both topics simultaneously in the framework of Inventory Routing Problem (IPR). The issues include solidification and harmonizing (integration and coordination) between the inventory management and vehicle routing, a major part of which is composed of the Vendor Managed Inventory (VMI) (Agra, et al 2013b).

Among the studies in this field we can refer to articles by Hoff Et al (2010), Coelho Et al (2014) and SteadieSeifi Et al (2014), in which the authors tried to survey the issue of inventory routing from the general and public points of the view. They also evaluated the entire related studies in a comprehensive classification.

Among the various models of transportation, the maritime transportation plays a high profile role in commercial transactions since based on a report in 2012 (UNCTAD, 2012), some 80 percent of the world trade in the year 2011 was done by the shipping industry; this proves the significance of this field of transportation. Parallel with the expansion of inventory routing in this sector, the discussions on maritime inventory routing problem (MIRP) were pursued. Studies by Christensen, Fagorholt Et al (2004, 2013), and Papageorgio et al. (2014c) have comprehensively summed up the procedure of past and contemporary related studies.

The studies in this field can be classified around various axes, the first of which is the time horizon that includes the strategic, tactical, and operational levels; a major part of the studies is conducted in the tactical level, as is shown in Figure 1.

Corresponding author email address: sheikhtajian@yahoo.com

- The strategic level studies are concerned with long-term decision-makings in the infrastructure field
- The tactical model mainly focuses on taking optimum advantage of the existing infrastructures through choosing services, allocating capacities to orders, planning for trips and voyages and proper timing of them.
- The operational level, side by side with the objectives set in the tactical field, is after surveying the issues in the framework of the actual conditions and examining issues such as dynamic and contingency programming. This is a very complicated field and it is in need of precise algorithms with high calculation speeds.

Figure 1. Levels of Programming in a Chronological Order (Sang and Ferman, 2013)

Keeping in mind the importance of the discussions on maritime routing and their strategic value, in this paper we have a different look at other studies in order to deduct a conceptual model for the maritime inventory routing problem. Although many studies have been conducted on the MIRP, a significant gap is observable and the necessity of constructing a conceptual model encouraged us to propose a model in the present paper. The primary goal is to present, define and structure the MIRP. By accomplishing this goal, two main contributions are made. First, the topic is reviewed and based on the review a conceptual model is proposed, and second, based on the framework main directions for future research are discussed to pave the way for it. To do so, we have taken account of an initial framework based on the supply chain in the field of maritime transportation and have developed the framework and presented it as a proper conceptual model in accordance with the structure of model-making in the articles (inclusive of initial hypotheses, variables, parameters, etc.) as well as the prevailing approaches to problem resolving.

The remainder of this paper is organized as follows: In section two the maritime inventory routing problem is presented in its general form; in section three the conceptual model for the questions is elaborated based on the framework of the maritime supply chain; in section four the aftermath of achieving the objective and the ways for solving the problem are dealt with, and in section five the grounds for the development of the model are described based on the conducted studies and the proposals made by the authors of this article. Finally, section six includes a summary of the discussions and the conclusion.

2. Maritime Inventory routing problem

Maritime inventory routing problem serves the purpose of simultaneously solving both issues of inventory management and routing problem in the maritime transportation sector. The positions of both issues in the maritime supply chain is depicted in Figure 2.

Figure. 2. Supply chain in the offshore (naval) sector

In various studies, there are different ranges of issues with the maritime inventory routing problem; in some cases, the whole chain from supply (provision) to consumption has been taken into consideration and in other studies, the focus has merely been on the transportation and inventory management. Going on with the issue, brief descriptions of the fields are presented as follows in order to get familiar with the generalities of the issue:

- <u>Supply (provision):</u> In the production sector, the manufacturer produces the goods based on a specific rate (fixed / variable rate). It must be noted that a relatively wide range of productions have been taken into consideration here in the field including ammonia, cement, oil and petroleum extracts, and petrochemical products. The products are temporarily stored and then loaded in somewhere close to the port terminal by special ships or tankers.
- <u>Storage and loading:</u> The manufactured products here are stockpiled in due places and will be stored based on some policies for goods control and storage limitations. A shipping transportation fleet is employed in order to send off goods from the points of production to various destinations. The said ships are also being loaded according to the limitations of their entry into any ports.

- Maritime Transportation: The ships head off to the destination ports after being loaded. The main aim here is to define the route and departure time for the ships. The fleet of ships could have been in the possession of the manufacturers or been chartered according to the manufacturer's policies.
- Maintenance and repairs: The ships are subject to a maintenance program in specific time intervals which is the basis for spewing them out of the list of available ships.
- Unloading (discharging) and storage: Ships enter the discharging ports based on the limitations and restrictions on accepting a specific ship type as well as their admission and discharging time. The products are being stored in the port before being consumed.
- Consumption: Consumers receive the products through two ways of long-term contracts or spot which have been modeled with different assumptions to deal with different issues.

The main objective of the problem here is to determine the policies for routing and inventory management along with the optimization of the manufacture's objective function which has already been defined in a way that it could maximize the profits or minimize the costs.

The policies will be finally implemented in different ways based on the related existing general restrictions in the field of transportation including restrictions on the capacities of the goods and fulfilling the contractual obligations of the optimization model. Pursuing solutions for this question, we have then gone over the main points of the studies in the field and deducted the conceptual model accordingly.

3. A review of the literature for developing a conceptual framework

To build a conceptual framework we use Meredith (1993)'s philosophical conceptualization approach, which is based on reading the papers over and over again (Seuring and Muller, 2008). We start with reviewing the conducted studies and using the maritime supply chain as a basis to categorize them. Table 1 gives a holistic view of the reviewed studies. From supply to consumption we summarize and highlight the main characteristics of each paper with regard to 3 main categories including (1) structure of modelling, (2) variables and parameters, and (3) uncertainties in each segment. Then, referring to each study's number (in Table 1) we classify the studies in a figure.

The second step towards conceptualization is to propose a model and framework. As mentioned before, the building blocks of the proposed MIRP conceptual model is the maritime supply chain (Fig. 2). The origin and validation source of this model is Papageorgio et al (2014c)'s paper in which the researchers categorized the MIRP studies in a systematic approach and developed a MIRP library.

3.1. Supply

3.1.1. Structure of Model Making

Model-making in the supply section, considering the types of products and the expanse of the question, involves production, extraction, and provision. Accordingly, we can put forward the model-making in three fields of product types, diversity of products[1], and production rate:

- Product Type: Because of the dominance of marine transportation, the strategic and important products which are carried by ships are naturally the focus of attention of the researchers in the field. Among them we can refer to the liquidated natural gas (LNG), crude oil, cement, liquid products, ammoniac, etc. Some articles have already resolved the problem in its general form, regardless of any certain type of product.
- Number of the Products: One of the characteristics of model-making is concentration on whether a single product or a combination of products are in question. Most of the research focuses on single-product consignments.
- Production Rate: The production rate is considered as an exogenous variable in most studies, but in articles in which the approach is based on a combination of discussions on production planning, routing and inventory management the production rate is regarded as a self-generating or endogenous variable in the model-making process. (Persson et al, 2005, Gronhaug et al, 2010) Those studies in which the production rate is considered as an input parameter in the question can be classified into two separate groups.
- Some researchers assumed a fixed rate of production while some others assumed variable production rates in accordance with the timespan or the production port.

[1] By diversity of products we mean whether there is a single product or multiple types.

Meanwhile, in some studies the researchers paid more attention to those factors leading to changes in the production rate and applied model-making prediction methods. As the classification of the articles is shown in the following chart based on the above-mentioned method, obviously using the production rate as a fixed and externally-generating (exogenous) parameter can be referred to as a serious restriction on model-making.
Since the production rate influences the general structure of the question - supposing that it is fixed - the validity and the generalizing capacity of the results are also affected.
A specific approach in this field is to use the stable methods for model-making in order to add to the credibility of the results.
Although merging the production planning issue with the routing and inventory management makes the question more complicated, it leads to its greater flexibility as well.

The reason is that the producers can regulate their production rate based on their commitments in the contracts and their goods stored in the warehouses in a way to minimize their expenditures in various phases. Fig. 3 classifies researches in this area according to their assumptions about product number and production rate.

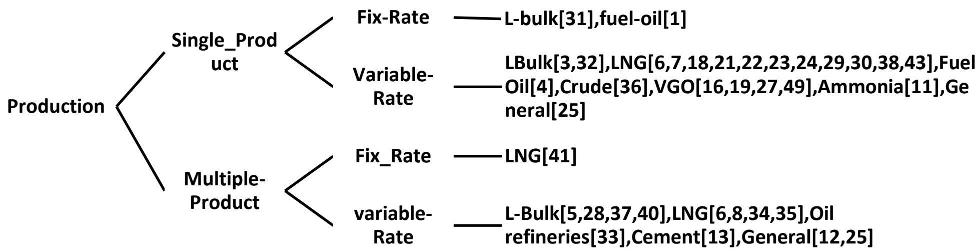


Figure 3. Distribution of the Researches in the Production Sector

3.1.2. Variables and Parameters

Variables and parameters in the production section are summarized in the following table. According to the researcher's viewpoint and objective, he or she can use all or some of the introduced variables and parameters in his or her model.

Table 2. Parameters and Variables of the Production Sector

Parameters	Variable
✓ Available Time for Production ✓ Specifications and Number of Production Terminals ✓ The Lost Production Expenditure ✓ Production Costs ✓ Production Rate*	✓ Production Rate

* The production rate, as mentioned before, is categorized as a parameter in some research works and as a variable in the problem-solving and model-making process in some other.

3.1.3. Uncertainty in the Production Sector

The most important parameter in the field under the influence of uncertainty is production rate, which is of course rarely dealt with in the related studies. Among those who have paid attention to this parameter are Halvorsen et al, 2013b) who have presented a discrete probability distribution for daily production rate as the percent of planned rates.

3.2. Storage and Loading

3.2.1. Structure of Model-Making

After the production or extraction of the product (in case the product is oil, gas, or their derivatives and the like), appropriate with the adopted storage policies and in accordance with the certain loading program the products are stored and forwarded to the planned destinations. Model-making in the field includes the control policies on inventory and stock type.

- <u>Lot-Sizing</u>: One strategy for responding to orders is summing them all up and responding to them altogether, which is done in various forms. In order to strengthen and improve formula-making for this purpose, in some studies about model-making the issue of defining the lot-size is considered. In this type of model-making it is proved that using the variables that show when the production and also the consumption occur leads to the strengthening and improvement of the models and formulations. (Hewitt et al, 2013)

Table 1. The MIRP studies in one view (Current studies' results)

No.	Author(s)	Product	*plan level			*Tim e		*Model		Method
			S	T	O	D	C	A	P	
1	Agra, et al, 2016	FUEL OIL		T		D	C	A		BC-local search heuristic
2	Agra, et al, 2013a	L-BULK		T		D		A		BC
3	Agra, et al, 2013b	FUEL OIL			O	D	C	A		BSSDP
4	Al-Khayyal and Hwang, 2007	LBULK		T			C	A		C-HEURISTIC
5	Al-Haidous, et al, 2016	LNG		T		D				ADP
6	Andersson, et al, 2015a	LNG		T					P	BC
7	Andersson, et al, 2015b	LNG		T		D			P	BC
8	Anderson, et al, 2010	LNG		T		D			P	MODEL ONLY
9	Arijit, et al. 2017			T		D		A		PSO-CP
10	Chengliang, et al. 2017			T				A		Heuristic method
11	Christiansen, 1999	AMMONIA		T			C	A	P	BPC
12	Christiansen and Fagerholt, 2009	GENERAL		T			C	A		construction-heuristic
13	Christiansen, et al, 2011	CEMENT		T						GENETIC
14	Drazen-Papvic, et al, 2011	GENERAL			O	D			P	HEURISTIC
15	Dung-Ying & Chang, 2018	GENERAL						A		Heuristic method
16	Engineer, et al, 2012	VGO		T		D			P	BPC
17	Ethan, et al. (2018)	liquid helium				D			p	Integer programming
18	Fodstad, et al, 2010	LNG		T		D				DEFALT SOLVER
19	Furman, et al, 2011	VGO		T		D		A		DEFALT SOLVER
20	Giami, et al, 2016	LNG			O	D		A	P	DEFALT SOLVER
21	Goel, et al, 2015	LNG	S			D		A		MIP BASED LS
22	Goel, et al, 2012	LNG		T		D		A		C&I- HEURISTIC
23	Gronhaug, et al, 2010	LNG		T		D			P	BPC
24	Halvorsen, et al, 2013	LNG		T		D		A		DECOMPOSITION
25	Hemmati, et al, 2016	GENERAL		T			C	A		HYBRID-HEURISTIC
26	Hemmati, et al, 2015	GENERAL		T			C	A		2 PHASE HEURISTIC
27	Hewitt, et al, 2013	VGO		T		D		A		BPGS
28	Li, et al, 2010	L-BULK			O		C	A		DEFALT SOLVER
29	Mutlu, et al, 2015	LNG		T		D			P	VRH_HEURISTIC
30	Nikhalat-Jahromi, et al, 2016	LNG			O		C		P	MILP
31	Papageorgio, et al, 2014a	L-BULK	S			D		A		APPROXIMATE
32	Papageorgio, et al, 2014b	L-BULK		T		D		A		BENDERS LIKE
33	Person and Gothe-Ludgren, 2005	Oil Refinery		T		D		A	P	CG-HEURISTIC
34	Rakke, et al, 2014	LNG		T		D		A		BPC
35	Rakke, et al, 2011	LNG		T		D			P	ROLLING HORIZEN
36	Rocha, et al, 2013	CRUDE		T		D		A		BB
37	Ronen, et al, 2002	L-BULK		T		D		A		GRASP
38	Shao, Furman, et al, 2015	LNG	S			D		A		LAGRANGIAN HEURISTIC
39	Shen, et al, 2011	CRUDE	S			D			P	GENETC
40	Siswanto, et al, 2011	L-BULK			O		C	A		CIH
41	Stalhane, et al, 2012	LNG		T		D			P	MILP BASED LS
42	Song and Furman, 2013	VGO		T		D		A		FIX-RELAX
43	Uggen, Fodstad , et al, 2011	LNG		T		D			P	FIX-RELAX
44	Yonneng , et al, 2015	GENERAL		T		D	C		P	MODEL ONLY

- Inventory Type: The stored products in the warehouses can be divided into two groups based on whether the products in question are deteriorated while they are in the storage or not. It is interesting to note that this issue is involved in the case of LNG product as some studies on this product defined the Boil-Off-Rate, which is considered both fixed and variable and is included in the model-making.

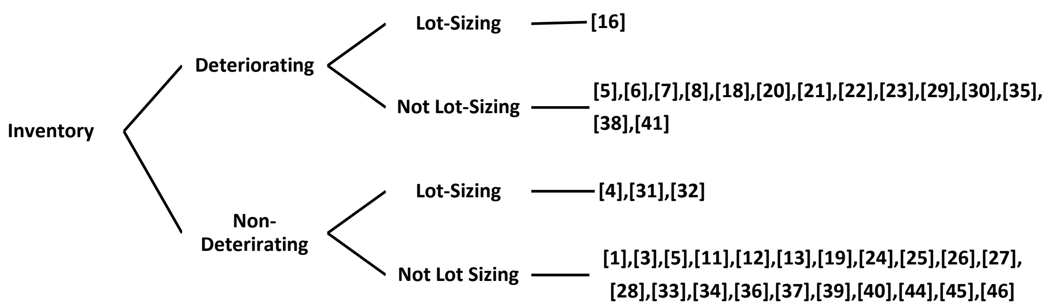


Figure 4. Distribution of the Researches in the Storage and Loading sector

3.2.2. Variables and Parameters

The variables and parameters of the storage and loading procedure are categorized in Table 2. Some of the factors are involved in the storing process and the others in the loading procedure.

3.2.3. Uncertainty Factor in Storage and Loading

One of the uncertain factors in the storage sector is the amount of goods in the case of deteriorating products. By deteriorating products, we mean goods like the LNG whose quantity is decreased over time due to various factors such as evaporation. Under such conditions the decreasing level of such products is an uncertain parameter, but it is generally given a fixed rate in model-making in order to simplify the calculations.

Among the other factors of uncertainty in the field of loading and ports which is mainly dealt with at the levels of tactical and operational studies is the ports' conditions and their availability, which are subject to change during protests, technical difficulties, etc.

Table 3. Parameters and Variables in the Storage and Loading Process

Parameters	Variables
✓ Inventory initial or final level ✓ Storage Capacity (Min & Max) ✓ Storage costs ✓ Stock out costs ✓ Value of Remaining products ✓ Specifications of ports (number of berths, entry limitations) ✓ Ports entry costs ✓ Loading cost ✓ Demurrage ✓ Waiting cost	✓ Replenishment level ✓ Safety stock level ✓ Spot cargo number

3.3. Transportations, Maintenance and Repairs

3.3.1. Structure of Model-Making

The most important part of the problem is related to the transportations field, thus compared with other fields, model-making in this field as well as in repairs and maintenance has more details including defining the type of shipping, fleet composition, the structure of transportation, and discussions on repairs and maintenance.

- <u>Type of Shipping</u>: There are three major types of operations for commercial ships: Liner, tramp, and industrial (Lawrence, 1972). In the first type, the ships initially move in a line in a fixed route based on a pre-defined program similar to the city bus fleets. In the second type, i.e. tramp, the ships are in pursuit of available goods for shipment, like moving taxies seeking passengers in their way, whose optimum objective is gaining maximum benefits at any given moment, keeping track of their initial positions, the place for unloading and the goods' conditions. In the third type, that is, the industrial operations, generally the owner of the operations is the owner of the carried goods and he or she is certainly interested in controlling the ships used in carrying his or her goods. The objective in this type is minimizing the expense. Among the clients of industrial shipment, we can refer to the vertically solid companies such as the oil and chemical product companies (Christensen et al, 2013). A major part of the studies in the field are a combination of the 2nd and 3rd types.

- Fleet Composition: Depending on whether the shipping fleet is homogenous or heterogeneous, this type of distinction is made. A heterogeneous fleet is one in which ships' specifications including their volumes, speeds, carrying costs, etc. differ while in a homogenous fleet all specifications of entire ships are exactly the same. A major part of the studies is done and designed on heterogeneous fleets.
- Transportation Structure: In accordance with the problem type in forwarding from one port of origin to one destination (1-1), or from one port of origin to a number of destinations (1-m), and eventually from various ports of origin to several destination ports (m-m), different types of model-makings can occur.
- Transportation Type: Two major types in the field are the successive and not-successive move. The successive move or split delivery in sea transportation means a ship being permitted to move from one port to several ports in a one-trip-program. The not-successive move or ship means ships are not allowed to request visiting numerous ports in one voyage before returning to their port of origin (Mutlu et al, 2015).
  One of the facts considered in many maritime routing problems is that split delivery is not

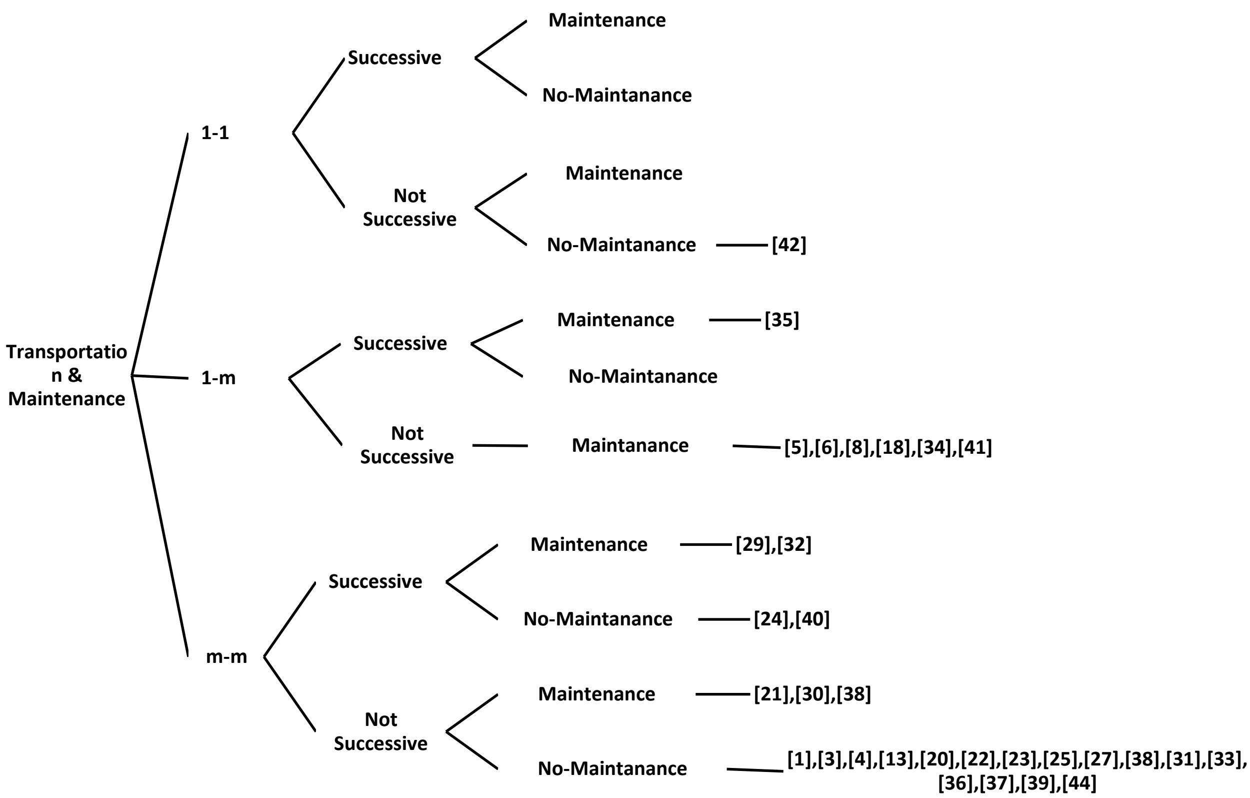


Figure 5. Researches' Transportations, Maintenance and Repairs section

3.3.2. Variables and Parameters

The variables and parameters related to ships' transportations, specifications of the fleets, and planning for maintenance and repairs are as follows:

Table 4. Parameters and Variables in Ships' Transportations

Parameters	Variables
✓ The number of ships classified according to ownership differences and types of contracts allocating them to this purpose ✓ Ships' specifications including capacities, speeds, and list of ports in which they can take side ✓ Available and unavailable ships (in accordance with being out of order, or under repairs and in maintenance procedure) ✓ Voyage costs and length of time	✓ Tracing the ships' navigation route (at what time, through which route and, towards which destination is each ship sailing?) ✓ Number of ships ✓ The status of ships, from availability point of the view ✓ The number of full,or empty storages and containers of each ship

3.3.3. Uncertainty in Transportation with Ships

The transportation sector, as the main ring in this chain, is affected by many uncertainty factors. One of the major uncertainty factors is weather conditions. This factor leads to changes in the voyage length as well as fuel consumption and is dealt with more than the other uncertainty factors in Cheng and Duran (2014), Shyshou et al, (2010), Halversen et al, (2014, 2015), and Agra et al, (2013c, 2015, and 2016). Another factor in the field is ship breakdowns. Although separate studies on this issue in maritime transport have been done, considering it in maritime inventory routing problems is not very common.

3.4. Unloading and Storage

3.4.1. Structure of Model-Making

In the unloading process, like the loading port, the main issue is the method for controlling the quantity of products and the related policies. Another issue is considering the buoy ports by the side of costal ports in some models.

- Storage in Unloading Ports: The inventory management in question is sometimes not merely restricted to the provision port as in some cases the inventory management is considered in both the provision and demand process and accordingly the studies are divided into two main groups.

  In one group the inventory management is considered in the demand side while in the other it is not.
- Port Type: In the real world, in addition to the coastal ports, there are the buoy ports where goods are unloaded before being delivered to the clients; the trip continues from there. Only in one article model-making based on such details was observed. (Fodstad et al, 2010).

  Distinctions between the articles based on the storage policies in destination ports are depicted in Fig. 6.

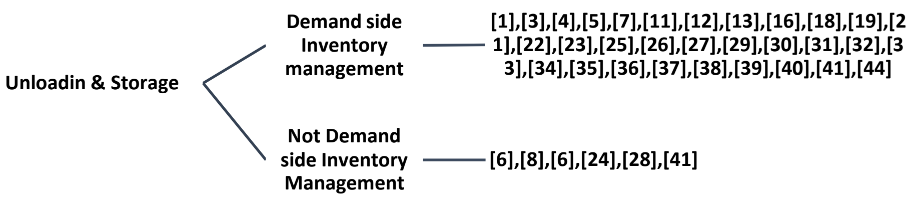


Figure 6. Distribution of the Researches in the Unloading and Storage Section

3.4.2. Variables and Parameters:

According to the specifications of the ports of loading and storage, the following factors are defined as bellow (Table 5).

Table 5. Parameters and Variables in Ports of the Loading and Storage Section

Parameters	Variables
✓ berths' specifications: Number of ports, capacities of each, loading restrictions ✓ Port visit charge ✓ Demurrage in port ✓ Storage capacity (minimum and maximum) ✓ Stock out cost ✓ Storage costs	✓ Unloading rate ✓ safety stock level ✓ stock out ✓ Unloading time

3.4.3. Uncertainty in the Ports of Loading and Storage

In addition to conditions such as protests and technical difficulties, which we referred to in ports of loading section (Agra et al, 2015), one of the uncertainty factors in the ports of unloading is due to not knowing exactly in which port goods are to be unloaded since only geographical specifications of the destination are defined. The manufacturer acts according to either his or her experience or the average of the existing ports in the region. The worst conditions are considered and various scenarios are surveyed in accordance with the time of voyage and other conditions and then the programming takes place.

Another difficulty in dealing with unloading ports is the holidays. Different methods can be applied to prevent the reaching of ships to ports on holidays, such as imposing penalties for doing so. (Christensen, Fagerholt et al, 2002)

3.5. Consumption

3.5.1. Structure of Model-Making

This part, which is the last ring in the chain of maritime supply chain, can be surveyed in three fields including consumption rates, types of contracts (long term or spot), and the ways for delivering products to markets and their distribution.

- Consumption Rare: Generally, the consumption rate is considered as the input to the problem. In problems in which uncertain rates are considered it is possible to use prediction methods to predict the consumption rate and insert it in the model. Of course, in studies in which the sphere of survey is the entire supply chain defining the consumption rate is considered as an indigenous variable. (Grunhag et al, 2010)
- Delivery Types: Depending on the responsibilities of sellers and buyers in the process of transferring products three common types can be surveyed:
    - FOB: the responsibility of transferring is up to the buyer as of the time of loading the goods onto the ship(s).
    - CIF: the responsibility of provision, paying the transferring expense and insurance of the goods is up to the seller.
    - DES: the responsibility of providing the ships and delivery are up to the seller and the ownership of the goods is transferred to the buyer as soon as they are unloaded and carried from the ship(s) to the buyer port. In these contracts the insurance costs are paid by the seller.

Among the studies done in this field only one article has focused on this issue. (Nikhalat et al, 2016)

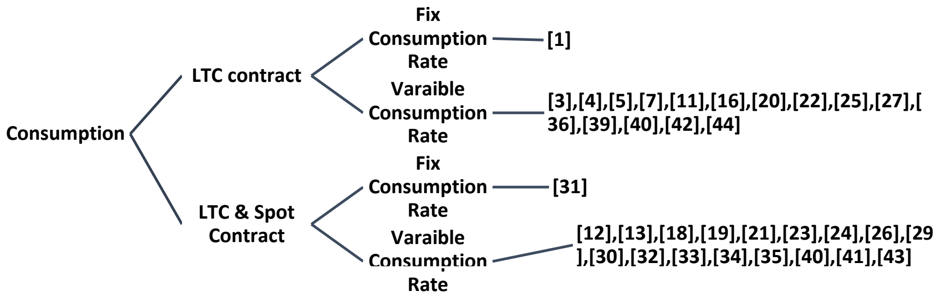


Figure 7. Distribution of the Researches in the Consumption Sector

3.5.2. Variables and Parameters

The variables and parameters related to the Consumption Section are as follows:

Table 6. Parameters and Variables in the Consumption Section

Parameters	Variables
✓ Contract penalty due to delays, early delivery, or failure to deliver the products in accordance with the contract (over/under) ✓ Spot sale costs ✓ Spot sale revenue (uncommitted, arbitrage, etc.)	✓ **Extent of violation of quantity of forwarded goods** ✓ **Total sales**

3.5.3. Uncertainty in Consumption

Price and level of demand are two variables and uncertain factors in the consumption section. Among the studies carried out in this field we can refer to those of Cheng and Duran (2004), Shyshou et al. (2010), and Alvarez et al. (2011).

3.6. The Conceptual Model for the maritime inventory routing problem

The main goal of this framework is to open possibilities of research rather than to categorize the related content of the existing literature. Considering this and following the aforementioned steps drawn from the literature review for conceptualization, we propose our model with the marine supply chain backbone. Based on the above review we identify 3 building blocks for the conceptual framework including modelling structure, variables plus parameters, and uncertainties. Then, integrating these with then marine supply chain we construct a conceptual framework (Fig. 8).

The model has two main sections. In the first section (the first column in each part) we define inputs and outputs of the model which are parameters and variables, respectively. The parameters are shown using straight lines and the variables are shown with stars and dotted lines.

The second part is inclusive of various conditions which can be considered in the model-making of MIRP. For instance, in the production sector it consists of 3 elements, namely product type, production rate, and product number. In the storage and loading section, the researcher should define the inventory type and inventory management strategies which are the same decision points in the unloading and storage segment.

The main part is transportation and maintenance, consisting of 5 elements as shipping type, fleet composition, transportation structure and type, as well as maintenance strategies; in the last ring which is consumption the modeler should decide about consumption rate, contract type, and delivery approaches.
Maritime transport is significantly affected by the uncertainty factors, but this has been ignored in most research works. In each group of the classified factors there can be uncertain factors included in the model, which are shown by triangles.

4. Objective functions and solving methods

4.1. Objective functions and constraints:

Supplier's utility can be either modelled as maximizing profit or minimizing cost. Surveying the studies in this field reveals that mainly the minimizing approach is applied in model-making, and in a limited number of cases using methods for maximizing profit, the model-making is pursued. (Gronhaug et al. 2010, Fodstad et al, 2010, Hewitt et al, 2013, and Anderson et al, 2015a).

The differences among the studies are either in the details of the expenses or revenue details in the models. Besides, the parameters related to each are presented separately in the conceptual model. The surveyed constraints in the studies are classified under five fields of constraints in production, storage and loading, transportations, repair and maintenance, unloading and storage, and finally in the field of consumption and contracts, most of which are presented in the framework of initial parameters in the model. The discrete time models present the planning horizon in a discrete manner and assume that the events (including loading/unloading, etc.) occur in certain points of time while the continuous models consider no restrictions on the occurrence of events. Of course, there are also some studies in which the discrete and continuous time horizons were applied in hybrid models (Agra, Chistiansen, et al. (2016), (2013), Yonneng, et al. (2015)). The arc-flow models include variables on decision making for the movement of the ships between the ports whereas the path-flow models pursue the sequence of the ships' frequenting to and from the ports. (Papageorgiou et al, 2014b) Although surveying the studies in the field indicates that the arc-flow models are more frequently used (Fig. 11), Gronhaug et al (2010) claimed that "the advantage of path-flow models are that indicate and nonlinear constraints and cost can easily be incorporated when generating the paths" (Papageorgiou et al, 2014). In two of those studies only the model for the problem is presented and there is no solution for it (Andersson et al, 2010, Yongheng et al, 2015), but in the other reviewed studies various types of methods are used for the maritime inventory routing problem.

The basis for classification has been gained from SteaddieSeifi et al. (2014)'s article. Accordingly, the methods applied for solving the problem are divided into exact, appreciative, heuristic, meta-heuristic, and hybrid-heuristic types; in the present paper another method which is commercial solvers is added to them. The articles whose models have used commercial solvers like the CPLEX, GAMZ, etc. are included in the classification. It is noteworthy that such methods for problem solving are appropriate for problems with smaller dimensions. Figure 8 shows the distribution method of articles from the viewpoint of the mathematical model-making and solving methods.

Another aspect of model-making is uncertainty modelling, which is investigated in the articles. As mentioned before, despite the significance of the uncertainty issue in the maritime inventory routing problem, the prevalent way for model-making in this issue is in definite and static models, and there are a limited number of studies which have discussed the uncertainty factor. In a general sum-up of the various methods used for handling uncertainty and reaching a robust model, we can refer to the following five groups. (Barnhart, C. & Laporte, G.2007).

- ✓ Simulation
- ✓ re-optimization of different scenarios or input parameters
- ✓ adding slack to the input parameters (e.g., service speed)
- ✓ deterministic models that incorporate penalties
- ✓ Stochastic optimization models

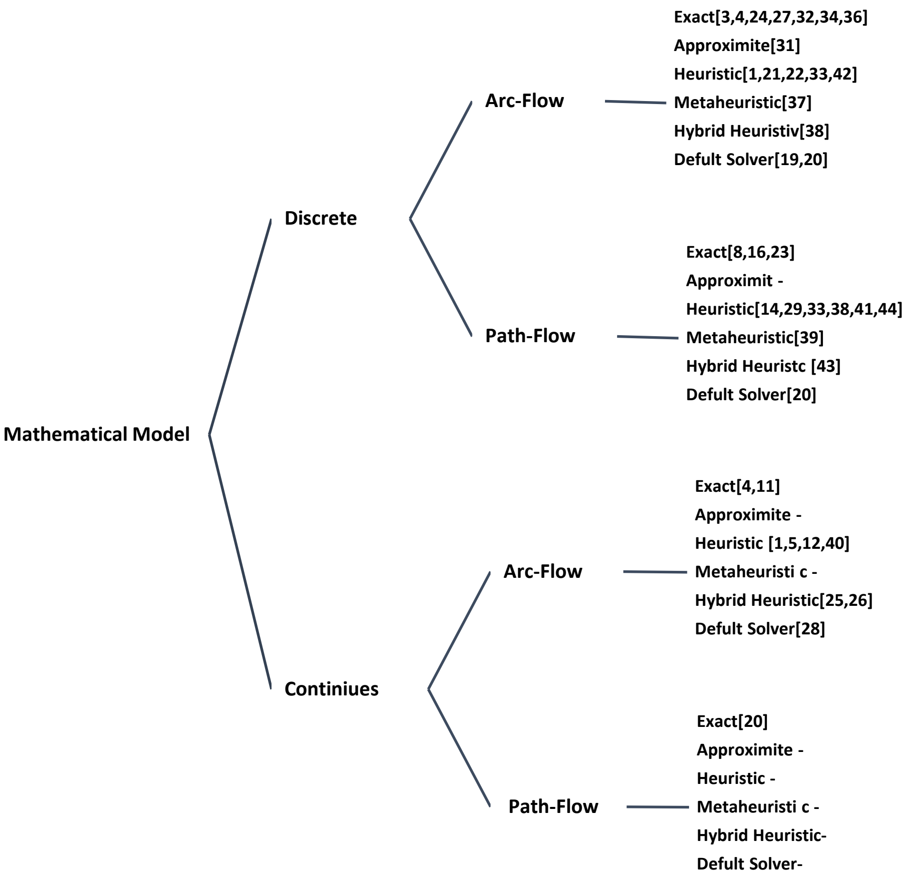


Figure 9. Distribution of the researches in the mathematical methods

5. Future Studies

A large number of studies have been done on the maritime inventory routing problem, but there are still lots of unpaved paths for further research.

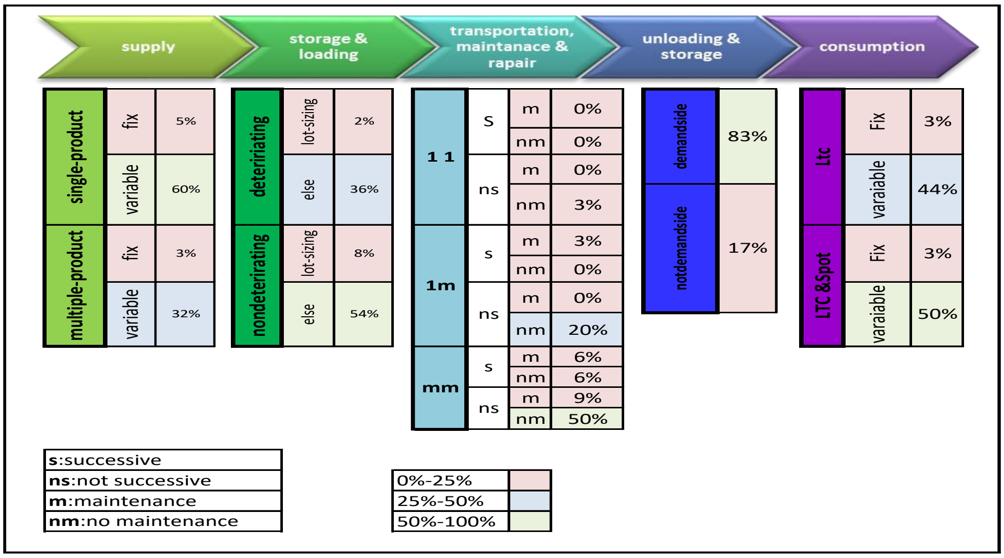


Figure 10. Distribution of the Studies on maritime inventory routing

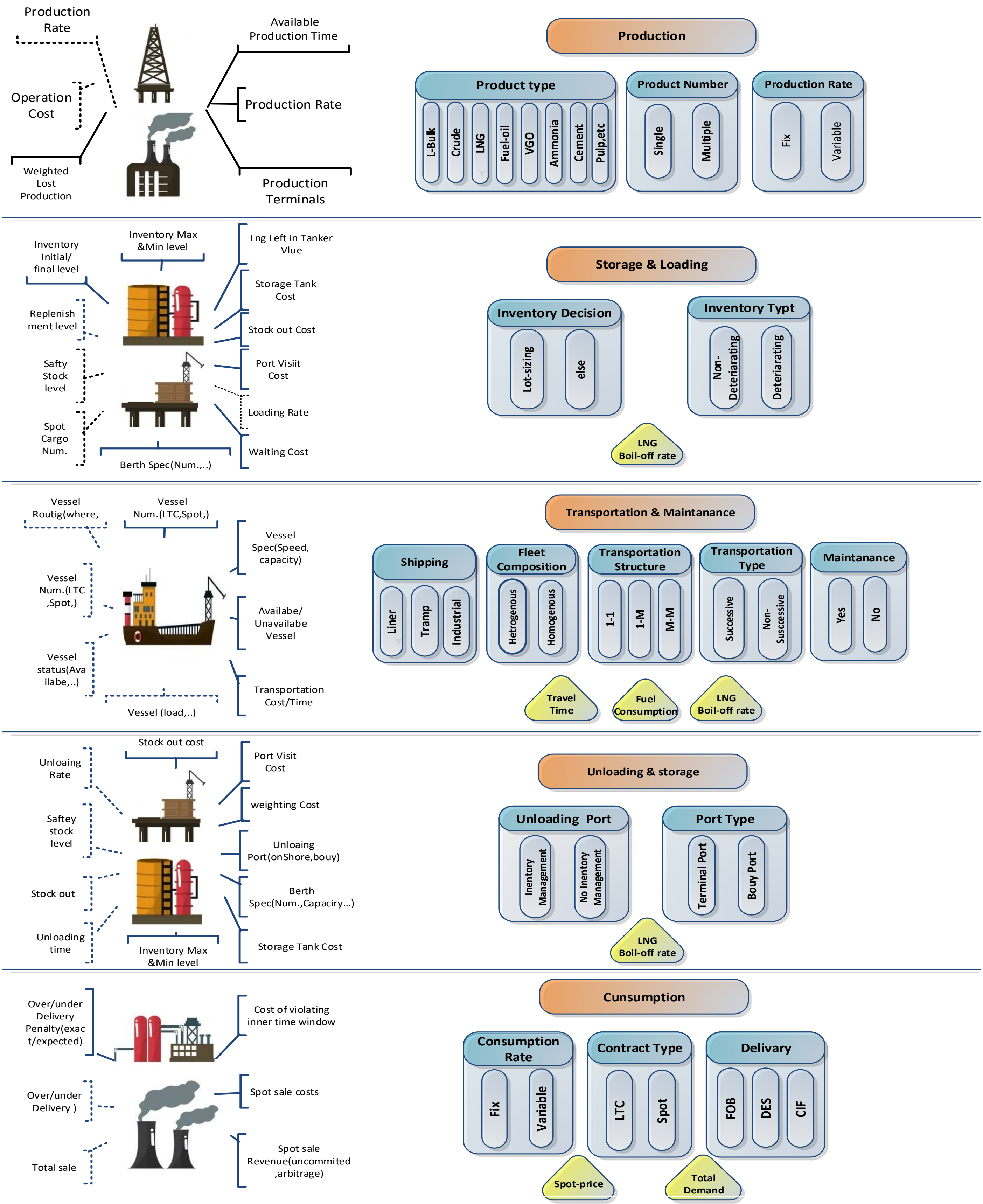


Figure 8. The Conceptual Model of the maritime inventory routing problem

In the remaining part of this article we have examined them in the framework of implementing the supply chain. Based on the distinctions made in the paper, the following sum-up about the percentage of articles on various fields is presented and accordingly the fields on which less work has been done are categorized into three groups of less than 25%, between 25 and 50%, and above 50%. (Fig. 10)

5.1. Supply

As you notice from the supply section the majority of articles have considered the production rate as a variable factor and have mostly focused on single-product goods. From the dimension of the required bases and involved concepts it is possible to merge the following fields in the supply section:

- ✓ The sustainable production in case of the non-renewable resources.
- ✓ Production based on the environmental regulations while observing the limitations upon producing pollutants and emissions.
- ✓ MIRP for a producer who plays in a carbon market.
- ✓ MIRP for a producer considering outsourcing policies.

5.2. Storage and Loading

In the storage and loading section, model-making is used regardless of strategies for lot-sizing as working on this issue and modern inventory management models can pave the way for major developments in the field.

5.3. Transportations, Maintenance and Repairs

- ✓ In transportations, maintenance and repairs modelling many to many delivery without considering maintenance and repairs is more prevalent. Besides, it is essential to pay more attention to repairs and maintenance as they comprise an important part of the maritime transport.
  Meanwhile, the other fields for development in this respect include:
- ✓ The green routing in maritime transportation
- ✓ Using fuzzy and other improved methods and analyzing techniques for decision making under unreliable situations such as bad weather conditions, delays in time of voyage, etc.
- ✓ Using multi-function optimization models (inclusive of costs, social issues, pollution, risks involved in the route, etc.)
- ✓ Merging the discussions on geographical navigations using software like the Arc-GIS in order to choose the best routes for shipping during implementing the model under real-life conditions.

5.4. Unloading and storage

Just like supply ports, inventory management issue at the demand side is the focus of attention of model-makers. Similar to the models applied in the loading side, using more modern methods of inventory management in this field is possible.

5.5. Consumption

The focus in the consumption phase is on the variable rate of consumption, and mainly long-term contracts are favored by the model-makers, along with adding other models of contacts in baskets of contracts, in which development is a matter of concern, too:

- ✓ Merging the pricing policies with discussions on inventory routing
- ✓ Maintaining balance in supply and demand using fuzzy methods for handling the uncertainties in pricing and demand
- ✓ Considering the various conditions for delivery (FOB, CIF, etc.) in the model
- ✓ Merging the Games Theory with optimization models
- ✓ Using the nodal network models for predicting level of demand and prices in the market

6. Conclusion

Maritime transport plays a very decisive role in world trade, thus there is a lot of attention on it and a high number of studies have been done on it. One of the most important characteristics of this field is the discussions on maritime inventory routing, whose roots can be traced back to as early as 30 years ago in the studies of Bell et al, 1983. Since then, this area of research has made a very satisfactory progress to the extent that many studies from various perspectives have been done in the field.

In this article we have examined the maritime inventory routing problem from the viewpoint of supply chain, and by elaborating the major and particular elements of the problem have presented a conceptual model for it. We have also studied the structure of model-making and the various methods for solving the model under survey. The findings can be categorized into two sections. First, we proposed a conceptual framework for modelling MIRP and then according to the model, we classify current studies in order to identify research gaps in this field and highlight future research paths.

According to the structure and statistical review of the studies (Fig. 10), there are many ways to develop researches with a variety of strategies in each ring of marine supply chain from production to consummation, mainly in the third and the last chains which are transportation, maintenance and consumption. Our review reveals that most of the studies were conducted in the tactical level and they mostly modeled the arc-flow model which has been solved with heuristic and exact methods.

To sum up, based on the results gained from most of the studied texts in the field of maritime inventory routing we can say that most of research works are at the tactical levels, on the basis of discreet time, and in the framework of arc-flow network models (Fig. 11); conducting strategic and operational level studies can be future developments in the field. Meanwhile, as you noticed in the former section, the reason the majority of models are discrete is that the rate of production and consumption is considered variable, which is in more in line with the reality.

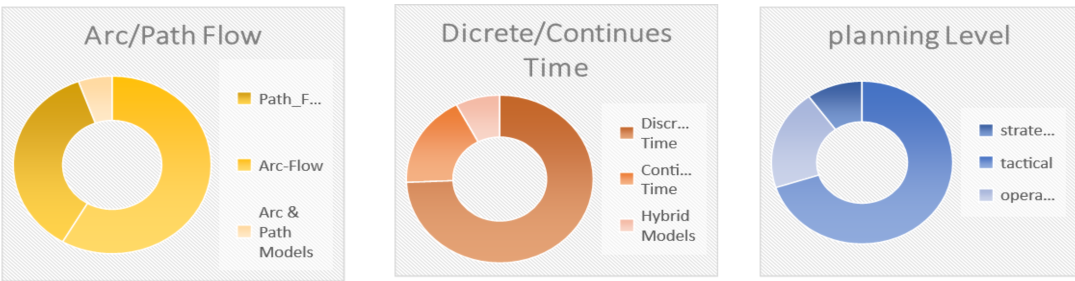
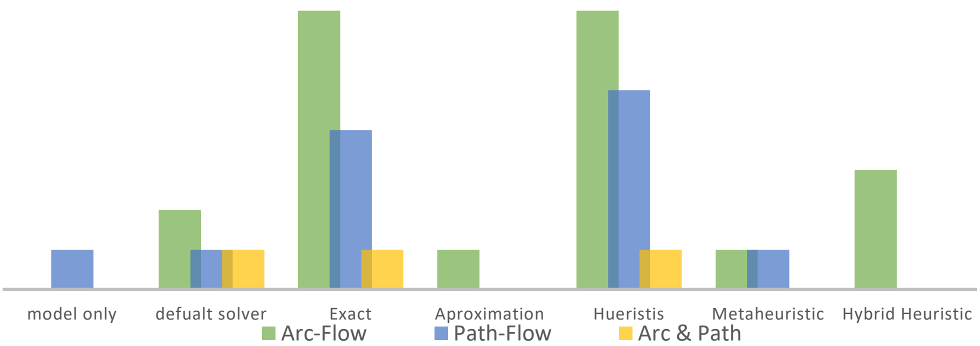


Figure 11. Distribution of the Studies based on Model-Making and Time Horizon

Various methods have been adopted in order to solve this model, among which the heuristic method, the exact method, and the commercial solvers have been the focus of attention of the researchers more than the others. In some of the reviewed studies, the results of applying different methods are compared with each other. According to them, the speed gained in the heuristic methods in comparison with the precise methods was more satisfactory, but the quality of their answers was sometimes lower than that of the precise methods. Yet, using the precise models for solving complicated problems is not always possible and this is one of the compelling reasons for using the heuristic methods. (Rakke et al, 2011, Goel et al, 2015, Agra et al, 2016).

Moreover, using the commercial solvers for complicated problems is not always possible, and consequently the gained results are less competent than those of the other methods. (Goel et al, 2012; Rakke et al, 2014; Papageorgiou et al, 2014b)

Figure 12. Distribution of the Studies based on the Solving Method



Another point is the flexibility and generality of the models. The maritime inventory routing models have their own specifications, and although their main structures have roots in the main body of inventory routing in consignments, their particular features are still unique.

These issues are in fact the merged version of the two issues of inventory management, vehicle routing, and in some cases production management. Thus, the relatively large number of parameters of the problems lead to complications in these models. Of course, using the parameters in the form of couples of related parameters and observing their ratios of effectiveness can decrease complications. (Mutlu et al, 2015). The last point is about the uncertainty discussions and the robust nature of the models, to which, despite their significance in the field of maritime transport, less attention is paid in the studies on the maritime inventory routing problems. They include some important uncertainty factors including climatic changes (which lead to changing the voyage time and the extent of fuel consumption), difference in the quantity of the delivered products in deteriorating goods such as the LNG, the changing daily production rate proportionate to the extent of the planning, the changes in the level of demand and also in the price, which need to be dealt with in the field. Many researches have been done on the MIRP but there is still lot to develop. We categorized all future directions according to our proposed model and distribution of the studies (Fig. 9) in section 5 which may be a good guide for further studies in the field.

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